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Energy Literacy Among Secondary School Students: A Multidimensional Study of Sociodemographic Patterns and Energy-Use Behavior

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Abstract: This study addresses the need for evidence-based energy education that links conceptual understanding to students' daily energy behaviors. This study analyzes the energy literacy of secondary school students across the domains of knowledge, attitudes, and behavior, examining the effects of age, gender, grade level, parental education, and participation in advanced physics electives. The study employed a quantitative survey using an energy literacy questionnaire adapted from the Energy Literacy Questionnaire framework. After data cleaning and reversing scores on negative statements, 303 valid responses were analyzed using descriptive statistics, Cronbach's alpha reliability test, Kruskal-Wallis test, epsilon squared effect size, and Bonferroni post-hoc test. Students' total energy literacy fell into the moderate category (M = 68.80). The knowledge (M = 72.32), attitude (M = 67.70), and behavior (M = 66.37) domains were also in the moderate category, with behavior being the lowest domain. Gender significantly differentiated knowledge and total literacy, while grade level significantly differentiated the knowledge domain. Age, father's education, mother's education, and enrollment in Physics as an elective subject did not significantly differentiate total literacy. Students' energy literacy is multidimensional and reveals a knowledge-action gap. Energy education needs to shift from conceptual learning toward real-world projects, school-based practices, and family engagement.

Keywords: energy literacy, adolescent students, gender, socioeconomic status, parental education.

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INTRODUCTION

Energy is a fundamental necessity for social development, economic growth, and environmental sustainability (Behera, 2026; Küfeoðlu, 2022; Garba & Abdulrahman, 2024; Shyu, 2024; Thai et al., 2023). The global transition toward clean and affordable energy, as reflected in Sustainable Development Goal 7, requires not only technological innovation but also educational transformation (Maniam et al., 2026; Nagamalla et al., 2024; Peters, 2025; Tsangas et al., 2023). In the context of a country still dependent on fossil fuel energy sources, education holds a strategic position in shaping a generation capable of understanding, evaluating, and using energy responsibly (Rohmatulloh et al., 2021). Energy literacy is a critical competency, as it encompasses knowledge about energy, attitudes toward energy use, and actual behaviors related to energy conservation (Buchtele et al., 2023).

Previous research conceptualizes energy literacy as a multidimensional construct that integrates cognitive, affective, and behavioral domains. The foundational framework developed by DeWaters & Powers (2013) defines energy literacy not only as students' knowledge of energy concepts, sources, transformation, conservation, and electricity use, but also as their attitudes, values, responsibility, and concrete energy-related behaviors. In this study, the cognitive domain refers to students' understanding of energy concepts, energy sources, energy transformation, conservation, and electricity use. The affective domain reflects students' concern, responsibility, and support for energy-saving practices, while the behavioral domain describes actual actions in using energy efficiently. Recent studies continue to apply and support this multidimensional framework in contemporary energy education research, including Khuc et al. (2023), Guimarães et al. (2023), and Buchtele et al. (2023). However, conceptual understanding does not always translate into consistent energy-saving behavior. This condition, commonly discussed as the knowledge-behavior gap, remains a major challenge in energy education.

Research on energy literacy has evolved across various educational contexts. Enhancing energy literacy among students can lead to more effective energy-saving behavior (Jusoh & Ishak, 2024). Several studies in Asia and other regions have examined students' energy literacy across domains such as energy knowledge, misconceptions about energy concepts, perceptions of renewable energy, and energy awareness (Hai, 2025). These studies indicate that energy literacy is not only related to conceptual understanding but also encompasses students' attitudes and behaviors in using energy responsibly.

In Indonesia, research on student energy literacy is emerging, but most studies still focus on improving literacy through learning strategies such as project-based learning and the collaborative creativity model (Lestari et al., 2025). Research specifically linking multidimensional energy literacy to students' socio-demographic characteristics still needs to be strengthened. Socio-demographic factors, such as gender, age or grade level, socioeconomic background, parental education, access to information, and learning experiences, can influence students' knowledge, attitudes, and behaviors regarding energy. Therefore, the relationship between multidimensional energy literacy and students' socio-demographic characteristics needs further examination to provide schools with an empirical basis for designing more targeted energy education interventions.

It is important to consider socio-demographic factors because energy literacy does not develop in a social vacuum. Gender can shape learning orientations, environmental concern, and student engagement with science topics (Zanocco et al., 2022). Class can reflect exposure to formal learning and curriculum development. Age can indicate developmental maturity, although age differences at the secondary school level are often not very wide. Parents' education can also be understood as a form of family cultural capital, as parents can provide access to information, discussions, and energy-related habits at home (Yang et al., 2025). However, the influence of parental education does not always emerge as a direct differentiator, as family energy behavior is also shaped by economic conditions, frugal culture, home facilities, and daily habits (Piao & Managi, 2023; Zhu & Chen, 2025).

Previous studies have shown that energy literacy cannot be treated as a single cognitive outcome, as students' knowledge, attitudes, and behaviors may develop unevenly. DeWaters & Powers (2013), for example, reported that secondary students showed relatively positive affective responses toward energy issues, but their cognitive and behavioral scores remained lower. Their findings also indicated that higher grade levels did not automatically lead to stronger conservation behavior, suggesting a possible disconnect between energy knowledge and daily action. This multidimensional character is further supported by studies showing that students' energy literacy may vary across demographic and educational backgrounds. Bahrami & Mohammadi (2021) found that gender, school location, and parents' education were associated with Iranian ninth-grade students' energy literacy, while Bia³ynicki-Birula et al. (2022) summarized that gender, parental income, educational profile, and school location are often reported as differentiating factors in student energy literacy research. Evidence from Taiwan also indicates that parental education and school-related background may shape students' energy knowledge, while affective responses do not always correspond directly with energy-saving behavior.

However, empirical evidence from Indonesia remains limited. A preliminary Indonesian study by Usman et al. (2021) described junior high school students' energy literacy and found a moderate overall profile with a weak cognitive domain. However, the study primarily provided an initial descriptive profile and did not simultaneously examine how knowledge, attitudes, and behavior differed across students' demographic characteristics. Therefore, the research gap addressed in the present study is the limited evidence on multidimensional energy literacy among Indonesian secondary school students, which jointly considers knowledge, attitudes, and behavior while accounting for age, gender, grade level, father's education, mother's education, and academic exposure to advanced physics learning. The novelty of this study lies in its integrated analysis of energy literacy domains and student characteristics, allowing the knowledge-action gap to be examined not merely as a general phenomenon but as a pattern that may vary across specific student groups.

Selecting Aceh as the study site has substantive relevance. Aceh has considerable renewable-energy potential, particularly in hydropower, solar, wind, and geothermal energy, while also facing the need to strengthen energy access and efficiency across geographically diverse areas. This context directly connects students' energy literacy with the province's development agenda. In addition, the Merdeka Curriculum allows Phase F students to select Physics as an elective subject, resulting in unequal formal exposure to energy concepts across grade levels. Schools in Aceh implementing the Merdeka Curriculum therefore provide a relevant context for examining whether differences in academic exposure are associated with students' energy knowledge, attitudes, and behavior (Energi dan Sumber Daya Mineral Aceh, 2025).

Based on this gap, the study addressed three questions: (1) What are students' energy-literacy levels in the knowledge, attitude, and behavior domains? (2) Are there differences in energy literacy according to gender, age, grade level, father's education, mother's education, and participation in the Advanced Physics elective? Furthermore, (3) Which sociodemographic factors show the most prominent variation? The null hypothesis (H_0) stated that there were no differences in energy-literacy scores among groups across sociodemographic characteristics. The alternative hypothesis (H_1) stated that at least one group differed on the sociodemographic characteristic being tested.

■ METHOD

Research Design

This study employed a quantitative approach using a descriptive-analytical survey design. This design was chosen because the study aims to map students' energy literacy and compare literacy scores based on socio-demographic groups without providing interventions or manipulating the learning environment (Kaya, 2023). The survey approach allows for the collection of data on knowledge, attitudes, and behaviors from a relatively large number of respondents within a relatively short timeframe.

This study was conducted in April 2026 and involved high school students from a school in Aceh that had implemented the Kurikulum Merdeka. In this curriculum context, students were no longer formally categorized into science and social science tracks, as in the previous streaming system. Therefore, the demographic description did not use the IPA/IPS classification. However, the study still considered differences in students' exposure to physics-related learning by identifying whether respondents belonged to classes that selected Physics as an elective subject. This variable was considered relevant because students who took Physics as an elective may have received additional exposure to energy-related concepts compared with students who did not take the subject.

All respondents had previously received basic exposure to energy topics in Grade 10 or Phase E, particularly in alternative energy. Therefore, participation in the Advanced Physics elective was treated as an indicator of additional physics-related exposure, not of whether students had ever learned energy topics. This variable was applied only to Grade 11 and Grade 12 students because they had entered the elective subject structure, while Grade 10 students were not included in this comparison.

Data were collected using an online questionnaire distributed to 401 students. A total of 310 students responded, yielding a response rate of 77.31%. Initial screening assessed completeness, duplicate identities, and response patterns. Five responses were excluded because they contained identical scores across all attitude and behavior items, and two responses were excluded as duplicate submissions. Thus, 303 responses were included in the analysis. This represented a usable response rate of 75.56% among all students who received the link and a data retention rate of 97.74% for submitted responses. Negatively worded statements were reverse-scored so that higher scores consistently indicated stronger energy literacy.

Participants

The questionnaire link was sent to 401 students, comprising 147 Grade 10, 145 Grade 11, and 109 Grade 12 students. Of the 310 responses received, 303 met the criteria for analysis. The valid sample consisted of 143 Grade 10 students, 106 Grade 11 students, and 54 Grade 12 students. Because the grade-level distribution of the valid sample differed from the distribution of invited students, post-stratification weights were calculated by dividing the invited-population proportion by the valid-sample proportion for each grade. The resulting weights were 0.777 for Grade 10, 1.034 for Grade 11, and 1.525 for Grade 12. Weighting was applied to aggregate descriptive estimates and category distributions. Between-group tests continued to use the actual unweighted number of respondents so that the weights were not treated as replicated cases. Generalization remains limited to the school studied because convenience sampling was used.

Participation in the Advanced Physics elective was coded as 'Yes' for students in Grade 11 and 12 classes that offered this subject, and 'No' for students in parallel classes that did not offer it. Grade 10 students were coded as 'not applicable' because they had not yet entered the elective-subject structure. The comparative analysis of this variable included only 160 Grade 11 and Grade 12 students, comprising 37 in the 'Yes' group and 123 in the 'No' group.

This research met ethical standards for research involving human subjects, particularly child participants. Prior to data collection, the researcher obtained official permission from the school. The researcher also explained the research objectives, procedures, benefits, participants' rights, and the guarantee of data confidentiality to the students' parents or legal guardians. Written informed consent was obtained from all parents or legal guardians before students were included in the study.

Furthermore, all child participants were asked to provide voluntary assent before participating in the study. Student participation in this study was voluntary and without coercion. Parents or legal guardians had the right to withdraw their child from the study at any time without penalty or negative consequences. All data collected were kept confidential and used solely for research purposes.

Instrument

The research instrument consisted of an energy literacy questionnaire adapted from the Energy Literacy Questionnaire framework, which is based on cognitive, affective, and behavioral literacy (DeWaters et al., 2013). The adaptation involved forward translation into Indonesian, back-translation into English by an independent bilingual reviewer, comparison between the original and back-translated versions, and revision of items that showed semantic differences. The translated items were also reviewed for content relevance, readability, and suitability for Indonesian high school students. This procedure was conducted to ensure that each questionnaire item retained an equivalent meaning in the Indonesian context before the scoring system was finalized.

The adapted instrument was validated through expert judgment and empirical testing after being adjusted to the Indonesian context. First, the instrument was reviewed by two experts to ensure the appropriateness of its content, language, indicators, and the relevance of its items to the constructs being measured. The expert validation used a 1-to-4 Likert scale. The validation results showed an average score of 3.25, indicating that the instrument was suitable for use. Inter-rater reliability was assessed using Percentage Agreement (PA), yielding 93%. This result indicates a high level of agreement between the validators.

After the expert validation process, the instrument was pilot-tested on 33 students to examine item validity and reliability. The results showed that all items were valid and suitable for use in the main study. The reliability test using Cronbach's Alpha showed a coefficient of 0.92 for the knowledge test, which falls into the very high category. Meanwhile, the attitude and behavior questionnaire obtained a Cronbach's alpha coefficient of 0.82 for affect and 0.83 for behavior, which falls into the high category (George & Mallery, 2003). These results indicate that the adapted instrument has strong validity and reliability and is appropriate for measuring students' energy literacy in the Indonesian context. The knowledge domain uses multiple-choice questions, while the attitude and behavior domains use Likert scales and frequency scales. The structure of the instrument is presented in Table 1.

Table 1. Structure of the energy literacy instrument

Domain	Indicator	Positively worded items	Negatively worded items	Numbering	Scoring
Knowledge	Basic concepts of energy, energy sources, conservation, electricity usage, and consequences of energy use	Not applicable	Not applicable	25	Correct = 1; incorrect = 0
Attitude	Energy awareness, responsibility, policy support, and environmental awareness	12	5 (A4, A5, A7, A13, A15)	17	1–5 Likert scale
Behavior	Electricity conservation, efficient energy use, and daily energy-saving in daily life	10	0	10	Frequency scale 1–5

Data Analysis

The knowledge score was calculated by dividing the number of correct answers by 25 and multiplying by 100. For the attitude domain, five negatively worded items (A4, A5, A7, A13, and A15) were reverse-scored using the formula new score = 6 " original score on the 1–5 Likert scale. The attitude score was then computed as the total reversed score divided by the maximum possible score of 85, multiplied by 100. The behavior score was computed as the total score of the 10 items divided by the maximum possible score of 50, multiplied by 100. This transformation to a percentage of the maximum score placed the three domains on a common metric, preventing differences in item counts from mechanically inflating the weight of any single domain in the composite score.

For descriptive interpretation, scores were classified as low (<60), moderate (60 d" score <80), and high (e"80). For the attitude and behavior domains, these thresholds were derived mathematically from the response anchors of the five-point scale. Because the percentage-of-maximum score is equivalent to the mean item score divided by 5 and multiplied by 100, a score of 60 corresponds to a mean response of 3, whereas a score of 80 corresponds to a mean response of 4. Thus, the low category indicates a mean response below the scale midpoint, the moderate category indicates responses from the midpoint to below the agree/often anchor, and the high category indicates a mean response at least equivalent to the agree/often anchor. For the knowledge domain, the same operational thresholds were applied to the percentage of correct answers to maintain consistency across domains, rather than serving as an externally validated mastery standard. These thresholds constitute an operational classification for descriptive communication, not a diagnostic psychometric cut-off or a universal competency standard. All inferential analyses used continuous scores; therefore, categorization did not affect test statistics, effect sizes, or significance decisions. Interpretation of the response anchors was based on the structure of the instrument's scale and the principles of Likert-scale development (DeWaters & Powers, 2013; Jebb et al., 2021).

The total energy-literacy score was calculated as the arithmetic mean of the percentage scores for knowledge, attitude, and behavior. Equal weights were assigned to the three domains because the energy-literacy framework treats knowledge, attitude, and behavior as complementary substantive components and does not establish a hierarchy of contribution among them. Once all domains had been expressed on the same percentage scale, equal weighting was selected as the most transparent approach because no theoretical or empirical basis existed for assigning greater weight to any particular domain. The total score was treated as a descriptive composite index. In contrast, each domain score continued to be reported and analyzed separately so that the multidimensional variation in energy literacy was not obscured by the aggregate score.

A sensitivity analysis comparing the two age groups was conducted using G*Power version 3.1.9.7 with a two-tailed Wilcoxon–Mann–Whitney test. The settings were a normal parent distribution, relative SD = 1.00, á = 0.05, target power = 0.80, n1 = 36, and n2 = 267 (Faul et al., 2007). Post-stratification weighting was used to reduce imbalance in grade-level representation. Weighted means and category distributions were calculated using these weights. Because each weight was constant within a grade level, grade-specific means did not change. Mann–Whitney and Kruskal–Wallis tests were conducted without weights and were supplemented with effect-size estimates.

RESULT AND DISCUSSION

The results and discussion are organized according to the three research questions stated in the introduction. The first subsection presents students' energy literacy levels across the knowledge, attitude, behavior, and total literacy scores. The second subsection examines differences in energy literacy based on sociodemographic characteristics. The third subsection identifies the most prominent sociodemographic variations in students' energy literacy domains and discusses their educational meaning.

Instrument Reliability and Respondent Characteristics

The reliability results indicate that the instrument has adequate internal consistency. The knowledge domain showed very good reliability (alpha = 0.914), the attitude domain also showed very good reliability (alpha = 0.857), while the behavior domain showed acceptable reliability (alpha = 0.752). The reliability results are shown in Table 2 below.

Table 2. Reliability of the energy literacy instrument

Domain	Number of Items	Reliability Coefficient	Interpretation
Knowledge	25	0.914	Very good
Attitude	17	0.857	Good
Behavior	10	0.752	Acceptable

Note: The reliability coefficient for the knowledge domain was calculated using KR-20, whereas Cronbach's alpha was used for the attitude and behavior domains. Coefficient interpretation followed George and Mallery (2003): values above 0.90 were considered excellent, above 0.80 good, above 0.70 acceptable, above 0.60 questionable, above 0.50 poor, and below 0.50 unacceptable.

Most respondents were aged 16–18 and female. Tenth graders constituted the largest proportion of respondents, followed by eleventh- and twelfth-graders. Most students reported that their parents had a primary-to-secondary education. These characteristics are relevant because formal school experiences and family educational backgrounds can influence how students understand, evaluate, and practice energy use. Sample characteristics are presented in Table 3 below.

Most respondents were 16–18 years old, comprising 267 students (88.12%), and 190 students (62.71%) were female. In the invited

Table 3. Respondent characteristics

Characteristics	Category	*n*	%
Age	13–15 years	36	11.88
	16–18 years	267	88.12
Gender	Male	113	37.29
	Female	190	62.71
Grade	Grade 10	143	47.19
	Grade 11	106	34.98
	Grade 12	54	17.82
Father's education	Elementary-secondary	244	80.53
	Higher education	59	19.74
Mother's education	Elementary-secondary	213	70.30
	Higher education	90	29.70
Advanced Physics elective participation	Yes	37	12.21
	No, Grade 11 and Grade 12 only	123	40.59
	Not applicable, Grade 10	143	47.19

Note: Advanced Physics elective participation was coded only for Grade 11 and Grade 12 students. Grade 10 students were categorized as not applicable because they had not yet entered the elective subject structure and were therefore excluded from the comparative analysis of this variable.

population, the proportions of Grade 10, Grade 11, and Grade 12 students were 36.66%, 36.16%, and 27.18%, respectively, whereas in the valid sample they were 47.19%, 34.98%, and 17.82%, respectively. These differences indicate that Grade 10 was overrepresented and Grade 12 underrepresented; therefore, descriptive estimates were adjusted using post-stratification weighting.

In the Advanced Physics analysis, 37 students were in the "Yes" group, and 123 were in the "No" group, while 143 Grade 10 students were categorized as "not applicable." Post-stratification weights were used in the descriptive estimates to adjust the grade-level composition. The reported n values remained the actual number of respondents.

Students' Energy Literacy Levels Across Knowledge, Attitude, and Behavior Domains

The descriptive analysis summarizes students' energy literacy levels across the knowledge, attitude, and behavior domains, as well as the total literacy scores. To present the findings concisely, the results are organized into two tables: Table 4 presents the overall profile and descriptive statistics based on individual characteristics (age, gender, and grade level), while Table 5 summarizes the findings according to family factors and academic exposure (parental education and participation in the Advanced Physics elective).

Furthermore, the descriptive statistics for energy literacy based on family-related factors and specific academic exposure, including parental education and participation in the Advanced Physics elective, are summarized in Table 5.

Table 4. Descriptive statistics of energy literacy by individual characteristics

Variable	Group	N	Knowledge	Attitude	Behavior	Total	Category
Overall	All students (weighted)	303	72.32	67.70	66.37	68.80	Moderate
Age	13-15 years	36	72.95	70.06	64.84	69.29	Moderate
	16-18 years	267	72.26	67.45	66.52	68.74	Moderate
Gender	Male	113	63.17	65.85	66.00	65.01	Moderate
	Female	190	78.25	68.90	66.61	71.25	Moderate
Grade level	Grade 10	143	74.60	69.35	67.36	70.43	Moderate
	Grade 11	106	77.32	66.81	64.00	69.38	Moderate
	Grade 12	54	62.59	66.64	68.19	65.81	Moderate

After post-stratification weighting, overall energy literacy was in the moderate category, with a mean of 68.80. Knowledge had the highest

Table 5. Descriptive statistics of energy literacy by family factors and academic exposure

Variable	Group	N	Knowledge	Attitude	Behavior	Total	Category
Father's education	Higher education	59	67.87	68.07	65.97	67.30	Moderate
	Primary-secondary education	244	73.41	67.60	66.47	69.16	Moderate
Mother's education	Higher education	90	70.33	70.11	68.26	69.57	Moderate
	Primary-secondary education	213	73.17	66.66	65.55	68.46	Moderate
Advanced Physics	Yes	37	73.55	64.99	65.10	67.88	Moderate
	No	123	70.12	67.34	66.03	67.83	Moderate

Note: N denotes the actual unweighted number of respondents, whereas the means and categories in Tables 4 and 5 are post-stratification-weighted estimates. Grade-specific means did not change because all respondents in the same grade were given the same weight.

mean (72.32), followed by attitude (67.70) and behavior (66.37); all three domains were in the moderate category. Compared with the unweighted results, the changes in the means were relatively small and did not alter the substantive pattern that conceptual mastery was stronger than both attitude consistency and energy-saving actions.

Score distributions showed the greatest variation in the knowledge domain. Some students demonstrated high conceptual mastery, whereas others had limited understanding. Attitude scores were more concentrated in the moderate category. This pattern suggests that literacy-strengthening efforts should maintain cognitive achievement while also improving the consistency of attitudes and behavior.

Based on the 1.5 × IQR boxplot rule, this study identified outliers across several domains: one outlier in knowledge (31), one in attitude (11),

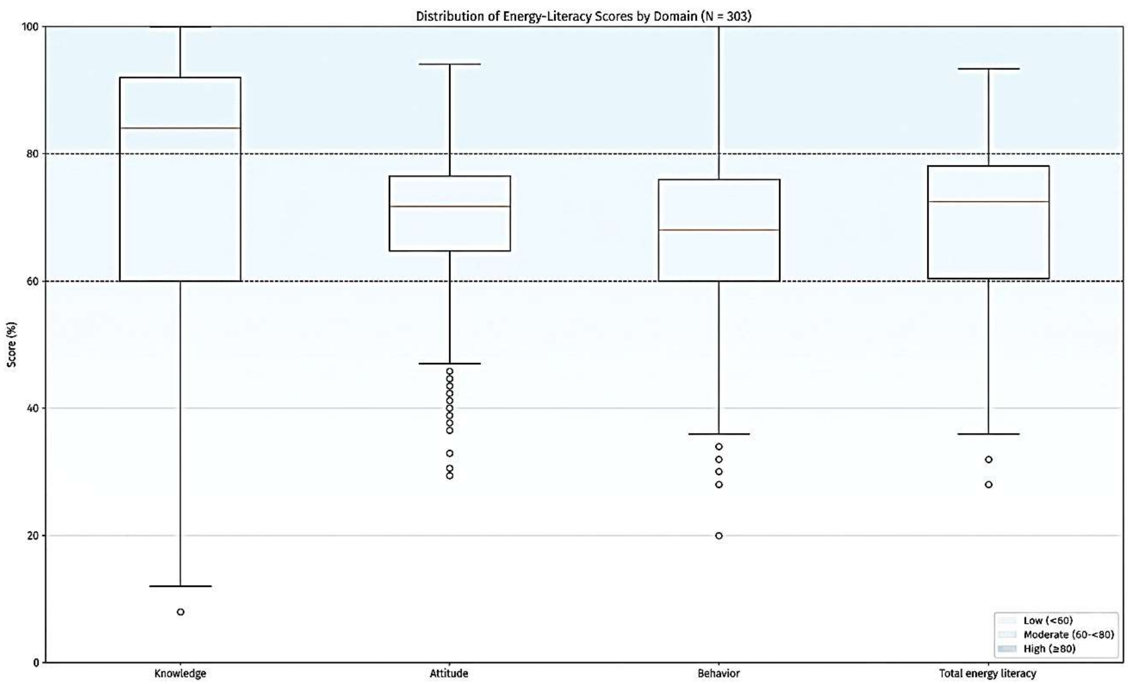

Figure 1. Distribution of energy-literacy scores with shaded category zones

one in behavior, and two in total energy literacy. The knowledge outlier was a male Grade 11 student. Meanwhile, the two total-literacy outliers were female students: one Grade 12 student aged 16–18 years and one Grade X student aged 13–15 years, both of whom had a low behavior score of 20. Generally, attitude and behavior outliers were distributed across both genders and all grade levels (Grades 10, 11, and 12), indicating they were not concentrated in a single demographic group.

Specifically in the attitude domain, all outliers were located on the lower side of the distribution (lower outliers). This indicates the absence of a ceiling effect or strong indications of social desirability bias, as there was no clustering of scores at the maximum value. The majority of these attitude outliers originated from Grade 10 and 11 students, reflecting a subgroup of respondents with distinct characteristics or environmental learning experiences. Furthermore, current data examination provided no evidence that these outliers were caused by specific response styles.

Through re-examination, it was confirmed that there were no scoring errors, duplicate responses, or straight-lining patterns across the instrument. Consequently, all outlying scores were retained as valid empirical variations in the analysis. Additionally, the use of non-parametric Mann–Whitney U and Kruskal–Wallis tests mitigated the sensitivity of the results to these extreme values.

Based on the weighted estimates, the proportions of total energy literacy were 25.02% in the low category, 59.92% in the moderate category, and 15.06% in the high category. These values are estimated proportions after adjustment for grade-level composition, rather than actual respondent counts. The categories were used as descriptive summaries, whereas inferential conclusions remained based on unweighted continuous scores. Students' energy literacy by domain is shown in Figure 2.

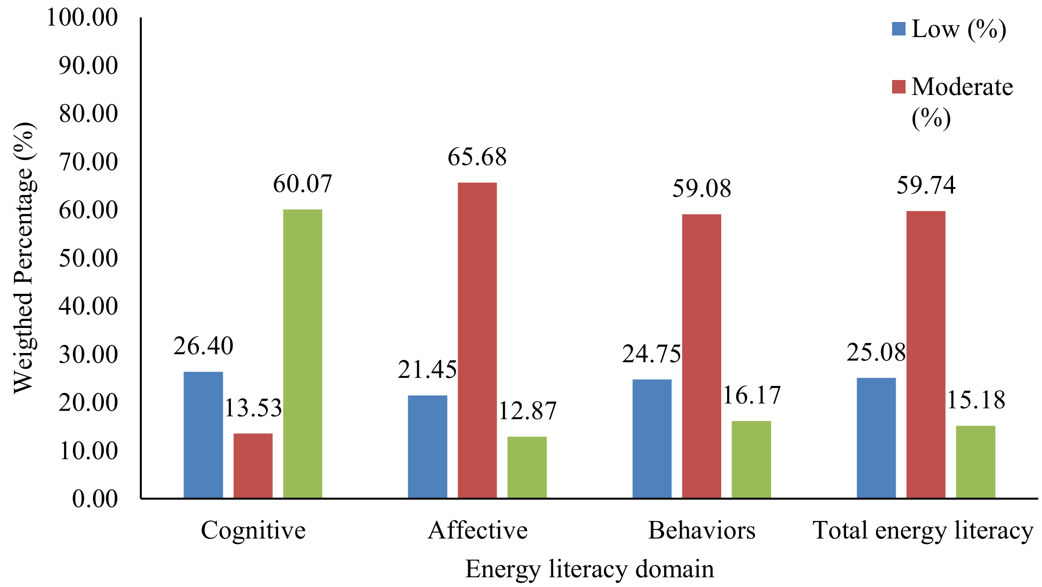

Figure 2. Distribution of energy literacy levels by domain

Differences in Students' Energy Literacy Based on Sociodemographic Characteristics

Recent research on youth energy literacy shows that students' literacy development is shaped by a learning ecology that includes school programs, classroom learning, information-seeking activities, peer interaction, and family environment (Ji et al., 2023). This perspective suggests that age should not be treated as an isolated determinant of energy literacy (Szulecki et al., 2024). Age may produce differences when it reflects different levels of educational exposure, grade progression, or access to energy-related learning experiences. However, the present study did not show a meaningful age-based difference because both age groups were still located within the same high school educational context (Ayata et al., 2024; Zulkarnaen et al., 2023). Students aged 13–15 and 16–18 likely received relatively similar exposure to science, environmental, and energy-related content through the formal curriculum. Therefore, age did not function as a strong differentiating factor in this sample. The absence of an age effect indicates that students' energy literacy was more likely shaped by shared curricular experience and comparable classroom exposure than by chronological age itself (Kuruppuarachchi et al., 2023).

A two-tailed power analysis was conducted in G*Power 3.1.9.7 for the comparison between students aged 13–15 years ($n = 36$) and 16–18 years ($n = 267$), using the Wilcoxon–Mann–Whitney procedure, á = 0.05, a normal parent distribution, and relative SD = 1. The sensitivity analysis with target power of 0.80 yielded a minimum Moment p1 of 0.6961, equivalent to an absolute rank-biserial correlation of approximately 0.392. As a supplement requested by the reviewer, the two-tailed post hoc analysis using the observed age effect (Moment p1 H" 0.5135; |r_rb| H" 0.027) yielded power of approximately 0.058. This value indicates that the design had very low power to detect an age effect as small as the observed effect. Therefore, the nonsignificant result does not demonstrate that an age effect is absent; the study primarily detected relatively strong, moderate effects and was limited in its ability to detect small effects. The unequal group sizes were incorporated into the calculation, but the small group of students aged 13–15 years continued to limit precision.

Female students obtained higher knowledge and total-literacy scores than male students. A difference also emerged in attitude, whereas behavior scores were nearly identical between the two groups. This pattern indicates that cognitive and affective advantages do not automatically produce differences in action. Behavioral constraints may arise from students' limited control over household appliances, divisions of household roles, and differences in self-efficacy for particular energy-related actions. The literature indicates that gender effects on energy behavior depend on the type of decision, decision-making position, household practices, and self-efficacy rather than on knowledge alone (Wang et al., 2021; Rainisio et al., 2022; Du & Pan, 2022). Students' energy literacy by grade is shown in the graph in Figure 3.

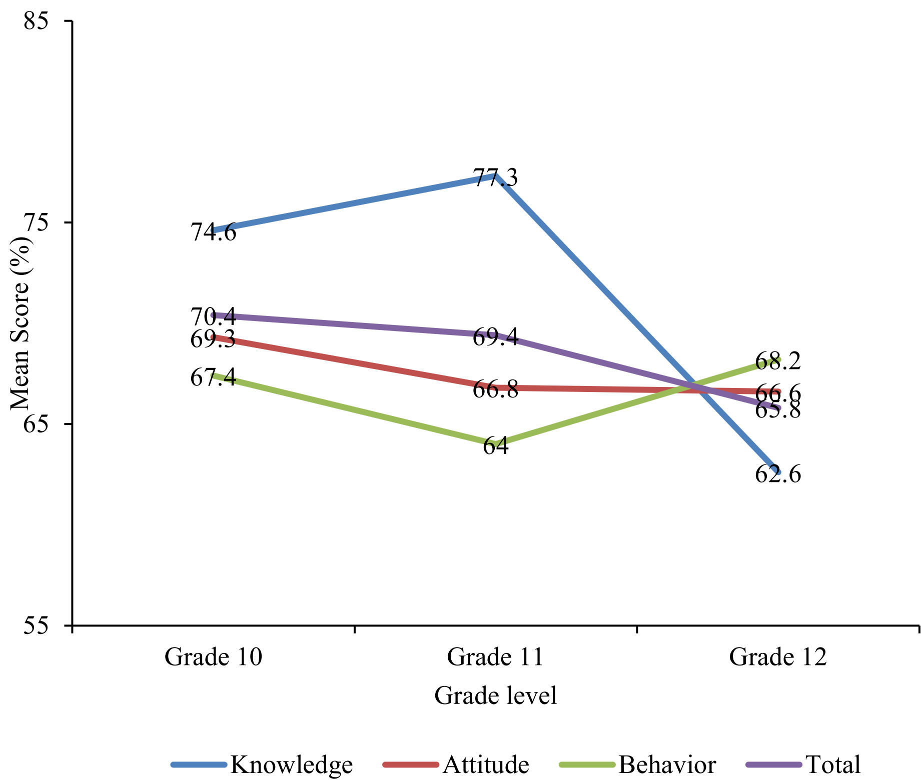

Figure 3. Comparison of energy literacy scores by grade

Energy literacy across grade levels showed a nonlinear pattern. Grade 11 students had the highest knowledge score (77.32), whereas Grade 12 students had the lowest knowledge score (62.59). In contrast, Grade 12 students obtained the highest behavior score (68.19). The decline in knowledge among final-year students can be attributed to reduced memory retention resulting from the increasing time elapsed since the energy concept was first studied. According to Radvansky et al. (2022), memory retention changes gradually over time; consequently, information that is not reinforced through repetition or re-application in a learning context is more susceptible to decay. This situation leads to a diminished understanding of the concept of energy when the material is not reinforced at subsequent educational levels. The higher behavior score in Grade 12 may have developed through longer-established habits, greater responsibility, and accumulated practical experience. These explanations are interpretive because the cross-sectional design did not directly test the proposed mechanisms.

Descriptive differences according to mother's education were not interpreted as a trend or relationship. Inferential testing indicated that mother's education did not significantly differentiate total energy literacy. Therefore, variations in group means were treated as sample fluctuation and were not used to infer an effect of mother's education on students' energy-related attitudes or behavior. The descriptive patterns in Table 4 show several group differences across domains. However, these descriptive differences require inferential testing to determine whether they represent statistically meaningful group variation.

Neither father's nor mother's education showed a significant difference in total energy literacy. This finding suggests that parents' formal educational attainment alone is insufficient to explain energy learning at home. Family practices, access to appliances, electricity costs, and everyday energy-use habits may be more proximal explanatory factors, but these variables were not measured in this study.

Participation in the Advanced Physics elective also did not differentiate total energy literacy (U = 2,285.500, p = 0.969). Additional exposure to Physics may focus more on mathematical modeling and formal problem solving than on everyday energy-consumption decisions. Moreover, energy literacy encompasses attitudes and behaviors shaped by family norms, habits, and control over appliance use. Consequently, additional exposure to Physics concepts alone may not improve all three domains simultaneously. The descriptive patterns in Tables 4 and 5 indicated several group differences across the domains. However, these descriptive differences required inferential testing to determine whether they represented statistically meaningful group variation.

Inferential Analysis of Sociodemographic Differences

Age, father's education, mother's education, and participation in Advanced Physics did not differentiate total energy literacy. Gender differentiated knowledge, attitude, and total literacy, while grade level differentiated the knowledge domain. All p values are reported to three decimal places, except values below 0.001. The main inferential-test results and effect sizes are presented in Table 6.

Table 6. Kruskal-Wallis results and effect sizes for the main comparison

Variable	Domain	Statistic	*p*	Effect size	Effect-size measure	Decision
Age	Total	U = 4,934.000	0.796	0.027	Rank-biserial	Not significant
Gender	Knowledge	U = 7,681.000	<0.001	0.284	Rank-biserial	Significant
	Attitude	U = 9,243.500	0.043	0.139	Rank-biserial	Significant
	Total	U = 8,029.000	<0.001	0.252	Rank-biserial	Significant
Grade level	Knowledge	H = 14.947	0.001	0.043	Epsilon-squared	Significant
	Total	H = 3.566	0.168	0.005	Epsilon-squared	Not significant

Father's education	Total	U = 7,791.500	0.326	0.082	Rank-biserial	Not significant
Mother's education	Total	U = 8,952.500	0.364	0.066	Rank-biserial	Not significant
Advanced Physics	Total	U = 2,285.500	0.969	0.004	Rank-biserial	Not significant

Key Sociodemographic Variations in Students' Energy Literacy Domains

Because grade level significantly differentiated the knowledge domain, follow-up pairwise comparisons were conducted using Mann–Whitney U tests with Bonferroni correction. Pairwise comparisons by grade level are presented in Table 7.

Table 7. Paired comparisons by grade level with bonferroni correction

Domain	Comparison	Mean 1	Mean 2	p	Adjusted p	Decision
Knowledge	Grade 10 vs Grade 11	74.60	77.32	0.023	0.070	Not significant
	Grade 10 vs Grade 12	74.60	62.59	0.017†	0.050†	Significant
	Grade 11 vs Grade 12	77.32	62.59	<0.001	0.001	Significant

The Grade 11–Grade 12 comparison showed a clear difference in knowledge (Bonferroni-adjusted $p = 0.001$), whereas the Grade 10–Grade 11 comparison was not significant (Bonferroni-adjusted $p = 0.070$). For the three comparisons, the Bonferroni correction yielded a raw-p alpha threshold of $0.05/3 = 0.0167$. The adjusted-p column was compared with á = 0.05. The Grade 10–Grade 12 comparison was significant at the boundary because the unrounded values were raw $p = 0.016533 < 0.016667$ and Bonferroni-adjusted $p = 0.049600 < 0.05$. The † symbol in Table 7 denotes a result very close to the decision threshold; three decimal places were retained in the table in accordance with APA 7, while the unrounded values are reported in this note.

Synthesis of Key Sociodemographic Patterns

Three main findings can be highlighted. First, energy literacy was in the moderate category, but knowledge was higher than attitude and behavior. Second, behavior remained the weakest domain, indicating that instruction needs to focus on habit change rather than merely delivering concepts. Third, the clearest variation occurred according to gender and grade level, whereas parental education, age, and participation in Advanced Physics did not differentiate total literacy.

Second, behavior is the weakest domain. This finding supports the existence of a knowledge-action gap. Students may understand the importance of energy conservation and hold positive attitudes, but consistent behavior depends on routines, social norms, the availability of facilities, and students' perceived control. Habit-based learning, interactive sustainability activities, and energy audit projects can help strengthen behavioral outcomes because students not only receive information but also practice making concrete energy decisions (Solanki et al., 2025; Yang et al., 2025).

Third, grade level and gender show specific patterns in certain domains. Female students have higher overall knowledge and literacy (Sardianou, 2025), but their behavioral advantage does not appear strong. Grade 11 students have the highest knowledge scores, while Grade 12 students demonstrate a higher tendency toward energy-saving behaviors. These findings challenge the assumption that higher knowledge automatically leads to better behavior. Energy education needs to build a bridge between concepts, attitudes, and actions through repeated, reflective, and practice-based learning experiences.

Parental education does not significantly differentiate total literacy. This finding does not mean that families are unimportant. Rather, the results indicate that parents' formal education is not the sole indicator of energy learning at home. Families with primary-to-secondary education may exhibit strong energy-saving habits due to economic reasons, a frugal lifestyle, or direct experience with electricity costs. Conversely, highly educated families do not automatically adopt energy-saving habits when a consumerist lifestyle and the convenience of using electrical appliances are dominant. Therefore, a family's cultural capital in energy literacy must be understood through daily practices, not merely educational levels (Azimi et al., 2023; Chodkowska-Miszczuk et al., 2021).

Implications for Energy Education

These findings call for more targeted educational interventions(Nag & Nag, 2025). For male students, teachers may employ diagnostic misconception tests, peer instruction, brief retrieval practice, and household electricity consumption calculation tasks to strengthen energy knowledge. For Grade 12 students, energy-related content should be reinforced through spaced review, concept mapping, and electricity bill case studies to maintain long-term knowledge retention. Behavioral reinforcement may be supported through weekly energy-use journals, classroom energy-reduction targets, pre- and post-learning feedback, and family-based energy-saving commitment agreements (Mudhofir et al., 2025). These strategies are more specific because they provide opportunities for practice, measurable assessment, and observable feedback. Furthermore, they can be implemented through STEM-based learning that connects energy concepts to contextual problem-solving, thereby supporting the development of students' energy knowledge, attitudes, and behaviors, particularly among groups with lower achievement (Nik Abdul Majid et al., 2025).

CONCLUSION

Overall, students' energy literacy was in the moderate category (weighted mean = 68.80). In response to the first research question, achievement across the domains was uneven: knowledge mastery was the main strength (M = 72.32), followed by attitude (M = 67.70), while behavior was the lowest domain (M = 66.37). This finding confirms that conceptual understanding had not been accompanied by consistent energy-saving practices, indicating a persistent knowledge-action gap.

In response to the second research question, inferential testing indicated that H0 was rejected for gender and grade level but not for age, father's education, mother's education, or participation in the Advanced Physics elective. Specifically, gender differentiated knowledge ($p < 0.001$), attitude ($p = 0.043$), and total literacy ($p < 0.001$), whereas grade level differentiated only the knowledge domain ($p = 0.001$). The other four variables did not statistically differentiate total energy literacy at the specified significance level.

In response to the third research question, the most prominent sociodemographic variation involved gender and grade level. The largest differences appeared in the cognitive domain: female students outperformed male students, Grade 11 students obtained the highest knowledge score, and Grade 12 students obtained the lowest. This pattern indicates that school-environment factors and gender-related differences showed more measurable variation than family educational background or chronological age in shaping students' energy literacy. Therefore, energy-literacy strengthening should be tailored to the needs of specific groups, particularly male students and final-year students, rather than implemented as a uniform intervention.

Future energy education should integrate conceptual reinforcement, decision-making practice, attitude reflection, and repeated practice to translate knowledge into concrete action. However, these findings should be interpreted in light of the cross-sectional design, self-reported behavior measures, and the single-school sample, which limit generalizability. Although categorical CFA supported the three-dimensional structure at the global level, the SRMR value slightly above 0.08 and several attitude and behavior indicators with low loadings indicate the need for replication in an independent sample. Future studies should combine questionnaires with behavioral observation, qualitative interviews, and experimental testing to assess the effectiveness of project-based and energy-audit interventions in bridging the knowledge-action gap.

■ DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

During the drafting of this manuscript, the author used several AI-assisted tools to support the writing process. ChatGPT was used for brainstorming and idea refinement, while DeepL and Google Translate were used to support English translation. After using these tools, the author carefully reviewed, revised, and verified the manuscript content. The author accepts full responsibility for the final content of this article.

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