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Empowering Energy Education: Region-Specific Insights into High School Energy Literacy Infrastructure across Nebraska (fundamental research paper)

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Empowering Energy Education: Region-Specific Insights into High School Energy Literacy Infrastructure across Nebraska

Abstract.

The growing demand for a skilled renewable energy workforce in the U.S. starkly contrasts with declining student interest in non-medical STEM fields, highlighting the need to reform K-12 energy literacy infrastructure. Addressing this requires a deep understanding of regional disparities—a need often overlooked, as it has been in Nebraska. To bridge this gap, we conducted a region-specific energy literacy study across Nebraska's high schools, analyzing curriculum content, teacher preparedness, and resource accessibility using survey data from high school science teachers across the state's six Behavioral Health Regions (BHRs). While 70-80% of schools covered foundational topics like solar, wind, and water energy, advanced subjects such as energy storage and nanotechnology were significantly underrepresented. Hands-on learning was more common in Regions 1, 3, 4, and 5, likely benefiting from professional development programs. However, teachers from Regions 3, 4, and 6 felt the least prepared to teach advanced energy topics due to insufficient academic background, experience, and training. Over 90% of teachers in Regions 1, 2, 3, and 6 cited resource shortages, while 73-100% of teachers in Regions 1, 2, 3, and 4 reported a lack of detailed instructional materials as a major challenge in implementing hands-on energy-focused STEM activities. Other challenges included time constraints, teacher shortages, and students' lack of prior background. More than half of responding teachers lacked experience in developing energy-related curricula, and participation in training varied widely (60-99%) across regions. Notably, regions from where teachers participated in training also emerged as leading adopters of hands-on activities. Teachers also emphasized the need for university support, advocating for collaborations, two-way communication, and access to ready-to-use lesson plans, activities, and online resources. Financial and travel constraints posed major barriers for students attending a potential 3-day summer camp at UNL, particularly in certain regions. Teachers recommended accommodating students' summer schedules and diversifying instruction with online courses, virtual university-led modules, and dual-credit programs. Overall, the study recognized Nebraska's diverse regional needs. Instead of a 'cookie-cutter' approach, tailoring education outreach materials to address region-specific disparities and needs can be a powerful and impactful strategy for expanding energy-STEM participation across both urban and rural Nebraska.

Keywords: energy, energy literacy, sustainable energy, renewable energy, STEM, engineering, K-12, education, outreach, Nebraska, Behavioral Health Regions, teacher training, virtual training

Introduction.

Why energy literacy matters. Energy literacy [1]–[5] is essential for building a skilled and diverse workforce to meet the demands of the growing energy industry. Clean energy jobs in the U.S. are projected to grow by 6.4% by 2025 [6], yet 76% of energy technology employers report difficulties in finding qualified workers [7]. While colleges are expected to fill much of this workforce needs, many Nebraska juniors are underprepared to pursue college education in STEM fields. In 2023, only 31% of Nebraska students met the ACT college readiness benchmark score (23 out of 36) in science, compared to the national average of 32% [8], a trend largely unchanged over the past 5 years [8],[9]. Compounding this issue, declining interest in non-medical STEM fields among middle and high school students poses a major obstacle to cultivating the next generation of energy professionals [10].

Bridging this skill gap requires targeted efforts to enhance high school energy curricula and K-12 outreach, aiming to improve energy and STEM literacy. The logical steps for this should be developing a sound understanding of current teaching and learning practices on energy-related topics in schools, identifying challenges faced by teachers and students, and providing need-driven support. However, curriculum development and outreach efforts often overlook or skip the crucial first step of understanding needs, the outcome of which is failing to adequately prepare students for energy careers. **In this article, we report our effort to tackle this issue by conducting a region-specific study of energy literacy infrastructure across the high schools of Nebraska.** A thorough, state-level database capturing the student-teacher challenges as well as teaching-learning practices on energy-related topics at high school level could be a valuable resource for organizations, authorities, and policymakers striving to strengthen energy education in Nebraska and beyond. Furthermore, such a comprehensive approach can serve as a model and inspire similar initiatives in other states and countries—not only in energy education, but across the broader STEM landscape.

Insights from energy literacy studies at global, national, state, and regional levels and our approach. Achieving energy literacy requires a strong STEM foundation that equips students with the knowledge and skills to address real-world energy challenges. However, a study on secondary students in New York[11] revealed that while students were concerned about energy issues, their cognitive and behavioral scores were low. This indicated **significant gaps in knowledge and skills to address energy-related challenges**. The study also emphasized the importance of enhancing energy education programs in public schools by incorporating a wider range of practical topics such as everyday energy use, alongside focusing on shaping students' attitudes and values to bridge the gap between awareness and actionable skills. In Alabama [12], a study conducted on high school students showed that participation in school-based clean energy programs, virtual learning, especially through video platforms, family interactions, and pre-existing STEM interests significantly influenced energy literacy. These highlighted the importance of integrating these elements into energy education programs to create interconnected learning environments.

A study in Japan [13] analyzed energy-saving behaviors of students in Fukushima, Tokyo, and Kyoto/ Nagasaki. Students in Fukushima scored lower than those in Tokyo due to two key factors. First, Fukushima consistently performed the lowest on Japan's National Educational

Achievement Test among regions assessed for energy literacy. Second, the economic, social, and educational disadvantages of a region may reduce community engagement with environmental issues. These findings highlighted the **critical influence of socioeconomic factors on energy literacy** and the **necessity for region-specific assessment** to address local challenges effectively. **In the U.S., only a few state- or region-level comparative analyses have been reported over the past 15-20 years, but not on a grand scale**. One study[14] on eighth-graders in urban schools across two Pennsylvania cities revealed that their understanding of energy acquisition, generation, storage, consumption, and conservation is not satisfactory, along with significant misconceptions. Students lacked basic knowledge of energy facts, U.S. energy trends, and the societal and environmental impacts of energy use. The study also emphasized the **need for better-designed** Earth and Environmental **Science curricula** and **better teacher preparation**. Similarly, a study in Maine and New Brunswick [15] revealed gaps in ninth-graders understanding of energy resources based on their gender and location. More recently, Wolters et al. [16] examined public knowledge of energy policies in Western U.S. states (California, Idaho, Oregon, and Washington), finding that socioeconomic factors and climate change viewpoints strongly influenced awareness and support for renewable energy initiatives. These studies collectively demonstrated that energy literacy is shaped by a combination of educational practices, socioeconomic factors, and regional dynamics, emphasizing the need for tailored interventions to address localized challenges effectively.

Efforts to understand energy literacy infrastructure in Nebraska. Our team has been actively involved in K-12 renewable energy outreach initiatives, alongside our core research on polymers and nanomaterials for energy technologies [17],[18],[19],[20],[21],[22],[23],[24] since 2016. While working with middle- and high school students from different communities, including prospective first-generation college students, we noticed significant variations in their knowledge, backgrounds, and needs, often leading to disconnects during energy-focused STEM camps at UNL. To address these disparities effectively and in a systematic manner, we must have access to Nebraska's energy literacy infrastructure data. However, before 2018, there had been no effort in Nebraska to collect data on its energy literacy infrastructure and understand it.

Recognizing the importance of understanding students' prior energy and STEM literacy status, we launched a 2-phase, IRB-approved energy literacy infrastructure study [25] in 2019-2020 across high schools in Nebraska, supported by the National Science Foundation (NSF) CAREER Award. Phase 1 featured qualitative interviews of selected high school teachers, which informed a statewide survey in Phase 2 targeting all high school science teachers in Nebraska.

Findings from this statewide study [25] revealed key deficiencies in the infrastructure, with 57% of teachers feeling unprepared to teach energy STEM topics due to limited professional development, resources, and hands-on activity guidance aligned with Nebraska College and Career Ready Science Standards (NCCRS-S) and the Next Generation Science Standards (NGSS) [26],[27]. Financial and travel constraints further limited access to in-person training, particularly for remote schools, emphasizing the need for alternative engagement modes. This study established a comprehensive state-level database on the current state of teaching and learning practices in energy-STEM education.

Since 2021, we have leveraged these data-driven insights to reshape K-12 outreach in Nebraska, prioritizing virtual STEM workshops and camps. Our notable initiatives include the Young Nebraska Scientists (YNS) Camp (2021) and the Nanoscience Summer Institute for Middle School Teachers (NanoSIMST) workshop (2024), sponsored by Nebraska EPSCoR and National Nanotechnology Coordinated Infrastructure (NNCI), respectively. These programs focused on the engineering, chemistry, and nanoscience behind renewable energy technologies. To support these activities, we developed science kits from scratch and shipped them to participants ahead of time, enabling them to perform experiments at their homes/workstations. Pre-camp prep videos and detailed instruction guides were also developed and provided, covering experimental procedures, STEM concepts, and Q&A sections that teachers could later adapt to enhance classroom engagement. The kits engaged participants in hands-on activities, teaching concepts such as how batteries, electrolyzers, and fuel cells work, equipping them with knowledge to design cleaner technologies. We reported these findings earlier [25]. Feedback from the NanoSIMST workshop was overwhelmingly positive:

- “This is extremely fun and applicable to what and how I teach in a small rural NE school. I appreciate the time it took to gather, sort, organize, and send us the box of materials. The ZOOM lab activities were fun and very useful. I am more motivated to do these with my 9th Physical class next year, and while out show it to my 11th Biology.”
- “I liked that we did NOT have to drive to LINCOLN yet were provided a box of lab equipment so that we could do the experiments together on ZOOM.”
- “This is fantastic! I'm so happy I decided to do this class. The packages were well thought out and I appreciate all the supplies!”
- “How easy it will be to incorporate activities like this in the classroom!”
- “This helped me realize how easy teaching circuits can be.”

These responses highlighted the effectiveness of our virtual camps, and how much teachers valued that we provided detailed instructions, kits, and supplies. However, participation remained concentrated in metropolitan areas [28], like Lincoln (Lancaster county) and Omaha (Douglas county). This prompted us to investigate region-specific needs and challenges in energy education, recognizing that these can be influenced by unique geographic, socioeconomic, and school-level factors in each region. Understanding these challenges will guide our future modes of action for energy-focused K-12 outreach and teacher training initiatives. While our earlier analysis of energy literacy infrastructure provided state-wide insights, it was not geographically segregated to understand region-specific diverse needs. Driven by this need, **we dissected our energy literacy data to identify region-specific trends in teaching-learning practices and energy literacy infrastructure**. To our knowledge, no other state in the U.S. has undertaken such a comprehensive initiative to analyze regional energy literacy data within the state for targeted interventions. The work uncovered unique zone-specific trends, empowering us with the ability to support energy education in geographically constrained, underserved, rural schools, expand energy literacy beyond urban centers, and add a new dimension to “broadening participation” in STEM education. Additionally, this pioneering study in Nebraska can serve as a foundation for designing similar interventions in other regions, contributing to the overall improvement of energy literacy.

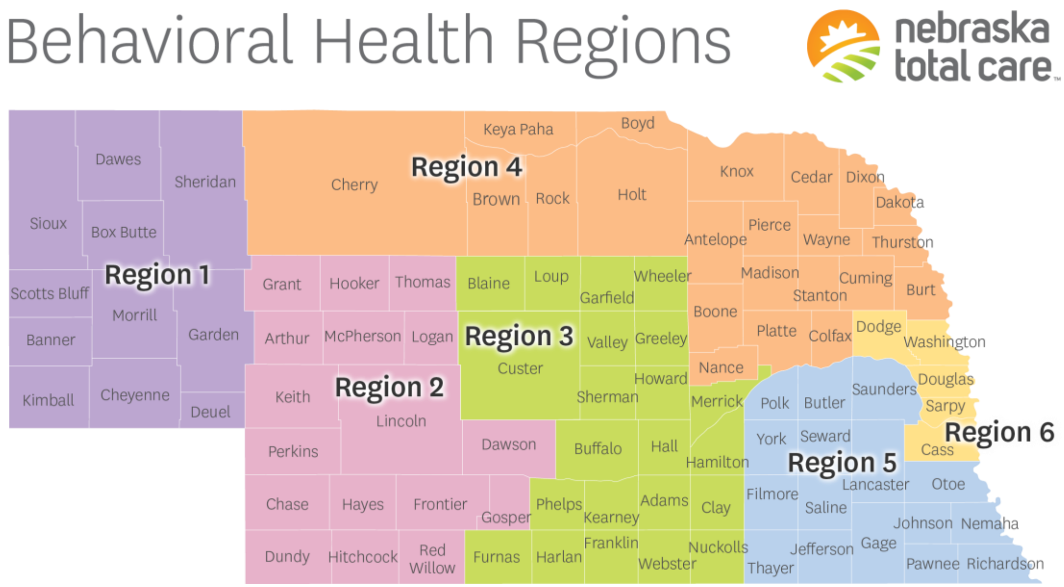

Figure 1. Nebraska's counties segregated according to the Behavioral Health Regions [29]. In some cases, to facilitate the discussion with other region-specific open-access data, Region 4 was sub-divided into 4 sub-regions (counties in parentheses): Sandhills (Boyd, Brown, Cherry, Holt, Keya Paha, Rock), Siouxland (Dakota, Dixon), North 81 (Madison, Pierce, Platte, Sutton), and Northeast (Antelope, Boone, Burt, Cedar, Colfax, Cuming, Knox, Nance, Thurston, Wayne).

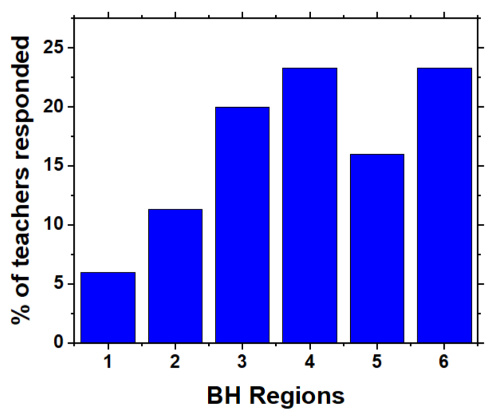

Figure 2. Percentage of teachers responding from each Behavioral Health Region (BHR). The plot should be read as follows: 23.3% of a total of 150 respondents are from Region 4.

Research Approaches.

In this study, we leveraged survey responses from high school science teachers across Nebraska (we collected in 2019) on teaching and learning practices, teacher preparedness, infrastructural challenges, and potential strategies to support energy literacy at high schools in Nebraska. After an institutional review board (IRB) approval, this survey was distributed among all high school science teachers (n=964). The contact information was sourced from the Nebraska Department of Education (NDE) and the survey was administered by the Bureau of Sociological Research (BOSR). Of the 964 teachers sampled, 6.8% (n=66) did not receive emails (emails bounced back), and 1.7% (n=16) were ineligible as they no longer teach high school science. Of the 948 eligible recipients, 150 teachers responded. Survey data were recorded using Qualtrics, securely stored on a UNL Sociology Department server, and analyzed using Statistical Package for the Social Sciences (SPSS) software. We used this energy literacy infrastructure data to perform **regional analysis using Nebraska's Behavioral Health Regions (BHRs).**

BHR is a common zoning method that groups Nebraska's counties into 6 different regions [29] (**Figure 1**). The BHR zoning was especially chosen as it allowed us to contextualize our findings with other open-access data, such as Nebraska's thriving indices. We opted not to use some other regional division styles, such as based on school districts because some school districts consist of only a few schools, which could lead to privacy breaches. **Figure 2** shows response distribution by region. Although the data was collected in 2019, zone-specific discussion of 2019 energy literacy data remain relevant as shifts in regional Education and Skills indices (<10% in 4 years), ACT scores (4% in 6 years), and NDE-identified school support needs have been minimal.

The ACT science scores were obtained from the Nebraska Department of Education database [30]. This database provided a list of schools along with their respective counties. The data was then processed and organized according to the BH regions. The database also included the state average ACT scores and the benchmark scores which we used in this work directly. For the region-specific student-to-teacher ratio, information was gathered from SchoolDigger [31] and categorized based on the BH regions. The averages were calculated using the collected data. Additionally, Jodi Sangster (Education and Outreach Program Manager, Nebraska EPSCoR) provided data on student and teacher training initiatives organized by NCMN and EPSCoR, which were already segregated by region.

By examining energy literacy infrastructure data alongside all these available resources, this pioneering study offers valuable insights for tailoring energy literacy programs for teachers and students in Nebraska—and can serve as a model for similar initiatives in other regions, states, or countries.

Results and Discussions.

Findings from the region-specific energy literacy study were categorized into four key areas: energy topics and instructional methods, teacher preparedness and instructional challenges, infrastructure and resource limitations, and university support opportunities.

Energy topics and instructional methods.

We analyzed the inclusion and delivery methods of energy-focused topics in schools by region. As shown in **Figure 3a**, 70-80% of respondents from each region reported that energy from solar, wind, and water in addition to fundamentals of renewable energy concepts, are included in their curriculum. In contrast, topics such as energy conversion and storage devices (e.g., batteries and fuel cells) were less commonly included, with only 40-50% of respondents indicating their inclusion, regardless of region. The least covered topics were materials and nanotechnology concepts related to renewable energy, with less than 20% of respondents in each region reporting their inclusion. Other included topics were biomass, geothermal, nuclear, tidal power, compressed energy storage, resource management, and the carbon cycle, reflecting a **growing**

focus on sustainable and regionally relevant energy education. While there were no notable region-specific trends in the selection of energy-related topics taught across Nebraska, we noticed that regions 3 and 6 adopted more diverse energy topics.

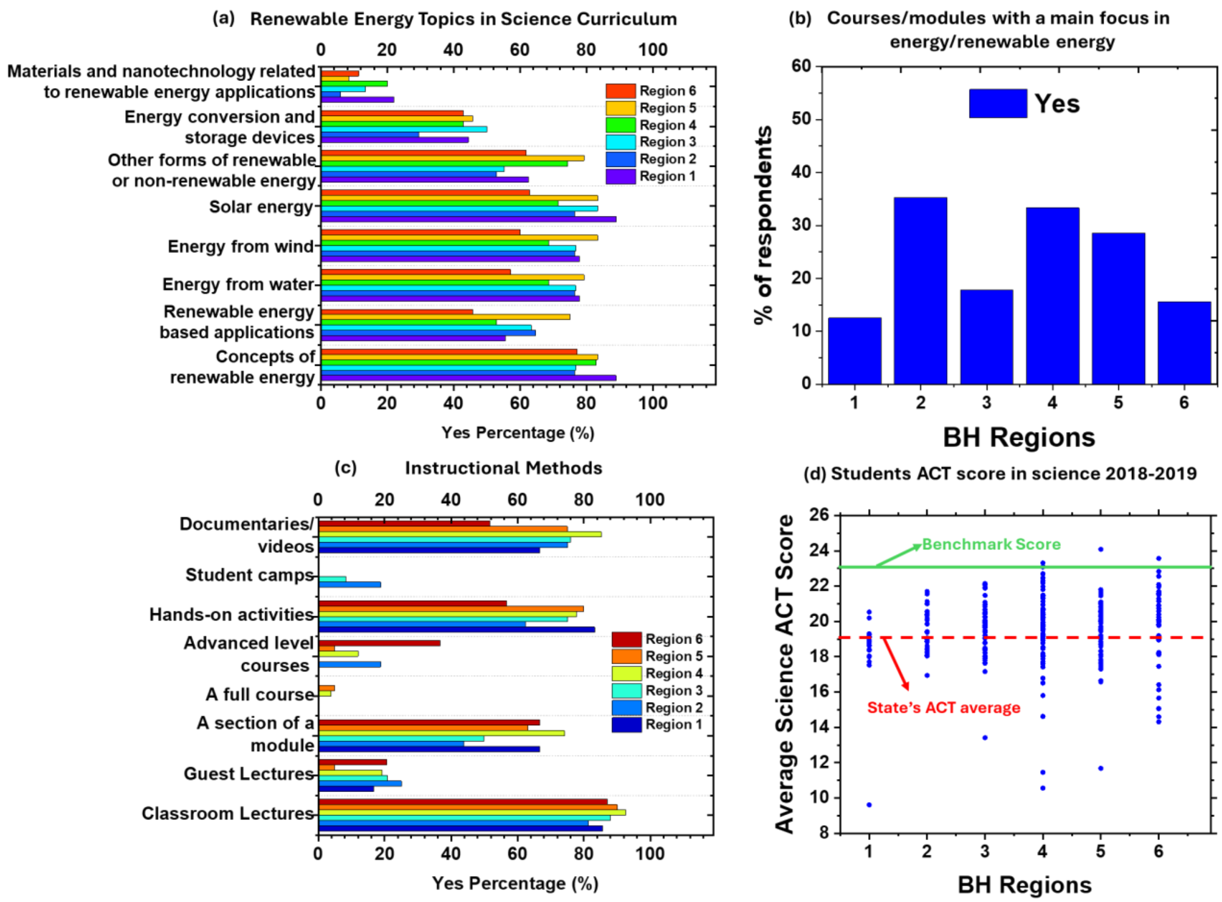

Figure 3. Teacher responses to the questions: (a) Are the following topics about energy and renewable energy technology currently included in the science curriculum at your school? (i) Concepts of renewable energy, (ii) Renewable energy-based applications, (iii) Energy from water, (iv) Energy from wind, (v) Solar energy, (vi) Other forms of renewable or non-renewable energy, (vii) Energy conversion and storage devices, and (viii) Materials and nanotechnology related to renewable energy applications. (b) Does your school have any courses or modules whose main focus is energy or renewable energy education? (c) Does your school currently teach energy or renewable energy education using: Classroom Lectures/Guest Lectures/A section of a module/A full course/Advanced level courses /Hands-on activities/Student camps/ Documentaries/videos? (d) Region-specific ACT score in Science for 2018-2019 including the state average and Benchmark score for college readiness in science. The data was obtained from the Nebraska Department of Education (NDE) [30].

Figure 3b highlights responses on **whether schools offer dedicated courses or modules focused primarily on energy or renewable energy education**. In general, the affirmative responses to this question are low (10-35% of teachers from each region). They were also asked **what the names of the courses or modules are**. Region 1 provided no response; Region 2 cited Physical Science; Region 3 mentioned Physical Science and Earth Science; Region 4 combined

Applied Science, Ecology, and energy-focused Earth Science chapters, offering Integrated Science for non-advanced students; Region 5 integrated renewable energy into Environmental Science, Earth Science, and Agricultural Technology with a focus on conservation and recycling; and Region 6 highlighted broader Earth system energy topics in Environmental Science and Physics. When asked **whether the courses or modules** (having a full focus on energy/renewable energy) **are classroom-based (in-person) or online**, 100% of teachers from Regions 2 and 3, and 80% of teachers from Regions 4, 5, and 6 reported that these courses are classroom-based (in-person). This indicated that in-person teaching is still the primary mode of delivering energy topics across Nebraska, with online options merging as a growing alternative.

Teachers were asked about **specific delivery methods for energy-related topics**. As shown in **Figure 3c**, the primary methods cited were classroom lectures, section of modules, documentaries/videos, and hands-on activities. Notably, more than 75% of teachers from Regions 1, 3, 4, and 5 leveraged some levels of hands-on activities, a proven method for effective STEM engagement. Regions 3, 4, and 5, benefiting from proximity to UNL, likely have greater access to teacher training. Interestingly, despite being geographically distant from UNL, Region 1 also had strong hands-on learning adoption, possibly due to its proximity to Denver, CO, which may provide additional training opportunities.

The strong presence of hands-on activities in Region 1 may explain its ACT science scores, aligning closely with the state average (dotted red line in **Figure 3d**) rather than showing extreme variations. Similarly, Regions 3, 4, and 5, where hands-on learning is prevalent, have more above-average than below-average ACT scores (**Figure 3d**). Region 6, which combines hands-on activities with advanced courses (**Figure 3c**), also shows more above-average ACT scores. These findings clearly showed that exposure to hands-on activities and advanced STEM topics can significantly impact and enhance energy literacy and STEM preparedness. Despite all of these, Nebraska's overall STEM performance remains a concern: most regions scored below 23 (out of 36), the ACT College Readiness Benchmark for science, with **only 33% of students exceeding the benchmark**, compared to the national average of 36%. This highlights a gap in STEM education in Nebraska that needs to be addressed through expanded hands-on teacher training and resources to enhance STEM engagement and energy literacy across the state.

Teacher preparedness and instructional challenges.

In addition to gaining an understanding of high-school energy-focused curricula and instructional methods, evaluating teacher preparedness is crucial for designing targeted training programs (**Figure 4a,b**). **Teachers from Regions 3, 4, and 6 reported feeling the least prepared to teach advanced energy and renewable energy topics (Figure 4a)**. Notably, these regions include all 6 school districts identified by the NDE [32] as needing additional support. The NDE has also acknowledged the need for focused efforts and assistance in these areas, including **high-quality instructional materials**, and fostering school partnerships [32].

Teacher preparedness trends can also be interpreted *via* Nebraska's Thriving Indices [33], which compares the state's economy to similar Midwest regions. The Education and Skill Index [33], particularly relevant here, measures high school, community college and 4-year college attainment, labor force participation, and employment in knowledge-based occupations. Region 4, which includes Sandhill (158), North 81 (117), Siouxland (-16), and Northeast (85), has highly polarized values of Education and Skill Index, while Region 3 scores notably low (68) [33].

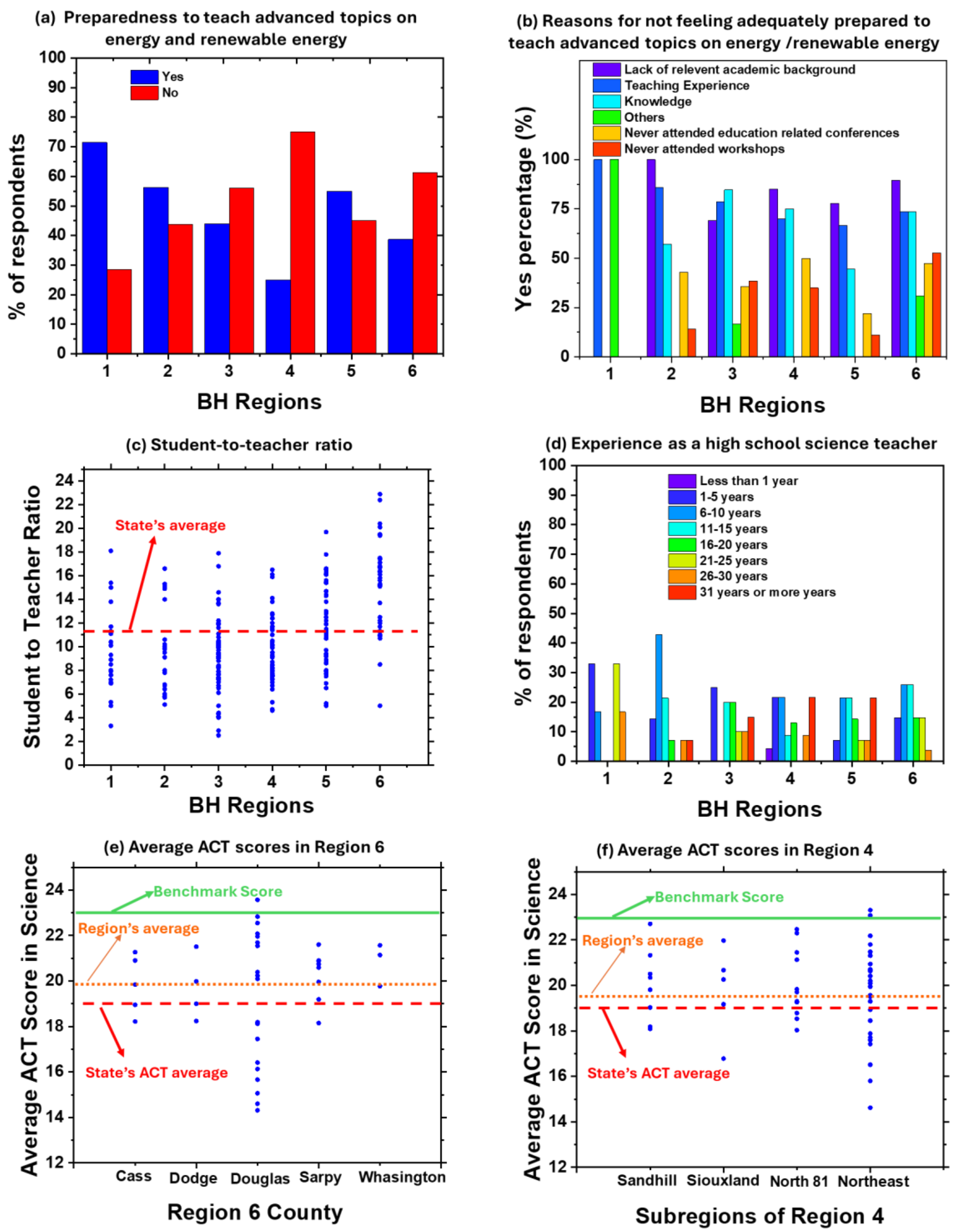

Figure 4. Teachers' response to the questions: (a) Do you feel adequately prepared to teach these advanced topics on energy and renewable energy?, (b) Please indicate whether or not the following statements are the reasons why you do not feel adequately prepared to teach these advanced topics on energy and renewable energy?, (c) Region-specific student-to-teacher ratio (from school digger ratings [31]). (d) Teachers' response to the question: How long have you been a high school science teacher?, (e, f) American College Testing (ACT) scores of students in science in Nebraska 2018-2019 for (e) Region 6, (f) Region 4 (data obtained from the Nebraska Department of Education [34]).

These suggested **broader challenges in education and skill attainment** that may stem and contribute to teachers' lack of preparedness, including gaps in relevant background, knowledge, and experience (**Figure 4b**). A similar analysis could not be done for Region 6 because it covers the Omaha metro areas (Dodge, Douglas, Sarpy, Cass, and Washington counties, **Figure 1**) and indexed differently [33]. However, 94% of its high schools exceed the state's average student-teacher ratio (10.5). This percentage is the highest among Nebraska's six regions [31]. This increased workload limits teachers' ability to engage in professional development (**Figure 4c**) and prepare and integrate renewable energy topics into curricula. Most importantly, teachers must adhere to Nebraska College-Ready Standards for Science (NCCRS-S) when introducing new content, further underscoring the need for targeted expert support and additional resources. Our predictions about teachers' lack of preparedness to teach advanced energy and renewable energy topics—insufficient materials, training, professional development time, and challenges integrating renewable energy topics with NCCRS-S—aligned with their cited reasons (**Figure 4b**). Teachers most commonly reported **lacking a relevant academic background**, **teaching experience**, **knowledge**, and **training** as **reasons for feeling not adequately prepared to teach advanced topics on energy and renewable energy**. Data shows a direct correlation between a lack of teaching experience and regional percentages of junior teachers (< 10 years of teaching experience). For example, 100% of teachers from Region 1, 85.7% from Region 2, and 69% from Region 3 cited inexperience as a barrier, closely matching the percentage of junior teachers in those regions (49%, 57%, and 25%, respectively) **(Figure 4d)**.

Similarly, lack of knowledge is strongly correlated with limited participation in education-related conferences and workshops. In Regions 3, 4, and 6, where 85%, 75%, and 74% of teachers cited insufficient knowledge, 39%, 50%, and 48% had never attended an education conference, and 39%, 35% and 52% had never participated in a workshop. In contrast, the % of teachers from Region 5 citing lack of knowledge (45%) is low and so is its % of teachers citing never attending conferences (22%) or workshops (12%). This is a testament that **not attending conferences/ workshops can certainly lead to a lack of teachers' knowledge and preparedness.**
It especially grabbed attention that despite having the Omaha metro area, Region 6 had the highest % of teachers who never attended education-related conferences (48%) or workshops (52%) (**Figure 4b**), indicating **disparities in training access** in Region 6. To explore this, we analyzed Region 6 ACT scores by county (**Figure 4e**). While some counties scored near or above the regional average, others showed wide variations, particularly in Douglas County (**Figure 4c**). On the other hand, 5-year data [28] from the NanoSIMST teacher training workshop revealed that most Region 6 participants were from Douglas County. Despite higher participation from Douglas, its broad ACT score distribution likely explained uneven access to training resources for teachers across Region 6.

A similar trend was observed in Region 4, which had the highest percentage of unprepared teachers (**Figure 4a**), with 50% never attending an education-related conference and 35% never attending a workshop (**Figure 4b**). Notably, Region 4 had zero participation in NanoSIMST workshops [28]. Its ACT scores (**Figure 4f**) and Education and Skill Indices (discussed earlier) also showed a broad distribution. Historically, Region 4 includes tribal communities (Siouxland) [33],[35] and under-resourced/underserved areas [36] which may contribute to reduced training and resource accessibility in certain areas. This evidence suggested that if the teachers' access to training and thus teachers' knowledge level widely vary across a region, the educational outcome can also vary. Also, **averaging ACT scores or any parameter may not be a good idea while understanding regional infrastructure as it may be misleading by obscuring the distributions/ disparities**. Addressing these disparities in teacher preparedness through regionally tailored training will better equip Nebraska's K-12 educators to deliver advanced energy education and foster a more skilled workforce.

Beyond inadequate academic background, teaching experience, knowledge, and training, teachers also cited a lack of time, materials, lab space, and well-developed modules as barriers to preparedness. Our K-12 outreach experience also clearly identified the critical need for well-developed teaching modules and STEM kits. To bridge this gap, we have developed and shipped **energy-focused science kits** to students and teachers before virtual workshops, expanding remote access to STEM education. This model has successfully broadened Nebraska-wide STEM participation, yielding impactful outcomes, as reported in our previous work [25],[37].

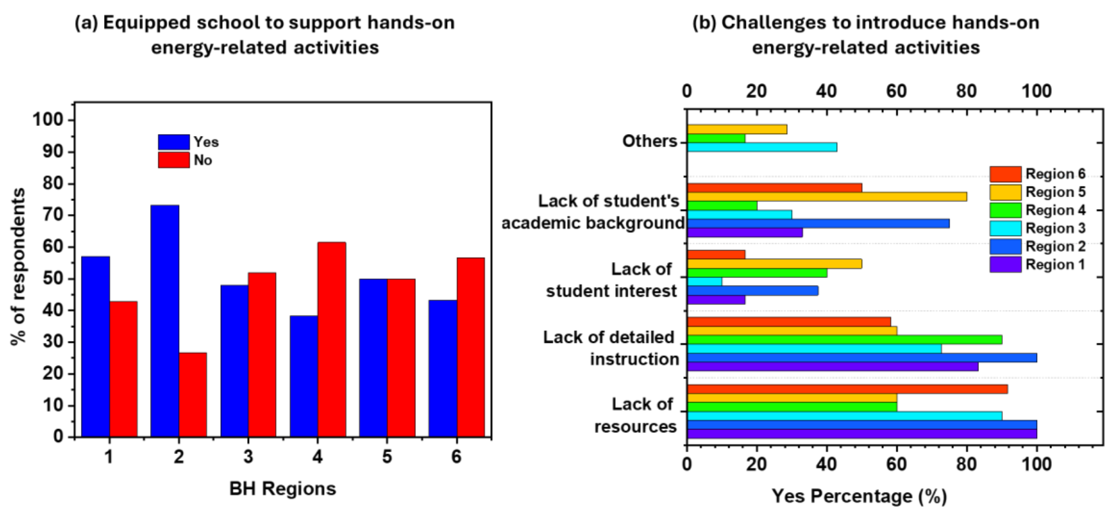

Figure 5. Teachers' response to the questions: (a) Is your school well-equipped to support hands-on, energy-related activities? (b)When introducing or trying to introduce hands-on, energy-related STEM activities at your school, have you encountered the following challenges: Lack of resources/lack of detailed instructions, lack of student interest/lack of students' academic background/others?

<u>Infrastructure limitations and resource gaps.</u>

This section examines teachers' insights on school infrastructure and resource limitations, which often act as limiting factors when introducing energy-focused activities/curricula and expanding teacher training opportunities. While at least 50% of teachers across all regions reported implementing hands-on energy-related STEM activities, 45-65% indicated their schools were not well-equipped to support them (**Figure 5a**). In answer to a separate question, over 60% of teachers across all regions cited the absence of energy-related outreach programs in their schools. When asked about **specific challenges when introducing hands-on energy-related STEM activities** at their school (**Figure 5b**), over 90% of teachers from Regions 1, 2, 3, and 6 cited **resource shortage**, while 73-100% from Regions 1, 2, 3, and 4 highlighted a **lack of detailed instructions**. In fact, teachers from all regions unequivocally expressed the need for **lesson plans/modules/curriculum** when asked a separate question: "Is there anything else you need at your school to help create substantial STEM education initiatives focusing on energy?" The data also revealed a lack of **training** (Regions 2, 3, 6), **time** (Regions 1, 3, 4, 5, 6), **enough teachers** (Regions 1, 2, 4, 5), and **equipment/resources** (Regions 2, 3, 6) as the barriers or teachers' needs from their schools to create substantial STEM education initiatives focusing on energy. This underscored the critical need for institutional resources and access to high-quality, detailed instructions.

Many of these challenges are interconnected. Teacher shortages can lead to increased workloads, which can take away their time for attending professional development, training, and developing energy-focused curriculum/initiatives adhering to NCCRS-S. It was not surprising to see time constraints and insufficient teachers reported by the majority of the regions across the state, as this aligns with high student-to-teacher ratios in many counties in each region (**Figure 4c)**. Within resources, some explicit mentions throughout the data were for lack of funding, lab space, lab supplies, and kits.

On another note, teachers from Regions 2, 5, and 6 pointed out the **lack of students' prior background** as another challenge when introducing hands-on energy-STEM activities (**Figure 5b**). This could be a complex outcome of socioeconomic disparities, curriculum gaps, and limited early STEM exposure to foundational concepts. Especially, early science engagement plays a crucial role in shaping students' interest and preparedness for advanced topics [38], emphasizing the need for hands-on STEM activities at the elementary and middle school levels.

***Curriculum development and professional training needs*.**

This section analyzes teachers' responses to questions regarding their curriculum development experience, training, and collaborations. **Over 50% of teachers statewide lack curriculum development experience in energy topics** (**Figure 6a**). Additionally, 80-100% had never developed such curricula through university research or internships (**Figure 6b**), highlighting the need for universities to offer and promote these opportunities. Such programs could facilitate faculty collaboration, expert-guided curriculum/lesson/activities design, and help teachers overcome time constraints during the school year. 40-70% of teachers reported no collaboration inside or outside their school districts for energy-related course materials development (**Figure 6c**). Rural areas showed slightly higher collaboration, likely due to resource-sharing needs, while urban teachers had more direct access to facilities/resources. Strengthening partnerships among schools, universities, and the Department of Education could help establish a broader support network for energy literacy.

Teachers' participation in training, workshops, fellowships for continuing education, and professional development varied widely (60-99%), with Region 1 scoring the lowest (**Figure 6d**). 90 teachers listed specific programs they attended, including Nebraska Association of Teachers of Science (NATS) Conferences (12 teachers), National Science Teachers Association (NSTA) Conferences (8 teachers), University of Nebraska Workshops (9 teachers), Education Service Units (ESUs) Training (7 teachers), NDE-UNL and NATS-ESU Collaborative Programs (TEAMS, Nebraska Science **K**eep Improving **C**ontent **K**nowledge and **S**kills 3 (KICKS3) (6 teachers) [39],[40]. KICKS3 and TEAMS provided deeper content knowledge, integrating **inquiry-based science and engineering practices** while aligning classroom instruction at all grade levels with Nebraska State Standards. Regions 3 (19 out of 90) and 4 (27 out of 90) had the highest training participation. Also, as previously discussed, these regions were among the leading adopters of hands-on activities for teaching energy-related topics. This alignment highlighted the impact of STEM workshops on teaching effectiveness.

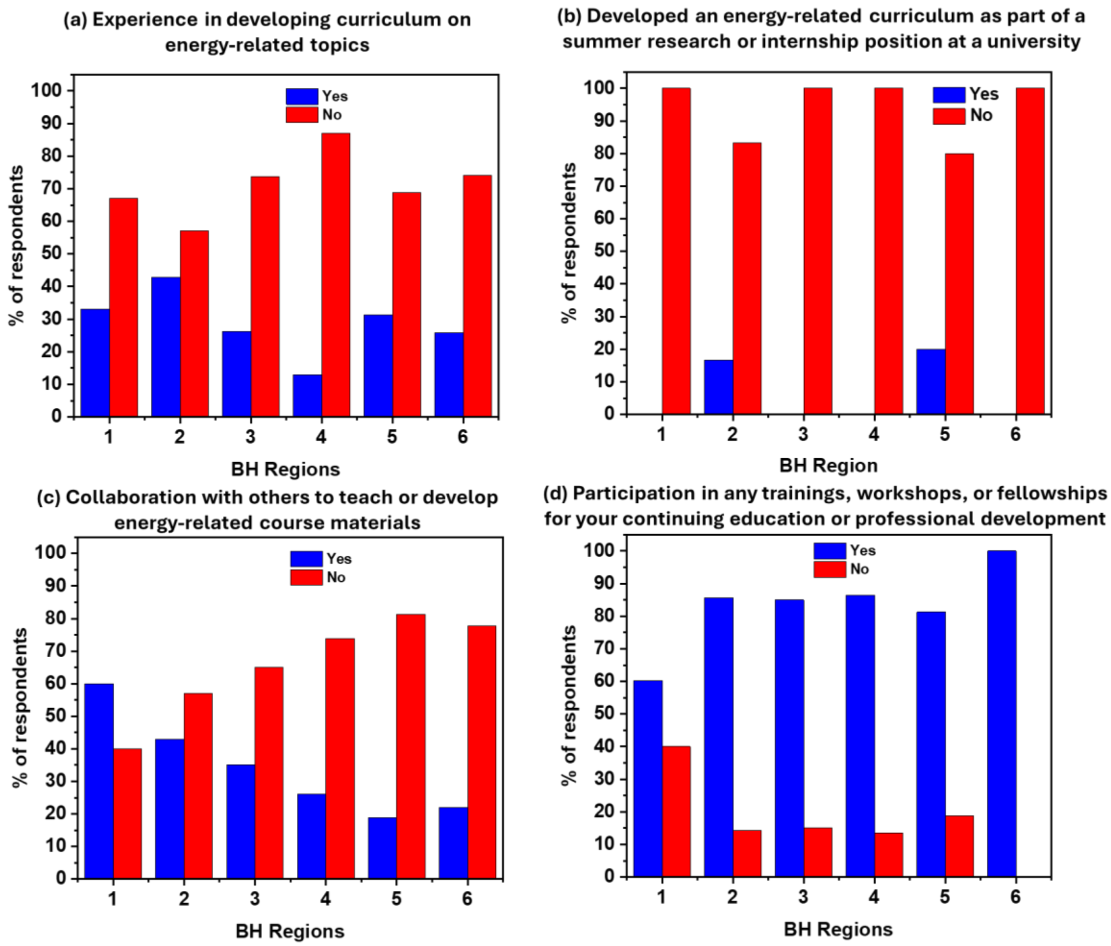

Figure 6. The responses presented in this figure correspond to teachers answering the following questions: (a) Do you have experience in developing curriculum on energy-related topics, (b) Have you ever developed an energy-related curriculum as part of a summer research or internship position at a university?, (c) Do you collaborate with others inside or outside of your school district to teach or develop energy-related course materials?, (d) Have you attended any trainings, workshops, or fellowships for your continuing education or professional development?

To support teachers in implementing NCCRS-S, we asked how university faculty could assist. From 52 responses received, 2 key requests emerged: (i) **Fostering Connections and Two-way Interactions (40%):** Teachers emphasized the need for collaborations with university faculty either through teachers participating in activities at UNL campus or school visits by university educators to bring hands-on learning directly to the classrooms. **(ii) Providing Ready-to-use Educational Resources (48%):** Teachers requested lesson plans, activities, online resources, and modules tailored to grade levels and aligned with NGSS/NCCRS-S standards.

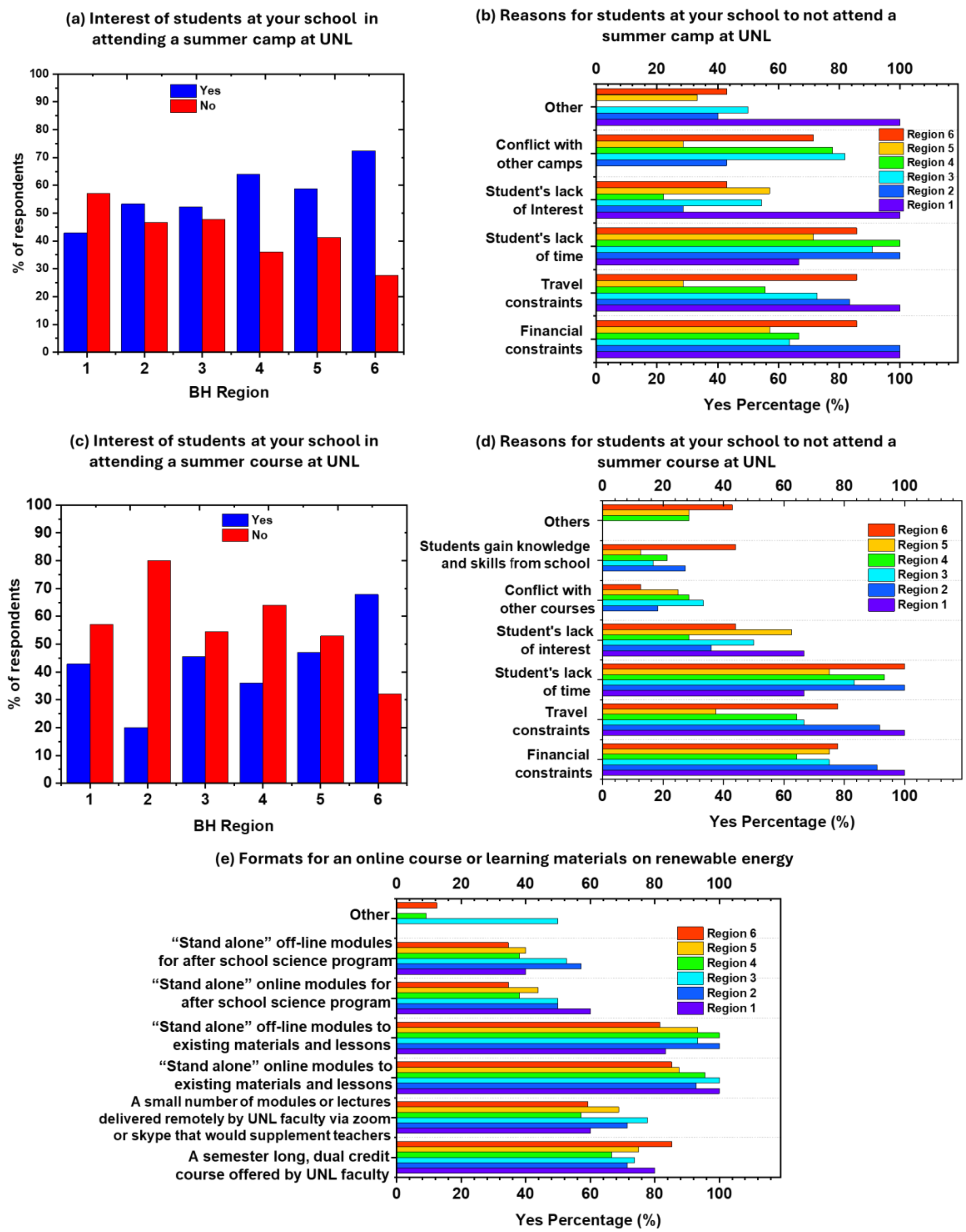

Figure 7. Teachers' responses to the questions: (a) If the University of Nebraska-Lincoln (UNL) was to offer a three-day, renewable energy-related STEM **summer camp**, do you think students at your school would be interested in attending?, (b) Are the following reasons why students at your school would not be interested in attending a three-day, energy-related STEM summer camp at UNL? (i) Financially, it would not be feasible for students at my school to attend, (ii) The travel required to attend this camp would not be feasible for students at my school, (iii)

Students at my school would not have time in their schedules to attend, (iv) In general, students at my school are not interested in energy-related STEM topics, (v) Students at my school attend other camps, (vi) Other. (c) If UNL was to offer a **summer course** on renewable energy that integrated both theory and interactive activities in a logical manner, would students at your school be interested in attending? (d) Are the following reasons why students at your school would not be interested in attending a summer course on renewable energy at UNL? (i) Financially, it would not be feasible for students at my school to attend, (ii) The travel required to attend this camp would not be feasible for students at my school, (iii) Students at my school would not have time in their schedules to attend, (iv) In general, students at my school are not interested in renewable energy topics, (v) Students at my school attend other summer courses, (vi) Students at my school gain the knowledge and skills they need from courses at our school, (v) Other (e) If an online course or learning materials on renewable energy are designed, would the following formats work well for your school? (i) A semester long, dual credit course offered by UNL faculty, (ii) A small number of modules or lectures delivered remotely by UNL faculty via zoom or skype that would supplement teachers, (iii) "Stand alone" online modules to existing materials and lessons, (iv) "Stand alone" off-line modules to existing materials and lessons, (v) "Stand alone" online modules for after school science program, (vi) "Stand alone" off-line modules for after school science program, (vii) Other.

<u>Identified needs for support through summer camps and virtual learning.</u>

We gathered teachers' input on supporting K-12 energy-STEM education through summer camps and summer courses. Over 50% of teachers from Regions 2-6 expressed student interest in a 3-day, in-person energy-STEM **summer camp** at UNL (**Figure 7a**). However, Region 1 reported the highest likelihood of non-participation, citing financial and travel constraints, and lack of student interest (**Figure 7b**).

Financial and travel constraints were most cited in Regions 1, 2, and 6 (**Figure 7b**). For regions 1 and 2, the long 4-6 h commute to Lincoln posed a travel challenge, while financial constraints for these regions were linked to socioeconomic factors. 6 out of 11 counties in Region 1, and 11 out of 17 counties in Region 2 had poverty rates above the state average (10.4%), with some counties reaching 19% in Region 1 and 17.4% in Region 2 [41]. Despite being 1.5 hours from Lincoln and comprising the Omaha metro, Region 6 cited both financial and travel constraints. Earlier analysis of ACT scores and student-to-teacher ratios suggested resource disparities, which were further confirmed by poverty data [41]: 2 of 5 counties in Region 6 exceed the state's 10.4% poverty rate, ranging from 5.6% to 11.2%. Additionally, poverty among those under 18 (a group likely comprising young families with school-aged children) is higher in metro areas (14.4%) than in rural areas (13%) [41], further explaining Region 6's socioeconomic challenges and travel cost barriers for attending in-person summer camps at UNL.

Several regions (2, 3, 4, 6) also cited student time constraints as a barrier to attending summer camps at UNL. Since the camps proposed were for summer, conflicts likely stemmed from students' summer commitments for jobs or assisting families, particularly in Nebraska's Agriculture-dependent counties (Lincoln (Region 2), Custor (Region 3), Cherry and Holt (Region 4)) [42],[43]. A teacher from Region 3 suggested an alternative: "Consider hosting a camp during Spring break or better your Fall break. You will see more attendance." Organizing camps during spring or fall weekends, rather than summer, could thus increase attendance and broaden participation.

When asked if their students would be interested in attending a **summer course** at UNL, more teachers across all regions responded “No” (**Figure 7c**) for obvious reasons, such as longer time commitments, conflicts with job obligations, travel, and financial constraints associated with extended stay (**Figure 7d**).

This analysis **highlighted the need for diversifying outreach strategies, combining in-person and virtual options** to enhance energy literacy. Since the COVID-19 pandemic, virtual learning has expanded, creating new opportunities to reach students facing geographical, time, and financial barriers. The success of our 2021 virtual Young Nebraska Scientists (YNS) Summer Camp reflects this impact, e.g.,

- “I actually enjoyed being able to do this online. It was very convenient because I live farther away. You should continue offering virtual camps so more people can participate, even if they don’t live nearby.”

These comments, along with our experience with these virtual camps/workshops, reaffirm the effectiveness of virtual STEM engagement in broadening access to energy literacy initiatives. **Figure 7e** summarizes teachers’ suggestions for designing and disseminating online courses or learning materials on renewable energy. The most widely accepted option (80% of teachers across all regions) was **stand-alone online/offline modules** to supplement existing materials and lessons. Additionally, more than 65% of teachers across all regions favored a **semester-long dual credit course by UNL faculty**. Giving students the opportunity to earn credits through an online course underlines the importance of valuing their time. Over 50% of teachers agreed that a **small number of modules or lectures, delivered remotely by UNL faculty** through platforms like Zoom, could effectively supplement their teaching. While 35-55% endorsed after-school science program modules, some noted their limited reach as not all students participate in after-school programs. Teachers also recommended pre-recorded videos, Google Classroom-compatible resources, and interactive Q&A sessions to boost engagement.

Summary of Findings.

This study highlighted region-specific trends in energy-related teaching practices, teacher preparedness, and needs for advancing energy literacy in Nebraska high schools. Survey data from high school science teachers were categorized by Nebraska's six Behavioral Health Regions (BHR) and analyzed to assess energy literacy infrastructure and inform targeted initiatives to address region-specific requirements.

Energy-related topics taught. The data revealed that 70-80% of respondents across all regions **include topics like solar, wind, and water energy in their curricula**, **but advanced topics like energy storage devices** (40-50%) and **nanotechnology concepts** (<20%) are **less commonly covered**. Dedicated energy courses or modules are limited (10-35%), with Regions 2 and 4 reporting the highest inclusion (30-35%). Regions 3 and 6 adopted more diverse energy topics in their curricula, while Region 5 integrated renewable energy into Environmental Science, Earth Science, and Agricultural Technology, emphasizing conservation.

***Modes of instruction*.** **Classroom-based instruction dominates**, with 100% of teachers in Regions 2 and 3 and 80% in Regions 4, 5, and 6 delivering content in person. Common methods to deliver these topics include classroom lectures, sections in modules, documentaries/videos, and hands-on activities, with more than **75% of teachers in Regions 1, 3, 4, and 5 leveraging hands-on approaches**. **Regions 3, 4, and 5 benefit from in-state teacher training**, while **Region 1**, distant from Nebraska's metropolitan areas, likely relied on **neighboring states for training** to implement hands-on energy-related topics—a proven STEM engagement strategy.

Teachers' preparedness. Teachers from **Regions 3, 4, and 6 reported feeling the least prepared to teach advanced energy and renewable energy topics**. We rationalized these region-specific trends in light of NDE's identification of schools "needing support to improve," Nebraska's "Education and Skill Index," high school student-to-teacher ratio, and socioeconomic factors. Our reasonings aligned well with teachers' reasonings for lack of their preparedness: **lack of relevant academic background, teaching experience, knowledge, and training**. We also found a notable **link between % of teachers citing a lack of knowledge** and **% of teachers citing that they never attended education-related conferences and workshops**.

***Resource gap and other challenges*.** Over 90% of teachers from Regions 1, 2, 3, and 6 **cited resource shortages**, while 73-100% from Regions 1, 2, 3, and 4 identified the **lack of detailed instructions** as **challenges to implementing hands-on energy-related STEM activities** at their school. These findings highlight the critical importance of institutional resources and access to high-quality, detailed instructions to support hands-on STEM activities, key to College Preparedness and Energy STEM workforce development. Over 60% of teachers in all regions mentioned the lack of outreach programs in their schools. **Time constraints** and **lack of sufficient teachers were common concerns across all regions**, aligning with high student-to-teacher ratios in many counties of each region. A shortage of teachers can limit the time available for educators to design new energy-focused curricula or participate in professional development opportunities. Lack of funding, lab space, lab supplies, and kits were also cited as specific resource gaps.

Regions 2, 5, and 6 also pointed to **students' lack of prior STEM background**, emphasizing the need for early exposure to foundational STEM concepts through targeted programs for younger students.

***Teachers' training and curriculum development experience*.** **Over 50% of teachers** across the 6 regions of Nebraska **do not have experience in developing curricula on energy-related topics**, and 80-100% have not created such curricula through summer research or internships at universities. This highlights an opportunity for universities to offer more summer research and internship programs, enabling teachers to collaborate with faculty and leverage faculty expertise in designing energy-focused curricula.

On another note, participation in training, workshops, or fellowships for professional development varied significantly across Nebraska's six regions, ranging from 60% to 99%. However, **regions where teachers cited participation in specific training programs also stood out as leaders in adopting hands-on activities for teaching energy topics.**

How can we help? To address teachers' needs, we asked **how university faculty could support implementing Nebraska College and Career Ready Science (NCCRS) standards**. Key requests included (i) **fostering connections and two-way interactions** and (ii) **providing ready-to-use educational resources**. Notably, **48% of respondents specifically requested lesson plans**, activities, online resources, and modules tailored to grade-level complexity and **aligned with NGSS/NCCRS-S standards.**

Over 50% of teachers from Regions 2 to 6 indicated that their students would be interested in attending a 3-day, in-person energy-STEM **summer camp** at UNL. However, Region 1 had the highest % of teachers reporting their students would likely not participate, citing **financial and travel constraints**, as well as a lack of students' interest. Travel and financial challenges were most common in Regions 1, 2, and 6, with Regions 1 and 2 facing long commutes (4-6 hours), and parts of all 3 regions facing socioeconomic barriers. Extended stays and associated costs also made summer courses less appealing than camps. Teachers suggested considering **students' time constraints**, noting that camps during the school year could boost participation, as many students may have summer job commitments.

The analysis underscored the importance of **diversifying opportunities** to enhance energy literacy. Even though the data were collected before the COVID-19 pandemic, the data highlighted the **critical importance of leveraging online or virtual instruction options**. 80%-95% of teachers across different regions were in favor of standalone online/offline modules to supplement existing lessons, while over 50% supported **small lecture modules delivered remotely by UNL faculty *via* platforms, like Zoom**. Additionally, 65% of teachers expressed that it would be good to have a semester-long dual credit course offered by UNL faculty. A relatively smaller, yet notable % of teachers (35-55%) supported online/offline modules for after-school programs, but some highlighted a limited scope of this option as not all students participate in after school programs.

Broader Impacts and Conclusions.

This study provides critical insights into energy literacy in Nebraska's high school education system, uncovering regional disparities in curriculum content, teacher preparedness, and resource accessibility. By identifying and rationalizing these gaps in relation to school resources, STEM preparedness, teacher training, and geographic and socioeconomic factors, this work offers a roadmap for improving energy education across both urban and rural Nebraska. To the best of our knowledge, no other study of this scale has been conducted to evaluate and guide energy literacy infrastructure in Nebraska or any other state.

The identified regional disparities will benefit not only high school teachers but also educators at all levels (pre- and post-high school), and state education authorities by **shedding light on systemic challenges across Nebraska's education system**. This understanding is crucial for planning and implementing **targeted, region-specific strategies to enhance energy literacy**. With these insights, we, the university-level educators, are now better equipped to design customized, energy-focused K-12 outreach activities tailored to specific regions, schools, and districts.

Teachers cited a lack of kits and detailed instructions for hands-on, energy-focused STEM activities as key challenges. In recent years, we have been working extensively on these aspects and expanding virtual camps/workshops with an aim to train students and teachers from both rural and urban Nebraska. Our long-term goal is to build sustained collaborations with high school teachers to align curricula with NCCRS-S. Also, by reaching out and supporting energy education in geographically constrained and underserved schools, we can expand energy literacy beyond metropolitan areas and add a new dimension to broadening participation in STEM education.

Over the last 8 years, we have been a key contributor to Nebraska's K-12 outreach, partnering with Nebraska EPSCoR, the Nebraska State Museum, Nebraska Center for Materials and Nanoscience (NCMN), Nebraska Center for Science, Mathematics and Computer Education (CSMCE), Educational Service Units (ESUs), and many more. Our passion to do something meaningful for Nebraska's energy-STEM education has deeply motivated us to make this effort, and we believe this study will serve as a valuable resource for organizations and authorities striving to enhance energy education infrastructure in Nebraska and beyond. Moreover, our comprehensive approach to assessing infrastructure can serve as a model and inspire similar initiatives in other states and countries, not only for energy education but across STEM disciplines.

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