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# Misconceptions and biases in German students' perception of multiple energy sources: implications for science education

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**ABSTRACT**
Misconceptions and biases in energy perception could influence people's support for developments integral to the success of restructuring a nation's energy system. Science education, in equipping young adults with the cognitive skills and knowledge necessary to navigate in the confusing energy environment, could play a key role in paving the way for informed decision-making. This study examined German students' knowledge of the contribution of diverse energy sources to their nation's energy mix as well as their affective energy responses so as to identify implications for science education. Specifically, the study investigated whether and to what extent students hold mistaken beliefs about the role of multiple energy sources in their nation's energy mix, and assessed how misconceptions could act as self-generated reference points to underpin support/resistance of proposed developments. An in-depth analysis of spontaneous affective associations with five key energy sources also enabled the identification of underlying concerns driving people's energy responses and facilitated an examination of how affective perception, in acting as a heuristic, could lead to biases in energy judgment and decision-making. Finally, subgroup analysis differentiated by education and gender supported insights into a 'two culture' effect on energy perception and the challenge it poses to science education.

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Energy knowledge; affective imageries; subgroup analysis



## Introduction

Energy is fundamental to our lives and underpins the functioning of our society (EU Commission, 2007). Sources to satisfy the world's hunger for energy can be categorized into nuclear, fossil (coal, natural gas, oil) and renewable (biomass, solar, wind etc.) energy sources. In recent years, heightening concerns about climate change, global warming and energy supply security as well as occurrences of energy catastrophes have put significant pressure on nations to restructure their existing energy systems (Lee & Gloaguen, 2015). Denmark, Germany and the U.S.A represent just some of the countries that are undergoing a transition in their energy systems today (Araujo, 2014). A lack of public support for proposed/planned energy policies and development plans relating to diverse

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energy sources can pose a significant dilemma for policy-makers and energy managers who are responsible for transiting a nation toward a low-carbon and sustainable system. This is particularly evident in democratic societies where the public expects and/or demands transparency and participative decision-making (Stagl, 2006). However, it is not easy for public citizens to obtain an overview of the energy environment and make an informed and considered decision regarding whether to support or reject a particular energy source and associated developments. Not only is a nation's energy system a highly complex and interconnected system where decisions regarding a particular energy source can have a significant impact on the stability and affordability of the entire system (Lee, 2015a), the vast amount of energy-related information and biased communication favoring one energy source or another in diverse media further complicates the picture. As such, science education can play an important role in equipping today's young adults and future decision-makers with the cognitive skills and knowledge necessary to navigate in the confusing energy environment and support their energy decision-making processes.

In view of its considerable socio-political-economic significance, energy is generally regarded as one of the most important topics in science education (Boyes & Stanisstreet, 1990). The science, technology and society (STS) educational movement emphasizes student understanding of the dynamic relationship among society, science and technology (Yang & Anderson, 2003). It thus supports the development of critical energy evaluation in young adults through curricula designed to improve scientific literacy and address misconceptions and potential biases at the interface between STS. Drawing on research in the fields of behavioral economics, psychology and risk perception, the current study is designed to investigate misconceptions and biases in students' perception of multiple energy sources representing viable alternatives in a nation's energy system so as to identify potential implications for science education. Specifically, the investigation focused on students' knowledge of the contribution of diverse energy sources to their nation's current energy mix as well as their affective perception of five key energy generation sources namely nuclear, coal, natural gas, solar and wind.

## Study background and objectives

First, although energy is essential to our daily lives, a large-scale Europe-wide study commissioned by the European Commission in 2006 found that not only did most Europeans consider energy-related issues to be of secondary importance in comparison to other concerns such as unemployment, crime, health care and economic situation; they also exhibited a somewhat vague idea of their nation's energy mix (EU Commission, 2007). A recent representative survey carried out in Germany also observed a lack of public knowledge about the contribution of different energy sources to the nation's energy mix (Nippa, Lee, Gloaguen, Meschke, & Hanebuth, 2013). Another study investigating eight-grade students' knowledge of energy resources in the U.S.A also came to similar conclusions (Bodzin, 2012). Students' beliefs about the contribution of various energy sources to their nation's current energy mix (i.e. their subjective feeling of knowledge of the energy mix) could have a potential influence on their preference for future energy developments by acting as reference points. Reference points are important as other outcomes are coded and evaluated in comparison to them (Kahneman, 1992). A person's beliefs about the role of diverse energy sources in his/her nation's energy mix could thus act as self-generated reference points and form the basis of evaluation and comparison for his/her future energy mix preference, where future preference would be unconsciously coded as gains or losses (Lee, 2015a). As such, any misconceptions or false assumptions regarding the contribution of an energy source to a nation's current energy mix could influence public acceptance of proposed energy developments associated with it. Moreover, it could drive unrealistic demands for changes relating to future energy developments in a nation's energy system. The first objective of the present study is thus to provide science educators with insights into whether and to what extent students hold mistaken beliefs about the role of multiple energy sources in their nation's energy system.

Second, in addition to knowledge, affect also has important relevance in the energy context. Affect refers to the spontaneous evaluation of like or dislike, of goodness or badness that a person experiences toward a stimulus object (Slovic, Finucane, Peters, & MacGregor, 2007). Energy-related discussions in the public sphere are often affect-laden (Grässler, Levitz, & Knight, 2011; Schulz, 2012; Smith & Prosser, 2011). In the complex environment where energy decision-making takes place, people generally have a finite amount of time, knowledge and resources to spend on a particular decision problem. As such, spontaneously generated affective responses toward various energy sources could be an effective decision heuristic – a mental shortcut – to facilitate quick and easy decision-making by the average man on the street/laypersons (Lee, 2015a). The reliance on spontaneously generated affect/feelings toward a stimulus in judgment and decision process has been termed 'affect referral' by Wright, the 'how-do-I-feel-about it' heuristic by Schwarz and Clore, and the 'affect heuristic' by Slovic and colleagues (Frederick, 2009, p. 550).

Research into energy risk perception also found that not only do people exhibit different affect/feelings toward multiple energy sources (Truelove, 2012), they also strongly associate energy sources with specific mental imageries (Keller, Visschers, & Siegrist, 2012; Slovic, Flynn, & Layman, 1991). An imagery associated with an object is a cognitive representation potentially containing both concrete and abstract impressions that is attached through learning and experience (Fiske, Pratto, & Pavelchak, 1983; Slovic, MacGregor, & Peters, 1998). Insights into people's imagery associations could thus reveal their subjective experiences and mental representations of reality (Slovic, Layman, & Flynn, 1990). In-depth investigations into energy imageries in recent years furthermore showed that different mental imageries associated with an energy source elicited different feelings, that is, different imagery-specific affect, providing evidence that an energy source is not perceived as simply good or bad (Keller et al., 2012; Lee, 2015b). More importantly, both mental imageries and imagery-specific affect are observed to remain relatively stable and resistant to change even in the aftermath of significant energy catastrophes such as the Fukushima nuclear incident (Lee, 2015b). The tendency to perceive different energy sources in certain ways by students may serve as 'anchors' for future judgments (Tversky & Kahneman, 1974) and bias their future energy evaluations. Moreover, it can lead to a subsequent filtering of information which students are exposed to so as to confirm their initial view in order to prevent unpleasant psychological arousal and discomfort resulting from cognitive dissonance (Festinger, 1957). As such, insights into how multiple energy sources are affectively perceived by students can support science educators in helping their students to more deeply understand their energy decision-making processes and address any potential biases. This leads to the second objective of the current study which is an identification of students' affective perception and mental associations with key energy generation sources.

Third, in designing science curriculum to address misconceptions and biases in energy perception, it is necessary to keep in mind that the public is not homogenous in its risk perception (Pidgeon, 1998). Education has been identified as one of the key factors shaping how students view energy sources (Lee & Gloaguen, 2015), and people from different education backgrounds are observed to diverge in their energy perception (Barke, Jenkins-Smith, & Slovic, 1997; Jenkins-Smith & Herron, 2007; Sjöberg, 2004). Of particular relevance for science educators are findings that young adults pursuing different education pathways (e.g. academic vs. non-academic; engineering/natural science disciplines vs. business/social science disciplines) already exhibit significant education-specific divergence in their energy perception (Drottz-Sjöberg & Sjöberg, 1991; Nippa & Lee, 2015). The divergence in energy perception observed between students from different education backgrounds suggests that attempts to address the 'average person' in designing science programs can be ineffective as it neglects heterogeneity between students. Insights into where education-specific divergence in energy knowledge and perception occur can thus support science educators in identifying the needs of different student subgroups.



Furthermore, not only are student subgroups distinguished by differences in their education levels and disciplines, a gender inequality is also observable in many disciplines (e.g. male students dominating hard and applied sciences such as engineering while more female students are enrolled in soft sciences such as humanities and social sciences). An additive effect of education background and gender on energy perception, in particular for nuclear energy is observed by risk perception researchers. For example, Barke and colleagues (1997) observed that women and life scientists perceived greater risks from nuclear energy. A similar observation is made by Sjöberg (2004) in assessing perception of nuclear waste, where risk alarmists are found more commonly among women with a low level of education. Such an additive effect of education and gender on nuclear perception is not only found in adults, it is already observable in students from different education disciplines whereby male students undergoing technical disciplines exhibited a more positive nuclear perception (Drottz-Sjöberg & Sjöberg, 1991). An education-specific divergence in energy perception compounded by gender effects can pose significant challenges for science educators in designing appropriate programs to address the needs of different student subgroups. To support such efforts, the third objective of the present study is an examination of the additive effect of education and gender on students' knowledge and perception of multiple energy sources.

The following research questions are formulated to guide the investigation:

(1) How accurate are beliefs (i.e. subjective knowledge) about a nation's current energy mix?
(2) What mental imageries are spontaneously and commonly associated with different energy sources and how are they affectively evaluated?
(3) Do knowledge, mental energy imageries and affective evaluation differ between student subgroups differentiated by education background and gender?

## Methodology

The aim of the study is to assess for misconceptions and biases in students' perception of multiple energy sources. Additionally, differences between education-gender subgroups are also analyzed so as to support science educators in identifying the needs of different student subgroups. Participants are informed that they are taking part in a research survey study investigating young adults' energy perception and knowledge of key energy sources used for electricity generation in their country. Survey participation was voluntary and anonymous, with no incentives (monetary or otherwise) provided.

The investigation focused on students undergoing tertiary education in Germany. Germany is one of the countries that has embarked on restructuring its energy system toward a low-carbon economy. Moreover, it has increased the pace of its ambitious energy transition project following the Fukushima nuclear catastrophe in March 2011. However, a lack of public acceptance has led to delays and/or failure in the implementation of innovative but contested energy technologies (e.g. carbon capture and storage), infrastructures (e.g. extension of the existing electricity grid) and facilities (e.g. location of a nuclear waste depository) (Lee, 2015a). Such protests have put significant pressure on German policy-makers and energy managers to respond to public concerns through changes to investment/development plans. This poses a dilemma for policy and managerial decision-makers who already have to deal with multiple technological and cost-related challenges associated with restructuring a nation's energy system. In view of the actual energy developments occurring in Germany and the importance of public acceptance to the success of its energy transition, it represents an excellent context for the present investigation.

### *Questionnaire*

#### *Energy knowledge*

To assess participants' knowledge of their country's energy mix, participants are requested to indicate what they thought were the percentage contribution of nuclear, fossil (defined as coal, natural gas and oil) and renewable energy sources (defined as biomass, solar and wind etc.) to Germany's energy mix in 2010. An option 'do not know' is also available to participants if they are uncertain about the role of an energy source.

#### *Affective energy imageries*

To gain insights into participants' affective perception of diverse energy sources, the word association technique used in earlier studies is adapted for the questionnaire (Slovic, Layman, & Flynn, 1991; Slovic & Peters, 2006). According to Szalay and Deese (in Slovic et al., 1990), word associations allow a person to reveal himself/herself in ways he/she would otherwise find difficult to do if required to articulate the reasons behind such associations through answers to concrete questions. It thus provides a valuable means through which researchers can gain access to and examine how a stimulus is subjectively perceived and evaluated by participants while minimizing researchers' bias that is typically imposed in closed questionnaires (Keller et al., 2012; Leiserowitz, 2006). As such, this technique has been widely utilized by risk perception and decision researchers to gain a deeper understanding of the nature of people's energy evaluation (Keller et al., 2012; Lee, 2015b; Leiserowitz, 2006; Truelove, 2012).

In the questionnaire, participants are requested to evaluate multiple energy sources. Each energy source is explicitly defined in the questionnaire to prevent misinterpretations by participants. The order of presentation of energy sources is randomized among participants to avoid systematic errors. Participants are asked to provide a maximum of three mental imagery associations that came to their minds when they think about each energy source, and to rate their feeling/affect toward each image on a scale from very negative (−3) to very positive (+3). The following example mirrors the structure of questions used to capture participants' affective energy evaluation:

> Solar energy refers to electricity generation through conversion of sunlight into electricity. Please write down the first three images that come to your mind when you think about solar energy. In addition, please rate your feelings toward each image on a scale from −3 (very negative), −2 (negative), −1 (slightly negative), 0 (neutral), +1 (slightly positive), +2 (positive) to +3 (very positive).

The first imageries that participants spontaneously associated with nuclear, coal, natural gas, solar and wind and their affective evaluation of such mental imageries are the focus of the current investigation.

### Demographics information

Participants are requested to indicate their education background (i.e. level and discipline) as well as their gender to facilitate an examination of subgroup differences in energy knowledge and perception. The characteristics of the variables investigated are presented in Table 1.

### Participants

Participants were young German adults undergoing academic (i.e. university) and non-academic (i.e. non-university) education in East Germany. The investigation focused on three student subgroups differentiated according to education levels and disciplines namely (1) university-engineering, (2) university-business and (3) non-university. At the time of the study, participants in the first two groups have completed their general secondary education ('Abitur' in German) and were pursuing different disciplines at the university level (i.e. same education level, different education disciplines



**Table 1.** Questionnaire characteristics.

| Categories | Variables | Type of responses |
|---|---|---|
| Knowledge | Nuclear<br>Fossil<br>Renewable | Numerical |
| Energy imageries | Nuclear<br>Fossil (coal, natural gas)<br>Renewable (solar, wind) | Qualitative |
| Affective perception | Nuclear<br>Fossil (coal, natural gas)<br>Renewable (solar, wind) | Continuous |
| Education background | Level (university, non-university)<br>Discipline[a] (engineering, business) | Categorical |
| Gender | Gender (male, female) | Categorical |

[a]Only applies for university students.

from the third group). Participants in the third group were undergoing their secondary education in a non-university institution providing full-time secondary education for young adults who did not obtain their 'Abitur' earlier. Hence, they are at a different education level from the first two sample groups.

A total of 728 young adults took part in a paper survey study administered during their lectures/lessons between May and August 2011. 399 (54.8%) of the surveys were fully completed and included in the analyses reported here. Participants were 187 university-engineering students (mean age 21.4 years, S.D = 1.77), 119 university-business students (mean age 21.5 years, S.D = 1.91) and 93 secondary students (mean age 23.6 years, S.D = 3.29). Table 2 presents the demographic breakdown of participants.



## Data analysis

### Quantitative data analyses (energy knowledge)

In 2010, Germany's energy mix (for electricity generation) is made up of 23% nuclear, 57% fossil, 17% renewables and 3% others (Fritsche & Rausch, 2011). To evaluate participants' knowledge of the energy mix, their responses are differentiated into four groups namely:

- underestimation – defined as a response which is greater than −5% of the actual percentage of the energy source in Germany's 2010 energy mix,
- accuracy – defined as a response which is within ±5% of the actual percentage of the energy source in Germany's 2010 energy mix,
- overestimation – defined as a response which is greater than +5% of the actual percentage of the energy source in Germany's 2010 energy mix, and
- do not know – for participants who selected the option 'do not know' instead of providing a percentage value for the contribution of nuclear, fossil or renewable energy sources to Germany's 2010 energy mix.

The *Z*-test is then used to test for frequency differences in education-gender subgroups holding major misconceptions about their nation's energy mix.

### Quantitative and qualitative data analyses (affective energy imageries)

A mean affect toward each energy source (i.e. mean affective energy perception) is obtained by averaging affective ratings for all imageries generated by the participants for that particular energy source. This facilitates a general overview of how different energy sources are affectively evaluated in comparison to each other.

Additionally, similar to Lee (2015a, 2015b), the imageries generated by participants are translated from German into English by a translator and the translation double-checked by a bilingual researcher. The English imageries then formed the basis for imagery coding.

**Table 2.** Participant characteristics.

| Education background | | Gender | | |
|---|---|---|---|---|
| Level | Discipline | Male | Female | Total |
| University | Engineering | 134 (72%) | 53 (28%) | 187 (100%) |
| University | Business | 63 (53%) | 56 (47%) | 119 (100%) |
| Non-University | – | 52 (56%) | 41 (44%) | 93 (100%) |
| | Total | 249 | 150 | 399 |

Using the coding categories developed by Lee (2015a, 2015b) as a reference, imageries generated by participants are examined thoroughly and coded into categories by the author. As per earlier studies (Keller et al., 2012; Lee, 2015b; Truelove, 2012), similar imageries (e.g. effective, effectiveness, efficient, efficiency etc.) are coded together to avoid assigning synonym separately to different categories while maintaining specificity in the imageries as much as possible.

Upon completion of the coding of generated imageries into categories, an index of affect toward each image category is obtained by averaging the affective ratings for imageries that are coded together. This allowed for an in-depth examination of mean affect associated with a specific imagery (i.e. imagery-specific affect) and therefore enabled additional insights into how participants perceived multiple aspects associated with an energy source. The statistic program Statgraphics Centurion is utilized for quantitative analyses related to imagery-specific affect. The normal probability plot, used to test for normality of the distribution of the variables to be evaluated in this study, indicated that not all variables are normally distributed. Therefore, non-parametric methods are used for the data analyses. Specifically, the Kruskal–Wallis test is used to assess for divergence in imagery-specific affect between participants from different education backgrounds and gender.

## Results

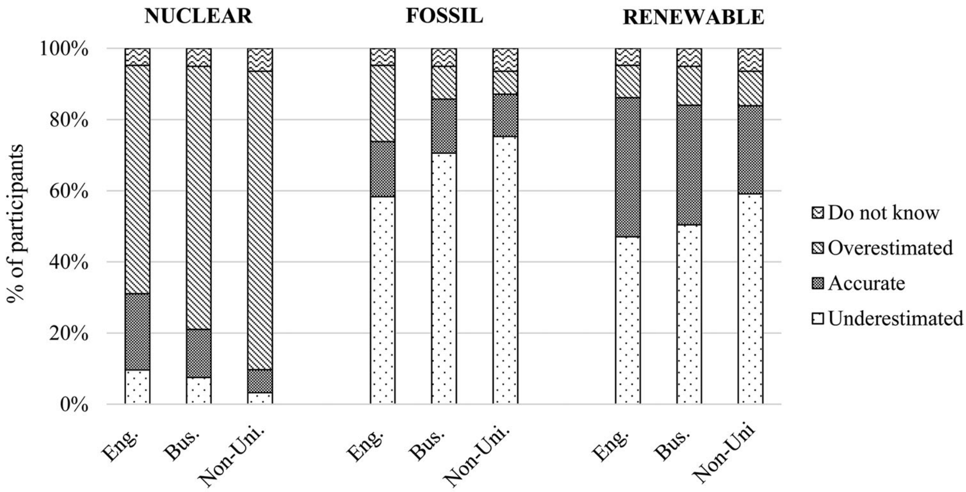
### *Energy knowledge*

Figure 1 presents a graphical illustration of the accuracy of participants' beliefs about Germany's 2010 energy mix. Their responses are presented in terms of the percentage of participants within each education subgroup who have underestimated, are accurate, have overestimated or who do not know what is the contribution of each energy source to Germany's 2010 energy mix.

Striking, only a minority of the participants were aware of the role that nuclear and fossil energy sources were playing in Germany's power generation capacity. Across all education subgroups, a majority of the participants overestimated the contribution of nuclear energy while underestimating the role of fossil energy sources in Germany's energy mix. This tendency was most evident in non-university participants. In comparison, participants were more aware of renewables' contribution to the country's energy mix. Nevertheless, most of them still tended to underestimate the role of renewables, with the underestimation most clearly observable in non-university participants.

Participants are thus observed to hold major misconceptions about the contribution of nuclear, fossil and renewable energy sources to Germany's 2010 energy mix. The majority of all student subgroups are found to overestimate the contribution of nuclear energy and to underestimate the contributions of fossil and renewable energy sources. In-depth analysis whereby education-gender student subgroups are ranked according to the proportion of each subgroup adhering to major misconceptions revealed additional insights (Table 3).

Though majority of all student subgroups overestimated the role of nuclear energy, the highest proportion is observed amongst non-university students, with 85.4% females and 82.7% males exhibiting this error. In contrast, significantly less engineering students (only 64.9% males and 62.3% females) exhibited a similar tendency to overestimate nuclear energy's contribution to Germany's energy mix. Moreover, while all student subgroups




N (Eng.) = 187; N (Bus.) = 119; N (Non-Uni) = 93

*Accurate = within +/- 5% of the actual % of the energy source in Germany's 2010 energy mix.*
*Underestimated = > -5% of the actual % of the energy source in Germany's 2010 energy mix.*
*Overestimated = > +5% of the actual % of the energy source in Germany's 2010 energy mix.*

**Figure 1.** Accuracy of participants' knowledge of Germany's 2010 energy mix.

are observed to overestimate the role of nuclear energy, non-university females are also observed to hold the highest mean degree of misconception regarding the role of nuclear energy in comparison to others. On the average, they attributed to nuclear energy 43.3% more importance in Germany's energy mix than its actual role.

Considerable differences are also observed between student subgroups in their underestimation of fossil energy. A significantly higher proportion of females undergoing non-university (82.9%) and business education (80.4%) are found to hold such misconception,

**Table 3.** Major misconceptions regarding energy mix by education-gender subgroups.

| Energy source – major misconception | Rank | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Nuclear – Overestimation | | | | | | |
| Education-gender subgroup | Non-uni. female | Non-uni. male | Bus. female | Bus. male | Eng. male | Eng. female |
| Proportion of subgroup (%) | 85.4[a] | 82.7[a] | 76.8[ab] | 71.4[ab] | 64.9[b] | 62.3[b] |
| Mean degree of misconception (%) | 43.3 | 38.2 | 40.4 | 27.5 | 26.9 | 38.0 |
| Fossil – Underestimation | | | | | | |
| Education-gender subgroup | Non-uni. female | Bus. female | Non-uni. male | Eng. female | Bus. male | Eng. male |
| Proportion of subgroup (%) | 82.9[a] | 80.4[a] | 69.2[ab] | 62.3[b] | 61.9[c] | 56.7[d] |
| Mean degree of misconception (%) | −37.1 | −34.3 | −36.7 | −29.8 | −24.0 | −25.0 |
| Renewable – Underestimation | | | | | | |
| Education-gender subgroup | Non-uni. male | Eng. female | Bus. female | Non-uni. female | Bus. male | Eng. male |
| Proportion of subgroup (%) | 63.5[a] | 56.6[ab] | 55.4[ab] | 53.7[ab] | 46.0[ab] | 43.3[b] |
| Mean degree of misconception (%) | −10.6 | −8.7 | −9.1 | −9.8 | −8.2 | −9.0 |

Note: Horizontal values (in a row) with the same superscript alphabet indicate subgroup proportions that are not significantly different at 95% confidence interval with the *Z*-test.

especially in comparison to male business (61.9%) and male engineering students (56.7%). Similar to nuclear energy, while all student subgroups underestimated the contribution of fossil energy to Germany's 2010 energy mix, non-university females are again observed to hold the highest mean degree of misconception regarding this energy source, believing it to contribute 37.1% less than its actual role.

The main difference between subgroups in underestimating the contribution of renewable energy is found between male non-university and engineering participants. Specifically, a considerably higher proportion of non-university males (63.5%) underestimated the role of renewable energy compared to engineering males (43.3%). Generally, all student subgroups are observed to hold similar mean degree of misconceptions regarding the role of renewable energy, believing it to contribute between 8.2% and 10.6% less than its actual role in Germany's 2010 energy mix.

## *Affective energy imageries*

Figure 2 presents a graphical illustration of participants' mean affective perception of five key energy sources. In general, participants perceived nuclear and fossil energy sources (i.e. coal and natural gas) negatively while renewable energy sources (i.e. solar and wind) are evaluated positively. However, while business and non-university students exhibited a tendency to view nuclear more negatively than fossil energy sources, engineering participants are observed to view coal most negatively.

Altogether, participants spontaneously generated 1796 imageries for the five key energy sources. Qualitative analysis of the generated energy imageries revealed that students commonly associated each energy source with specific mental associations (refer to Table 4). For example, nuclear energy is most strongly associated with danger and safety issues while imageries of air/carbon emissions and environmental impacts were highly salient in participants' minds when they thought about coal. Natural gas also elicited imageries of emission and environmental impacts. In contrast, solar and wind energy sources are

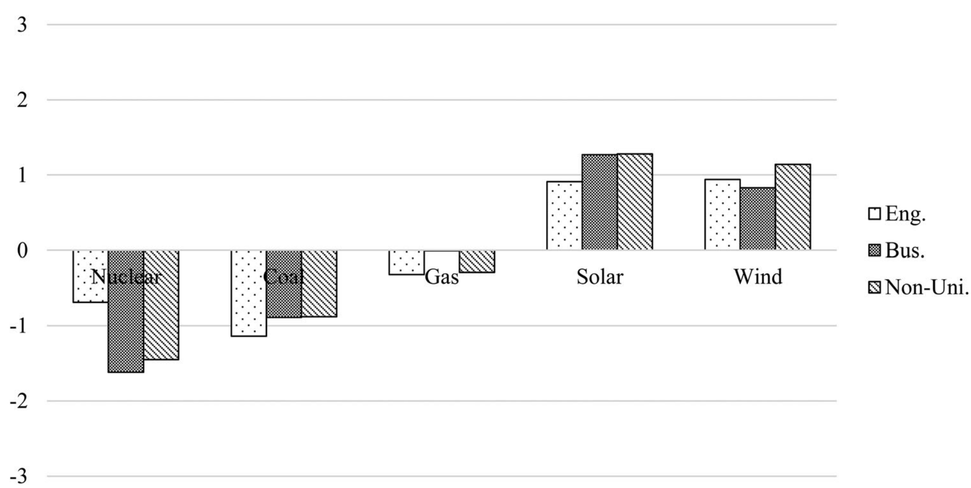



**Figure 2.** Participants' mean affective energy perception.

frequently associated with imageries of associated plants and equipment (i.e. solar panels for solar energy and windmills, -wheels and -parks for wind energy) as well as they being a clean and environmentally friendly energy source. In general, the top three imageries that participants associated with an energy source accounted for between 50% and 70% of all imageries that they generated for a particular energy source.

An examination of imagery-specific affect for each imagery by education-gender subgroup showed divergence in participants' affective evaluation for some imageries and consensus in others. Specifically, while all participants evaluated nuclear's association with danger and safety negatively, engineering males in particular viewed this imagery least critically while business females evaluated it most negatively ($Affect_{male\_eng.} = -1.60$, $Affect_{female\_bus.} = -2.92$; $K = 9.76$, $p < .01$). Additionally, while all participants also evaluated coal imageries of air pollution, $CO_2$ and emissions negatively, engineering males are again observed to exhibit the least negative affect toward this imagery. In contrast, non-university females viewed this imagery most negatively ($Affect_{male\_eng.} = -1.81$, $Affect_{female\_non-uni} = -2.83$; $K = 7.46$, $p < .01$).

An analysis of affect toward dominant imageries associated with each energy source within each education-gender subgroup revealed further insights. For example, when thinking about nuclear energy, engineering males viewed danger and safety issues associated with nuclear less critically than associations with specific nuclear incidents (e.g. Fukushima and Chernobyl) and with nuclear waste and disposal issues ($K = 12.3$, $p < .01$) . Furthermore, most participants' subgroups (except for non-university males and females) also viewed coal imageries of digging and mining less negatively compared to other coal imageries. In the case of wind energy, while all participants associated it with positive imageries of wind plants and equipment as well as being a clean and environmentally friendly energy source, they also exhibited a strong negative association of this energy source with a blemished landscape.

## Discussion

Public acceptance and support are crucial building blocks to the success of a nation's energy transition. This is particularly the case in democratic societies where the public expects and/or demands transparency and participative decision-making (Stagl, 2006). As mentioned earlier in the methodology section, a lack of public acceptance for proposed and planned energy developments presents a significant dilemma for German policy and managerial decision-makers who already have to deal with multiple technological and cost-related challenges associated with restructuring the nation's energy system. Germany, however, is not the only nation facing challenges in this respect. Other mature economies such as UK and U.S.A as well as emerging economies such as China and India are also having to deal with an increasing demand for transparency, accountability and participative decision-making with regard to their energy developments (APB, 2012; Lakshmi & Denyer, 2012; Smith & Prosser, 2011; Zeit Online, 2012).

In view of the importance of public acceptance to a successful restructuring of a nation's energy system, it is not a surprise that people's energy knowledge and perception have become the focus of numerous investigations. Large-scale representative studies of citizens' energy knowledge and perception have been carried out in multiple countries with the goal to inform policy-makers and energy managers and to support their

**Table 4.** Main energy imageries and mean imagery-specific affect by education-gender subgroups.

| Energy source | Frequency (%) | Mean imagery-specific affect by subgroups: Males, Eng. (% Frequency) | Males, Bus. (% Frequency) | Males, Non-Uni. (% Frequency) | Females, Eng. (% Frequency) | Females, Bus. (% Frequency) | Females, Non-Uni. (% Frequency) | Kruskal–Wallis test[b] |
|---|---|---|---|---|---|---|---|---|
| Nuclear (*N* = 377) | | | | | | | | |
| Danger & safety | 103 (27.3%) | −1.60 (8.0%) | −2.47 (4.5%) | −2.25 (4.2%) | −2.12 (4.8%) | −2.92 (3.7%) | −2.13 (2.1%) | * |
| Nuclear incidents | 69 (18.3%) | −2.88 (4.5%) | −2.40 (4.0%) | −2.38 (2.1%) | −2.60 (1.3%) | −2.86 (5.6%) | −3.00 (0.8%) | – |
| Nuclear waste & disposal | 36 (10.3%) | −2.33 (3.2%) | −2.50 (2.1%) | −2.33 (0.8%) | −2.57 (1.9%) | −2.33 (0.8%) | −3.00 (1.6%) | - |
| Kruskal–Wallis test[a] | | ** | – | – | – | – | – | |
| Coal (*N* = 367) | | | | | | | | |
| Air pollution, $CO_2$ & emissions | 87 (23.7%) | −1.81 (9.8%) | −2.07 (3.8%) | −2.17 (1.6%) | −2.43 (3.8%) | −2.36 (3.0%) | −2.83 (1.6%) | * |
| Dirty & environmental impacts | 81 (22.1%) | −1.97 (8.2%) | −2.21 (3.8%) | −1.89 (2.5%) | −1.11 (2.5%) | −1.58 (3.3%) | −0.43 (1.9%) | – |
| Digging & mining | 50 (13.6%) | −0.47 (4.1%) | 0.71 (1.9%) | −1.00 (1.6%) | 0.11 (2.5%) | 0.00 (2.2%) | −0.60 (1.4%) | – |
| Kruskal–Wallis test[a] | | ** | *** | – | *** | ** | * | |
| Gas (*N* = 300) | | | | | | | | |
| Emissions & env. impacts | 87 (29.0%) | 0.15 (13.7%) | −0.40 (5.3%) | 0.44 (3.0%) | −0.45 (3.7%) | −1.14 (2.3%) | −3.00 (1.0%) | – |
| Sources | 42 (14.0%) | −0.91 (3.7%) | −0.67 (4.0%) | 0.17 (2.0%) | −0.75 (2.7%) | 0.00 (1.7%) | –(0.0%) | – |
| Mining, transport & storage | 38 (12.7%) | −0.67 (4.0%) | −0.33 (2.0%) | −0.88 (2.7%) | −0.50 (2.0%) | 0.33 (1.0%) | 0.00 (1.0%) | – |
| Kruskal–Wallis test[a] | | – | – | – | – | – | * | |
| Solar (*N* = 376) | | | | | | | | |
| Clean & env. friendly | 101 (26.9%) | 2.53 (8.5%) | 2.43 (5.6%) | 2.82 (2.9%) | 2.50 (3.2%) | 2.80 (4.0%) | 2.80 (2.7%) | – |
| Solar panels | 76 (20.2%) | 1.13 (6.1%) | 1.88 (2.1%) | 1.67 (3.2%) | 1.33 (2.4%) | 1.64 (3.7%) | 1.00 (2.7%) | – |
| Renewable & alt. resource | 59 (15.7%) | 2.00 (5.6%) | 1.90 (2.7%) | 2.50 (1.6%) | 1.86 (1.9%) | 2.36 (2.9%) | 1.50 (1.1%) | – |
| Kruskal–Wallis test[a] | | ** | – | * | – | * | * | |
| Wind (*N* = 376) | | | | | | | | |
| Windmills, -wheels & -parks | 128 (34.0%) | 0.33 (8.0%) | 0.80 (4.0%) | 1.14 (5.6%) | 0.73 (5.9%) | 1.00 (6.4%) | 0.75 (4.3%) | – |
| Clean & env. friendly | 82 (21.8%) | 2.42 (9.6%) | 2.54 (3.7%) | 2.88 (2.1%) | 2.13 (2.1%) | 2.75 (2.1%) | 2.88 (2.1%) | – |
| Blemished landscape | 41 (10.9%) | −1.00 (3.7%) | −2.50 (1.1%) | −1.17 (1.6%) | −1.50 (1.6%) | −0.89 (2.4%) | −2.50 (0.5%) | – |
| Kruskal–Wallis test[a] | | *** | *** | *** | ** | *** | *** | |

[a]The Kruskal–Wallis test tests for significant differences between affect associated with diverse imageries for each energy source.
[b]The Kruskal–Wallis test tests for significant differences between education-gender subgroups in their affect toward each imagery.
*$p < .05$.
**$p < .01$.
***$p < .001$.

decision-making process. However, while some evidence of a lack of public knowledge about a nation's energy system has been observed in such representative samples (EU Commission, 2007; Nippa et al., 2013), progress is slow in providing specific insights into its manifestation in young adults which could provide valuable input to inform the development of science education programs. Furthermore, though quantitative measurements of energy perception utilized in previous studies are highly useful in providing a quick overview of how multiple energy sources are perceived, they mask information relating to specific aspects that are underpinning people's energy support and/or resistance. Though effortful, a qualitative investigation of imageries that are spontaneously generated by young adults in association with different energy sources could provide science educators with a deeper understanding of potential biases that may be influencing their students' perception and support for alternative energy sources.

The present work thus complements and extends previous investigations as it concentrates on identifying misconceptions which students – young adults today who will be involved in activities and decisions relating to differing energy technologies and infrastructures in the future – hold regarding the role of diverse energy generation options in their nation's energy system. Moreover, an in-depth analysis of their dominant affective imagery associations for five key energy sources enables an identification of specific aspects generating high levels of concern/support for different energy sources which could function as potential biases in students' reactions toward proposed/planned energy developments.



### *Energy knowledge*

A deliberately simple question requesting student participants to indicate their beliefs (subjective knowledge) of the role of nuclear, fossil and renewable energy sources in their country's energy system facilitated an examination of whether and to what extent misconceptions exist. Strikingly, as can be seen from Figure 1, the majority of participants are found to be wrong in their beliefs of the contribution of nuclear, fossil and renewable energy sources to Germany's 2010 energy mix. This is particularly disturbing as the investigation is conducted shortly after the occurrence of the Fukushima nuclear accident in March 2011, in the midst of intensive media reporting and debates about Germany's current and future energy mix. One would expect that in view of the high public interest and abundance of information available, misconceptions regarding the role of nuclear, fossil and renewable energy sources in Germany's energy system would be minimal. However, current findings paint a different reality whereby the majority of student participants are observed to hold inaccurate beliefs about the role of different energy sources, with the major misconceptions being an overestimation of the contribution of nuclear energy and an underestimation of the role of fossil and renewable energy sources. This observation is in line with the findings of a German representative survey study carried out by Nippa and colleagues (2013) and strongly suggests that a lack of knowledge about the composition of Germany's current energy mix is prevalent throughout the society.

Mistaken beliefs or 'false assumptions' about the role of an energy source in a country's energy mix could influence public support/resistance toward proposed energy developments associated with it by acting as self-generated reference points (Lee, 2015a).

Addressing such false assumptions held by young adults thus represents a first step toward encouraging students to critically evaluate their preference for their country's future energy mix. Consider the following example: Fossil made up about 60% of Germany's 2010 energy mix. Student X, however, thinks that the energy mix is composed of only 30% fossil and would like to see a drastic decrease in reliance on such energy sources. Hence, he is opposed to any proposals extending the life span of fossil power plants or increasing fossil power generation capacity in the country. Moreover, he may make unrealistic demands regarding the pace of fossil phase-out in Germany and is frustrated when such demands are not being addressed by politicians and energy managers, thus setting the stage for potential conflicts. Science education could play a key role in addressing students' misconceptions and preventing escalations of frustrations and conflicts relating to restructuring a nation's energy system. In challenging their students to acknowledge and confront misconceptions regarding their country's energy mix as well as understand how this may influence their preference for changes to the energy system, science educators can encourage the development of critical thinking skills in young adults and pave the way for informed decision-making.

### *Affective energy imageries*

In the current study, the word association method is used to elicit mental imageries that participants spontaneously associated with five key energy sources, namely nuclear, coal, natural gas, solar and wind. An in-depth analysis of qualitative energy imageries as well as quantitative imagery-specific affect is undertaken to identify dominant associations with these energy sources as well as students' affective evaluation of such mental associations.

Taylor noted that one's judgments are always based on what comes to mind (in Schwarz & Vaughn, 2009). A content analysis of mental associations with diverse energy sources is thus useful in enabling a deeper understanding of underlying concerns underpinning people's energy support/resistance (Keller et al., 2012; Lee, 2015b; Slovic, Flynn, et al., 1991; Truelove, 2012). In identifying dominant imageries that students spontaneously associated with alternative energy generation options (refer to Table 4), this study supports such efforts by providing first insights into how different energy sources are subjectively perceived by young adults. Take wind for example. Participants strongly and positively associated wind as being a clean and environmentally friendly energy source. However, at the same time, they are also concerned about wind projects blemishing the German landscape. Present findings thus provide empirical evidence that an energy source is not simply perceived as good or bad. Rather, there appears to be differentiated aspects underpinning support (as indicated by imageries which elicited a positive imagery-specific affect) and resistance (as can be seen from imageries eliciting a negative imagery-specific affect) for it. In the case of wind energy, study results thus point to the potential for protests against proposed wind developments should concerns regarding the associated destruction of surrounding landscape not be adequately addressed (e.g. NIMBY 'not in my backyard' or BANANA 'build absolutely nothing anywhere near anything/anyone' driven protests), regardless of the support it may elicit as a clean and environmentally friendly energy source.

Strong affective associations of energy sources with particular imageries may have their roots in early learning whereby exposure in a person's early years could have significantly influenced his/her energy perception such that certain imagery associations are made intuitively, without conscious thought or consideration of alternatives (Lee, 2015b). As such, affective evaluation of energy imageries could play a role as a 'fast and frugal' heuristic (Gigerenzer & Todd, 1999; Todd & Gigerenzer, 2000) to support judgment and decision processes in the energy context through easy searching, stopping and decision rules. To elaborate, searching rules specify the direction of search in the search space; stopping rules specify when the search is to be stopped; and decision rules specify how the decision is reached (Gigerenzer & Gaissmaier, 2011; Gigerenzer & Todd, 1999). Staying with the example of wind energy, when faced with the decision problem whether to support a proposed wind energy development in his region, student Y searches his memory for imageries associated with wind (search rule). He stops searching once an image is spontaneously generated in his mind, for example, a blemished landscape (stop rule). He then uses his affect toward this imagery as basis for making judgment or decision toward the decision problem, for example, protest against the proposed wind development project (decision rule). This example illustrates how an affective energy imagery, that is, negative association of wind energy with a blemished landscape, in providing a basis for decision, could discourage a person from considering the issue more carefully and facilitate a fast and frugal judgment/decision. Though facilitating quick and easy decision-making, reliance on affective energy responses to support energy decisions could lead to potential biases. For one, through providing a basis for judgment and decision-making, existing affective responses could discourage further analysis (Frederick, 2009). Additionally, they could subsequently influence students' motivation to seek out information to support their existing views in addition to potentially biasing their analysis of conflicting energy-related information and their responses toward an energy issue (Lee, 2015b).

In particular, when a person is facing constraints of time, attention, motivation, knowledge and other resources which is usually the case for laypersons/the average man on the street, affective energy imageries can act as a simple heuristic to facilitate quick, easy and efficient energy judgment/decisions. Policy-makers and energy managers, however, seldom have this luxury as they generally have a long planning horizon and have to consider multiple social, technological, economic, ethical and political factors in their energy decision-making (Lee, 2015a). This sets the stage for potential disagreements and conflicts regarding energy developments associated with different energy sources. To further complicate matters, both energy imageries and imagery-specific affect have been observed to remain relatively stable and resistant to change even in the aftermath of a significant energy catastrophe such as the Fukushima nuclear incident (Lee, 2015b). This suggests that affective energy associations are deeply anchored and points to a potential lock-in of specific imageries with diverse energy generation options in a society (Lee, 2015b). Such a strong tendency to associate an energy source with particular affective imageries, already detectable in students as observed in this study, can be very hard to change. This makes the tasks of managers of a nation's energy transition so much harder.

To support a successful restructuring of a nation's energy system, it would therefore be necessary to consider and address people's subjective energy associations. Insights from a pilot study with French students identified education as one of six contextual factors playing a key role in shaping young adults' energy perception and support (Lee & Gloaguen, 2015). This suggests that science education is in a unique position to have a strong influence on students' perception and support for alternative energy generation options in their country. By engaging their students in dialogues and discussions on how and why they view different energy sources the way they do, science educators could help young adults recognize the potential for biases in their energy responses resulting from a reliance on spontaneously generated affective evaluations. In encouraging students to not only consider the reasons behind their energy responses more deeply but to also critically evaluate conflicting energy information and reflect on the 'big picture', educators could help them develop the cognitive skills they need to make an informed and considered decision regarding whether to support or reject a particular energy source and associated developments. Through such efforts, science education can make a significant contribution toward reducing affect-driven decisions and conflicts in discussions about proposed/planned energy developments.

### *Education-gender subgroups*

Subgroup differences in energy perception have elicited considerable research interest. Earlier studies on divergence in energy perception have focused predominantly on nuclear energy and associated waste disposal issues whereby diverging nuclear perception is observed not only between experts and laypersons (Sjöberg, 1999; Sjöberg & Drottz-Sjöberg, 1994, 2008), but also among professionals from different disciplines (Barke & Jenkins-Smith, 1993; Barke et al., 1997). However, progress has been slow in explaining when the seeds for a diverging nuclear perception may be planted. Nor could previous studies provide insight into whether such subgroup divergence is unique to perception of nuclear energy or applies more generally across a range of alternative energy sources in a nation's energy system. The present investigation thus extends previous research by investigating the manifestation of education-gender subgroup differences in misconceptions and affective imageries associated with diverse key energy sources in young adults.

That education plays a key role in contributing to differing viewpoints was originally thematized by Snow (1956) in his influential essay 'The Two Cultures' which spoke about the division between what can be broadly defined as the arts and the sciences. Forty years later, not only did Barke and Jenkins-Smith (1993) use the term two cultures to describe the gulf between professionals from different disciplinary background in their nuclear perception, Newby (1997) also referred to the differences in risk approaches between natural scientists/engineers and social scientists as a clash of 'two cultures'. Though four decades apart, these observations emphasized how education can shape people to the extent that standpoints adopted by those from different education backgrounds appear to be as diverging as that from different cultures.

Current findings provide evidence that an education-induced cultural difference do exist in students' misconceptions about the energy mix and their energy perception. For example, while the tendency to overestimate the role of nuclear energy and underestimate the roles of fossil and renewable energy sources in Germany's energy mix was most evident in non-university participants (refer to Figure 1), university-engineering students are observed to be also less critical of nuclear energy compared to their peers from other academic disciplinary culture (i.e. business) as well as non-academic (i.e. non-university) culture (refer to Figure 2). Such an identification of where education-specific divergence in energy knowledge and bias occurs represents the first step in developing targeted programs to meet the needs of different student subgroups. For such efforts to be truly successful, science educators could furthermore benefit from understanding their role in contributing to their students' energy knowledge and perception.

Broadly speaking, as pointed out by Nippa and Lee (2015), in entering different education levels (e.g. academic vs. non-academic) or disciplines (e.g. engineering or business), students gain access to specific knowledge and are exposed to standards, methodologies/approaches and mindsets that are of considerable differences (Weidman, Twale, & Stein, 2001). Such education and socialization are not only important for the production, acquisition and use of knowledge (Windolf, 1995), they also contribute significantly to the underlying structure of generic knowledge, assumptions, expectations and decision rules/criteria which an individual relies on in evaluating new information and experiences (Nisbett & Ross, 1980; Yim & Vaganov, 2003). As such, when faced with an energy source, students from different education backgrounds will draw on their education-specific knowledge bases and criteria in evaluating the related information and experiences (Barke & Jenkins-Smith, 1993). This can result in differing degrees of motivation and abilities to process diverse types of energy-related information, in addition to sensitivity to/focus on different aspects associated with an energy source. Consequently, this could lead to education-specific differences in energy misconceptions and biases as observed in this study.

As key reference persons in the education system, science educators play a critical role in influencing the cultures that their students are exposed to and in shaping their mindsets. Awareness of and understanding their role in contributing to education-induced 'two cultures' effect in their students' energy perception thus represents an essential step in developing effective science education programs. This could prevent the development of what Becher has referred to as educational 'tribes', where each tribe exhibits its own dispositions to think and behave in a specific way (Becher, 1994; Huber, 1990).

In addition to an education-induced 'two cultures' effect, a considerable body of research also points to the significance of gender cultures in environmental perception (see review by Davidson & Freudenburg, 1996). Researchers even suggested that there is a 'white male effect' in people's risk perception (Finucane et al., 2000; Palmer, 2003). Different proposals have been put forward to explain gender differences in environmental and risk perception, including social and biological hypotheses which focused on differences in socialization, knowledge, trust, economic salience, safety concerns and parental roles (Barke et al., 1997; Davidson & Freudenburg, 1996).

A divergence in energy misconceptions and biases resulting from education background compounded by gender effects can pose significant challenges for the successful transition of a nation's energy system. This is because a gender imbalance remains prevalent, especially in science, engineering and technology sectors (Wynarczyk & Renner, 2006). As these are fields that play an important role in contributing to the development of transition policies/technologies and in managing risks associated with restructuring an energy system, insights into how gender interacts with an education-induced cultural divergence in energy knowledge and perception could provide valuable information to support the development of appropriate programs for different student subgroups to address their specific needs.

Study findings provide some evidence that energy misconceptions and biases span both education cultures and gender boundaries. Breaking participants down into education-gender subgroups enabled a more specific identification of subgroups where misconceptions regarding the contribution of different energy sources are most prevalent, and are thus in need of most urgent attention and intervention (refer to Table 3). Moreover, results provide in-depth insights into exactly who disagrees with whom in their energy perception. Take the instance of coal. While all student subgroups associated this energy source with negative imagery of air pollution, $CO_2$ and emissions, male engineering students are observed to evaluate this imagery considerably less negatively while female non-university students were most critical of this imagery (refer to Table 4). In illustrating the heterogeneity of misconceptions and biases between different education-gender subgroups, the current study points to a key challenge faced by science education. A lack of consensus in knowledge and perception of different energy sources is already observable in students from different subgroups. This cautions that science programs which make the assumption of a homogenous student population and do not consider inter-individual differences and commonalities among different subgroups in their designs and implementation may have limited effectiveness in engaging its intended audience and having a sustainable impact.

## Conclusion

Public acceptance and support are crucial building blocks to the success of a nation's transition toward a low-carbon economy. However, due to the complexity of the energy system and the vast amount of conflicting and biased energy information in diverse media, it is not easy for public citizens to make an informed and considered decision regarding whether to support or reject a particular energy source and associated developments. Science education thus plays an important role in equipping today's young adults and future decision-makers with the cognitive skills and knowledge necessary to navigate in the confusing energy environment and support their energy decision-making. This study investigated misconceptions and biases in German students' perception of multiple energy sources. The aim is to identify implications for science educators so as to support the development of appropriate and targeted education programs and pave the way for informed decision-making. The investigation provides evidence of widespread misconceptions regarding the role of nuclear, fossil and renewable energy sources in Germany's energy mix and assesses how false assumptions could underpin support/resistance toward energy transition measures. An in-depth examination of affective energy imageries that students strongly associated with five key energy sources also supports an analysis of how they could potentially bias students' energy judgment/decision-making by acting as a heuristic. In addition, the study provides a deeper understanding of the additive role of education and gender in contributing to a 'two culture' effect on energy perception and the challenge it poses to science education. Insights gained from the current investigation provide practical tips to support the development of targeted programs to develop critical thinking skills in students as well as to reduce affect-driven decisions and conflicts in the energy context. It furthermore cautions against an assumption of homogeneity in the student population in designing and implementing science programs if the goal is to have a sustainable impact on addressing students' energy misconceptions and biases.

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