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Energy literacy: towards a conceptual framework for energy transition

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ABSTRACT

Energy is fundamental to our existence. And yet, energy remains difficult to understand and discuss, particularly the impacts or limitations of certain energy systems and how energy functions in sociocultural contexts. Bridging theory and practice, energy literacy expands what we know about energy and how we may think about it in the world around us. Acknowledging how the world's energy supply and use directly connects to the climate emergency, this article demonstrates how energy literacy can offer environmental and sustainability education other ways of addressing the energy transition. Understanding the underpinnings of energy – with integrated aspects of epistemology, ontology, and application (i.e., *what energy is*, *what energy is about,* and *what energy does*) – leads to the question: what approach effectively translates these experiences and knowledges to a wide range of users, learners, and stakeholders? This article proposes a conceptual framework of energy literacy that considers theoretical ideas and concepts to translate complex systems and understand energy more holistically.

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Energy literacy; energy transition; energy epistemology and ontology; energy cultures; citizen-engagement; environmental and sustainability education

Introduction

Energy systems are one of the most complex and defining issues of our age. As Urry (2013) stated, societies must know how energy systems are energized and powered through various interlinking systems of energy production, distribution, and consumption that play into other aspects of society. And yet, energy remains difficult to understand, discuss, and represent, even though it affects every aspect of contemporary life. At a time when the focus on systemic energy transitions is critical to global energy supply and the climate, opportunities exist for how we might communicate and educate more widely about the interplay of the technical and sociocultural aspects of energy. With increasing numbers of universities and schools declaring a global climate emergency (Latter and Capstick 2021; Reid 2021), energy literacy offers environmental and sustainability education integrated ways of addressing the ongoing crisis.

Energy literacy requires knowledge of energy supply and systems, and how they function in society and culture (McCaffrey 2015), including the ways society envisions building sustainable energy transitions and futures. Even as energy is primarily taught in specific technical disciplines (e.g., Hecht 2019), energy is something that is vital to the everyday lives of people, as well as

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for the global collective. Developing knowledge and understanding about energy emphasizes how to think about energy in society and our place within it (Szeman and Boyer 2017). As Butler, Lerch, and Wuerthner (2012) proclaimed, "there is no task more urgent than promoting widespread energy literacy" to support a sustainable civilization for the future (4).

Because energy fundamentally influences the world around us, fueling our social lives as much as our automobiles (Szeman 2013), energy literacy expands what we know and how we may think about energy, as well as assisting us through an unpredictable global energy transition (Smil 2016). One significant aspect of exploring energy literacy as part of environmental education, even though it might seem peripheral, is to acknowledge and respond to an ongoing transition of accessibility, use, and consequences of various forms of energy (Saul and Perkins 2022). Energy transition is a process of shifting from fossil fuels (oil, gas, coal), and the inherent injustices associated with them, towards renewable and equitable forms of energy that include alternative visions for reducing energy consumption (Petrocultures Research Group 2016). Moving to sustainable forms of energy to support low carbon futures remains less of an issue of technology and capability, however, and more of an opportunity for education to support energy transitions (Sovacool 2019; Michel 2020).

Energy can be approached from technical (Geels 2010), cultural (Szeman and Diamanti 2019), artistic (Lord 2014), social (Urry 2013), economic (Bellamy and Diamanti 2018), and political (Brown and Spiegel 2019) domains, among many others, but how might these also speak to and with each other? In our own attempt to answer this question, we propose an integrated and holistic approach to energy literacy. As an epistemology (knowing), ontology (being), and application (doing) – i.e., *what energy is*, *what energy is about,* and *what energy does* – energy literacy translates experiences and knowledges for a wide range of users, learners, and stakeholders, while also building a path to creating sustainable energy futures. Acknowledging that learning about and translating energy requires an integrated framework, we have decided to co-author this article as two researchers from historically disparate disciplines in literacy education and chemical engineering, but both of whom conduct research on energy literacy and environmental education. We aim to further conceptualize energy literacy to encourage effective dialogue and common understanding for educators, researchers, and decision makers to mobilize collective efforts towards engaging in a sustainable energy transition.

Context and review

Life is created from the self-organizing energies of the universe. These living energy systems and networks transform and create communities, countries, and civilizations (Shiva 2015). Despite this vital force governing known existence, people often know little about energy, particularly the impacts certain energy systems create for the planet and how energy functions in sociocultural contexts (e.g., what is our social and personal relationship with energy?). These energy systems impact a wide range of activities beyond driving a car or heating homes, and underline an increasing need for developing widely adopted language and literacy practices of how to know and communicate about energy in our daily lives.

Conceptualizations of literacy as an educational tool or practice have shifted over the years. Originating as a way to build reading and writing as discrete skills, literacy is currently more widely applied as a social practice performed by people in their daily lives (The New London Group 1996), as affectively situated in a complex world (Truman 2019), or as entangled with the material world (Burnett and Merchant 2020). In this sense, literacy education has significantly evolved into multiple modes of learning and experience (e.g., Vasquez 2019). It is now considered as an integrated practice focused on what literacy is and does as actionable processes (Horst and Gladwin 2022), such as interpretation, creation, communication, and identification (Montoya 2018), where various modes of meaning-making can be examined with an emphasis beyond singular monolithic modes of literacy (Serafini and Gee 2017).

Bridging contemporary developments of energy studies and literacy together, energy literacy assumes an understanding of how energy functions in the universe, on the earth, and in our social and personal lives. According to McCaffrey (2015), an energy-literate person can identify: (a) the basic functions of energy systems (e.g., fossil fuel, nuclear, hydroelectric, solar, biomass, geothermal); (b) where forms of energy come from and how they are extracted or transported; (c) social and ecological consequences of energy forms and their uses; (d) credible information about energy; and (e) ways of understanding and envisioning the role of energy in society. Another element to add in this otherwise extensive definition, as well as in the literature addressed in this section, is how to integrate these aspects into a holistic framework involving social practices and processes of learning and doing, particularly through a range of disciplines and perspectives.

The term "energy literacy" has predominantly emerged in the literature as either specific to energy systems or studies that document social energy use in homes, businesses, or larger institutions (Brounen, Kok, and Quigley 2013; Van der Horst et al. 2016). Energy literacy can also be found in literature funded by governments aimed at conducting energy surveys and providing civic education (Moore et al. 2013; Comeau et al. 2015; Eisler 2016), literature that highlights citizens who lack basic energy knowledge (Mascone 2013), literature focused on K-12 education (DeWaters and Powers 2011; Chen, Liu, and Chen 2015; Aguirre-Bielschowsky et al. 2017; Akitsu et al. 2017; Lee, Nguyen, and Sung 2022), and literature expressing concerns about energy in the present or futures (Brown and Spiegel 2019; Michel 2020).

Energy literacy may also overlap with energy education, even though they somewhat differ. Energy education often involves science curricula, enhancing general scientific, technical, or environmental literacy (DeWaters and Powers 2011). In the field of engineering, energy education is often specific to the engineering discipline (Nelson et al. 2020). Hoople et al. (2020) and DeWaters, Powers, and Bilow (2021) recognized the need to train engineers through innovative approaches to energy education to tackle technical and social aspects of a complex problem. In the field of physics, representing and conceptualizing energy through metaphors, indicators, or substance ontology has been well documented (e.g., Keirstead and Van Dam 2010; Harrer 2017). Scherr, Close, and McKagan (2012) posited the idea to use energy representation to inform "what kind of thing … energy is" (343). They reviewed how ontology is applied in science, technology, engineering, and mathematics (STEM) fields to provide a process to understand energy conservation, as well as transfers and transformations of energy. Reflecting on the past two decades of energy education, Dias et al. (2021) noted how personal values, attitudes, and behaviours must also be considered to effectively deal with education about energy.

Energy literacy continues to exceed limited approaches to knowledge production within energy education (Chen, Liu, and Chen 2015; Akitsu et al. 2017), even as it remains underdeveloped outside of specific disciplines and educational domains. Building on research by Lawrenz (1988), DeWaters and Powers (2013) acknowledged the need to broaden energy literacy and its roots in educational contexts, leading to citizenship and how actions might be measured and implemented. Being energy literate has been measured in literature using questionnaires and applied in other global contexts (e.g., DeWaters and Powers 2013; Das and Richman 2022). An emerging theory of critical energy literacy was developed by Lowan-Trudeau and Fowler (2022) through the critical lens of decolonizing STEM education. The authors aim to denote an intersectional understanding of the social, environmental, political, and economic impacts of energy, and support more equitable energy transit, construction, and environmental planning.

Despite the extreme significance of energy as a social practice and environmental reality, there continue to be limited scholarly examples about how to integrate it into larger conversations connected to environmental and sustainability education (Jorgenson, Stephens, and White 2019) or as a part of civic discourse (Eisler 2016). Some studies show how energy literacy might directly link with environmental education as a specific area of consideration (Lowan-Trudeau and Fowler 2022; Gladwin, Karsgaard, and Shultz 2022). Jorgenson, Stephens, and White (2019)

reviewed environmental education, specifically in the context of climate change and energy education, and highlighted the need for approaches that address collective action, multi-actor networks, and sociotechnical dimensions of energy transition. McCaffrey (2015) noted how environmental education prepares students to make informed energy decisions, underscoring that the connection between human activities and the changing climate must shape energy curriculum and pedagogy. McCaffrey maintains that energy and climate literacy efforts should be combined and ideally infused throughout all stages of education and subject areas, including STEM, commerce, civics, social sciences, and humanities.

As a sociocultural response to energy literacy, and one that highlights specifically what energy is about, knowledge production about energy can be considered through qualitative fields of process and practice, such as the humanities, arts, communication, or social sciences. The theoretical and practical applications of an emerging area called the energy humanities, for instance, help draw on the power of narrative and imagination to enhance energy literacy as a social and cultural necessity (Szeman and Boyer 2017). Perspectives in energy humanities might focus on theoretical and historical approaches within individual creative texts (Wenzel 2017), collective political structures (Daggett 2019), or global ethnographies (Watts 2019) to address ways of understanding and then changing attitudes and behaviours. In this sense, energy fundamentally links to culture (Szeman and Diamanti 2019), and the affective approaches to it, which involve emotional and personal responses to various experiences and encounters with energy.

One of the ways to change our energy futures is to engage citizens who are becoming energy literate (Campos and Marín-González 2020). According to DeWaters and Powers (2011), energy literacy encompasses "citizenship understanding" of energy (1700), describing energy-literate citizens as possessing knowledge of: basic energy science and technology; the environmental and social impacts of energy production and consumption (i.e., prosumption); the need for energy conservation and transition from fossil-based energy resources; the interconnectivity and impact of one's personal energy decisions on the global community; and the need for sustainable lifestyles related to energy resource and use. Energy literacy is ultimately about creating generative conditions for decision making (Yeh, Huang, and Yu 2017), where cognitive, affective, and behavioural educational approaches work in tandem (DeWaters and Powers 2011), supporting the need for greater sociocultural engagement leading to change with and through energy.

While at one time energy literacy was demarcated through various types of studies as a necessity for building an educational approach or way of understanding energy use and behaviour, an expansive conceptual framework would assist in supporting and translating it into broader approaches to individual and collective forms of public and formal education about or for energy. Expanding energy literacy relies upon knowledge production not as a cognitive end to itself, but as a way of knowing and understanding the world that can then be applied to various educational and social processes and practices.

Methodology

A conceptual framework is a network of interlinked concepts leading to a comprehensive understanding of complex phenomena (Leshem and Trafford 2007). Such frameworks rely on synthesis and interpretation to offer possible theories and/or approaches, and they are often validated against examples and/or studies (Jabareen 2009). Because any research on energy requires a range of approaches and applications, we expand upon multiple bodies of knowledge (multidisciplinary literature) to conduct a qualitative analysis of key concepts around energy literacy.

The methodology outlined here draws on Jabareen (2009). The review of literature was conducted on the Web of Science using primarily the search term "energy literacy", but with added attention to links to the terms "energy education", "environmental energy education", and "sustainability energy education". The aim was to understand how "energy literacy" appears explicitly and in what ways it has been applied across various fields, and in particular

environmental and sustainability education (see Context and Review), which informed the need to theorize a conceptual framework of an integrated energy literacy based upon "a multidisciplinary phenomenon" through a synthesis of literature (Jabareen 2009, 55). While certain topics and concepts around energy emerged as a result, the goal of this research was not to conduct an exhaustive literature review. The preliminary analysis of the literature searched led us to organize thematic and repeated topics related to energy literacy, as shown in the first three columns in Table 1. We analyzed how these topics were related to specific fields and influences, and how they connected with our conceptual framework.

Noting that these areas of knowledge are often isolated within disciplinary constraints, the framework was developed to synthesize connections to energy literacy as a system and social practice of learning across formal and informal educational contexts (i.e., schools, universities, publics, etc.). Based on our findings, a question then arose of how to theorize and interpret energy as an integrated framework that considers holistic ways of *knowing* (epistemology), *being* or existing (ontology), and *doing* or applying (application) in our everyday lives. In other words, how does this framework contribute to deep forms of learning about and application of the complexity of energy? We concluded that what we know, what exists, and how to apply what we know in a realm of existence all collapse into a theory and practice of energy literacy (see Figure 1).

These emerging insights were applied to build our conceptual framework on how to effectively experience energy that might be applied to other research, teaching, and civic contexts within environmental and sustainability education. By adding the fourth column to Table 1, we illustrate the added dimension of the framework which is further elaborated in the Conceptual Framework section. Note that both Table 1 and Figure 1 are used to illustrate the process of building the framework and do not necessarily represent comprehensive topics related to energy literacy.

Conceptual framework

One of the benefits of using conceptual frameworks is how they allow for theoretical ideas and concepts to unpack complex systems and see them more holistically. Because energy is a

Table 1. Concepts and influences of a conceptual framework of energy literacy.

Energy Topics	Concepts or Areas of Knowledge	Influences	Epistemology (knowing), Ontology (being), Application (doing)
Energy knowledge and translation	Thermodynamics, Energy education	Energy consumption, Utility	*What energy is* *What energy does*
Energy cultures	Petroculture	Meaning-making, Empathy	*What energy is about*
Energy transition	Renewable energy	Climate emergency, Social and ecological change	*What energy is* *What energy is about* *What energy does*
Energy efficiency	Thermodynamics, Technology	Conservation	*What energy is* *What energy does*
Energy systems	Social dynamics, Environment	Meaning, Communication, Citizenship	*What energy is about*
Energy source, use, security	Infrastructure	Policy, Equity, Consumption	*What energy does*
Energy source	Sustainability, Environmental education	Social, Ecological	*What energy is* *What energy does*
Energy supply	Policy, Politics	Accessibility	*What energy does*
Energy accessibility	Equity, Justice, Sovereignty	Behaviour, Attitudes	*What energy is about* *What energy does*
Energy humanities and arts	Energy interpretation and presentation	Values, Appreciation, Affective	*What energy is about*
Energy economics	Economy	Priorities	*What energy is*
Energy futures	Futuring, Planning, Anticipation	Imagination, Visioning, Storytelling	*What energy is about* *What energy does*

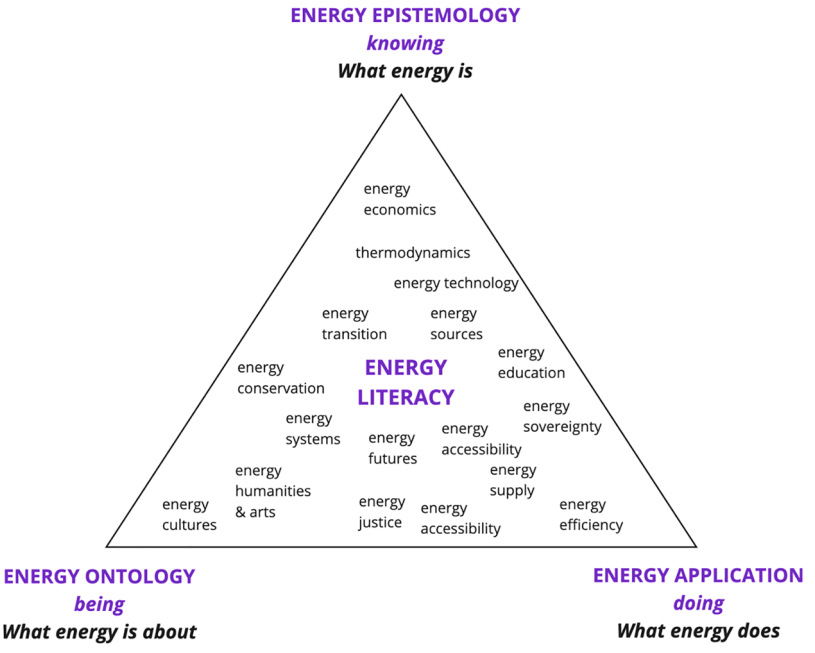

Figure 1. Emergence of energy literacy topics.

complex system, we bring together dimensions of energy-related epistemologies, ontologies, and applications to capture the emergence of these complementary and overlapping approaches. Energy has largely been taught in the area of energy education (DeWaters and Powers 2011), focusing on the technical properties and applications derived from the physics of energy as work or force that powers civilization. Another function of energy literacy involves how energy creates meaning in the social world – or how knowledge about energy is socially constructed within human practices and contexts – as much as energy as a source of fuel can be measurable and quantified through technical applications.

Drawing on definitions of epistemology as a theory of knowledge or ways of knowing (i.e., how we learn and "know what we know") (Crotty 2003, 3), energy literacy functions as a way of explaining and understanding energy both materially and theoretically, rooted in sociocultural and technical worlds. Szeman (2013) used the term energy epistemologies to show how fossil fuels (and energy more generally) have historically been viewed as separate from sociocultural systems, as opposed to how fossil fuels have actually emerged out of society through historical trends and needs. Lord (2014) similarly claimed that energy produces and sustains art and culture. The invisible sources of energy can be found in the values and perceptions that emerge in cultural representations, such as how coal and oil both historically brought specific sets of values of production and consumption to industrialized countries.

Knowing *what energy is* – energy epistemology – offers deeper epistemic questions about how we know or learn about energy in our lives and societies beyond its material and technical capabilities. It has been established thus far that we need to know what energy is because it is worth knowing and influences our lives in every possible way. But the question remains, why is it worth knowing and what do we know about energy? To answer this question, we might connect energy epistemologies to the *why* – ontologies, or how we know *about* it (also known as being in the world and adopting a worldview).

Ontologies underscore ways of being through what exists or the "structure of reality" (i.e., the worlds we can investigate and understand and those we cannot) (Crotty 2003, 10). Exploring what *energy is about* – energy ontology – provides ways of experiencing our existence through

a lens of energy, whether that be through sociocultural or technical systems and often interconnected in a complex web or relations that define the nature of our reality. Whereas epistemology asks how can we *know* if real things exist (Morton 2013), ontology reframes the inquiry to help us understand what *is* real (or not) and "what is there that can be known" (Guba and Lincoln 1989, 83). Put more simply, ontology provides access to understanding the nature of existence, illuminating what existence is all about. Epistemology assists in uncovering how we may understand and validate forms of knowledge, and ontology explores what we know as real and what existence is all about – or, put in the energy literacy framework: *what energy is* (energy epistemology) and *what energy is about* (energy ontology).

When trying to understand fossil fuel energy, for example, we might consider how it is both material (i.e., as an energy source drawn from decomposed and carbon-rich remains of plants and animals deep within the earth and forged over millions of years) and sociocultural (i.e., how we value and conceptualize fossil fuel energy in our daily existence through beliefs, behaviours, and attitudes). Linking the *what energy is* to *what energy is about* fuses two integrated theories that both include and extend beyond the function of material energy and applications of *what energy does* in our lives.

Rather than it only being a tool or resource, energy functions in our daily lives in ways that change how we think, act, and make meaning. On a conceptual level, energy literacy encourages how we exist as energy subjects in an energy paradigm. This framework also addresses energy on a practical level, where energy literacy allows exploration and applications for how we respond to energy and engage with it in material ways. For example, energy conservation from a quantitative viewpoint may not make a significant collective impact because switching to energy efficient lighting or heating in homes will not be enough to overcome the limited energy supply. If this knowledge were merged with how we exist and think in this world, it can invite actions such as citizen engagement through public discourse and informal conversations, affecting values and voting to create change. As a result, the framework further clarifies the application portion of *what energy does*.

The conceptual framework of *what energy is* (epistemological; knowing), *what energy is about* (ontological; being), *what energy does* (applied; doing), which integrates the theory and practice, operationalizes the knowledge-existence-application nexus and provides an integrated energy literacy (see Figure 1). An energy-literate person or group might identify with energy in various ways, such as through personal or collective beliefs, while also seeing this connection to aspects of energy, such as energy policy on various levels (e.g., municipal, national, and global) and personal use through various fuel needs. Beliefs, policy, and utility are interdependent because policy emerges from a consideration of individual beliefs and actions. Policy may be more influenced by practical aspects of the energy economy, while personal beliefs may emerge from specific energy ontologies involving how people know about and view energy.

Affirming the conceptual framework

In this section, we offer three examples that validate aspects of the conceptual framework, illustrating how holistic approaches to energy literacy can lead to further understanding, interpretation, translation, and/or action on energy-related topics.

Example 1: Campus as a living lab

Highlighting a technical innovation in practice, we consider the process of a living lab that provides "a network that integrates both user centered research and open innovation" (Leminen, Westerlund, and Nyström 2012, 6). As Schuurman, De Marez, and Ballon (2015) reviewed various conceptualizations and applications of living labs, they ultimately conceived a living lab as a way to create space for sociocultural and technical innovation. The living lab example captures

some of the merits of energy literacy as an integrated framework and helps to identify how conceptual modes can apply to practical outcomes.

Universities are increasingly recognized as being in unique positions where they can demonstrate and support transformations in the realm of sustainability (Cuesta-Claros et al. 2021). The province of British Columbia in Canada) was one of the first jurisdictions to implement a carbon tax (British Columbia's Carbon Tax 2022). In strategizing to reduce greenhouse gas emissions, the University of British Columbia (UBC), located on the traditional, ancestral, and unceded lands of the Musqueam peoples, decided to install a biomass gasifier that reduces the amount of natural gas used for the campus district heating system (Bioenergy Research Demonstration Facility 2022). This was done on campus as a living lab, allowing open innovation with benefits to stakeholders who were various technology providers, researchers, and users on campus. The switch from natural gas to biomass for heating was motivated by the carbon tax and drive for sustainable solutions to decarbonize energy systems (Clean Energy Fund 2015). The multidisciplinary research team including faculty, staff, student researchers, and volunteers dealt with not only the technical aspects (e.g., efficiency of certain types of biomass in the gasifier, impurities in the produced gas, etc.). They also explored the social aspects (e.g., having two large trucks entering the campus to deliver biomass challenged public perception of biomass gasification and opened up how to present and communicate about it).

A primary motivator of this project was exploring how being the leader in this field (i.e., adopting an innovative technology on campus to reduce greenhouse gas emissions) affected the identity of the academic institution. As documented by Pajouhesh (2016), the campus has provided an opportunity to implement and test many innovative technologies at a local, neighbourhood scale, contributing to the notion of campus as a societal test bed, and fostering a culture of innovation and risk tolerance. Campus as a living lab projects can advance the technology readiness levels and cultivate the spirit of experimentation and demonstration (Save 2014), particularly through educating *what energy is* and *what energy is about*, not only its more apparent aim of *what energy does*.

Anecdotally, we hear students talking about the smell of biomass when walking by the facility on campus, connecting to their knowledge of how biomass is heating the campus through the district heating system. The affective elements of the observed sensorial experience of the students, coupled with the applied system of the living lab, links to the technical relationship with energy. By integrating the sociotechnical aspects of energy through the PESTEL framework (political, economic, social, technical, environmental, and legal), and connecting to students' lived experiences, Hoople et al. (2020) documented the possible shift in students' perception of "engineering as a sociotechnical endeavor" (3). The biomass gasifier has created an opportunity to connect affective lived experiences of *being* with technical and social knowledge and awareness of *knowing* and *doing*.

The neighbourhood communities residing adjacent to campus have also been engaged with the development of the biomass gasifier unit through air quality monitoring and other social aspects of the operation. This has led to deeper civic engagement through the discussion of how they may consider a similar unit to reduce greenhouse gas emissions from heating (UBC Campus & Community Planning Report 2014). Understanding the technology, seeing it operate, and connecting to how they feel when experiencing it, allowed residents to engage in meaningful discussions around their future decisions.

This is an example of a technical innovation allowing participants to gain knowledge, and experience the interconnected translation of energy in their everyday on- and off-campus lives. While understanding the energy efficiency and sources alone may have fulfilled the need to reduce the greenhouse gas emissions on campus, connecting to other dimensions nested in the energy literacy framework, such as affective, behavioural, and social elements (see Table 1), allows for a richer interpretation to emerge. It has shown that advancing energy literacy can influence individual and collective behavioural changes that can support energy transition futures.

Example 2: Energy storytelling

People often use elements of storytelling through writing, digital media, oral culture, or in educational settings to conceptualize disruptions in systems and act, such as imagining and creating scenarios of low carbon energy futures. Research has shown that using the methodology of storytelling can activate educational pathways in learners that fundamentally alter how we see and know the world around us in order to put such experiential knowledge into use (Archibald 2008; Keller 2012). Storytelling has the potential to animate our relationship to energy through empathy and affective experiences.

Everyone has energy stories – whether the stories are about working in the energy industry, protesting pipelines, experiencing a winter power outage, or remembering a class we took in school. Listening to and experiencing the energy stories of others, whether in real or imagined contexts, is not only part of the affective and empathetic processes, but also educational in how they showcase examples of *what energy is* and *what energy does*. Building energy stories as a form of arts-based literacy allows opportunities for experimentation and reflection.

We facilitate energy story workshops for the public, and for university and high school educators, many of whom are in STEM fields. These workshops allow educators and citizens the space to reflect on their own energy stories and those of others. The workshop begins with first outlining the conceptual framework of energy epistemologies, ontologies, and applications, starting with the technical aspect of *what energy is* (i.e., energy systems, types, etc.), and quickly turning *to what energy is about*, exploring how energy has been part of our personal and collective stories and affects our perceptions, behaviours, and attitudes. It then turns to application of *what energy does*, concluding with how to operationalize energy stories in our lives.

In one of the workshops for high school STEM teachers, participants left with a 3-minute crafted oral energy story that exemplified how they first began to consider energy from sociocultural and affective perspectives – particularly how they are energy beings in their lives. Not only did teachers obtain skills to imagine, reflect on, and tell their own stories; they also had space to listen to other stories, which often serves as the most powerful form of literacy as social practice. We took an informal survey at the start of the workshop and none of the 38 teachers had ever considered incorporating energy storytelling into their STEM courses. By the end of the workshop, all of them were either extremely or somewhat willing to include energy storytelling. They witnessed through personal experience the benefits of storytelling as an educational practice of energy literacy. Continuing this exploration of an integrated energy literacy, it is increasingly important to acknowledge how the history of energy is a story and all our personal and communal stories are part of that larger narrative. This example affirms the conceptual framework from an arts-based perspective, highlighting the methodology of storytelling as a practice of *knowing*, *being*, and *doing*.

Example 3: Creating energy literate citizens

As governments globally target 2050 emission goals, they are rolling out various funding and literacy programs to enhance education for citizens. They recognize the need for technical education and its role in global society as a vital aspect of supporting energy transition and change (e.g., Lennon, Dunphy, and Sanvicente 2019). Social acceptance of technical innovation is often a barrier for energy transition. For example, moving from a centralized to a more decentralized energy system via a microgrid system – where people can generate and store small-scale energy through various sources, such as solar, wind, or biomass – requires participation in and contribution of participants in energy production (Wolsink 2012). Knowledge of and experience with using a microgrid system allows for public engagement with energy in community and local scales, creating greater energy sovereignty because people are not as reliant on larger centralized energy systems (e.g., city grid or larger power stations). Applying

the conceptual framework, we see that the holistic understanding of energy literacy in this example of microgrid systems, incorporating the aspects of energy epistemologies, ontologies, and applications, can expand our positions from being merely a passive consumer to becoming an engaged citizen with and co-producer of energy.

Another example of engaging citizens who can make informed decisions about energy is through the citizen science approach. Wahlund and Palm (2022) review the ways citizens may participate in energy transitions and highlight the individual and collective as agents of change. Connecting citizens through their concerns for energy bills, the "walking with energy" project has engaged citizens in energy conversations around decarbonization and heating, while walking around their urban energy system (Ambrose et al. 2021). This form of civic facilitation enables citizens to share and reflect on their experiences around heating and energy, leading to a more meaningful sociocultural and technical awareness of energy decisions. Michel (2020) similarly documented on knowledge and value transfer through the citizen science approach as a transformative process. Once again, intentionally cultivating the holistic view of energy literacy can lead to future change by *knowing*, *being*, and *doing* in the complex energy system.

An ongoing challenge of developing energy literacy, whether it is teaching a class or addressing the public, is communicating in a way that generates a change of viewpoint, activity, or practice. Misconceptions about fossil fuel and renewable energy sources, for instance, can alter the development of energy-literate citizens (Yeh, Huang, and Yu 2017). Energy literacy ultimately creates empowered citizens, improving communication, behaviour, and decision making, which can foster civic and social change. Citizens can see these connections and improve discourses around energy and decisions. How energy literacy promotes these types of decisions is integral to how people frame and think about things – how we might access decisions through understanding that the nature of our existence is mediated through energy.

Discussion

As discussed thus far, energy literacy encompasses more than defining energy or the systems that enable energy production or transport. It also involves unpacking the perceptions that influence certain values and behaviours about energy on various scales individually, collectively, and globally. By validating the conceptual framework against the three previous examples, we demonstrate how the holistic experiences of energy as social practices and processes of literacy are possible and could apply in different contexts. Because energy relies on a systems approach, it is necessary for the examples to showcase how the energy literacy framework applies and could be reproducible in other contexts. For example, while the previously cited story about a comment by a student walking by a biomass gasifier plant smelling biomass may have been dismissed, the experience can be reinforced and invite further curiosity and education about the holistic system of energy. In cultivating energy literacy among us all, the framework can provide ways to engage in and bring together various elements related to the energy system at hand.

We acknowledge the challenge of bridging theory and practice together, particularly with something as amorphous and abstract as energy, as epistemological and ontological systems of thought, experience, and application. And yet, it is our hope that the conceptual framework posed here can guide and support our individual and collective efforts through the critical energy transition, and help lead us to low carbon futures by providing examples for people to understand how much energy influences our perceptions, values, and practices. Increasing individual and collective energy knowledge is vital (Martins, Madaleno, and Dias 2020) – both in formal education and public literacy – because such ways of *knowing*, *being*, and *doing* embedded in an energy literacy framework can assist in imagining and promoting global energy transitions and futures.

One of the key benefits of building the conceptual framework on energy literacy is how it can lead to an imaginative *futuring* perspective. Expanding perspectives of literacy is as much about building pluralistic education models and civic engagement as it is about developing more sustainable futures. Futures studies use methodological imagining, applying social and technological advances and forecasting – to imagine, anticipate, and plan for possible futures – whereas "futures literacies" consider future(s) as a platform for inquiry across disciplines, ontologies, and epistemologies, and enables an education for transition and change (Gladwin et al. 2022). Through a process of futuring we can anticipate, forecast, and construct equitable social processes to both support and question technological advances (Urry 2016; Horst and Gladwin 2022).

Take, for example, the hydrogen economy (i.e., hydrogen as an energy carrier) that could be envisioned as the future of energy initially through technology development. For the hydrogen economy to become reality, it must also gain social acceptance, political support to build infrastructure, and a commitment for energy transition from industry, all of which must be supported through an integrated way of knowing and communicating about energy. Coupled with energy arts and humanities – promoting ways of understanding and knowing about energy through qualitative and experiential methods, such as storytelling – the hydrogen economy is a good example because the future potential is so strongly embedded within the social story. The critical energy transition we face can be supported through imagining the future through sociocultural narratives as much as through technological advancement, leading to concrete actions at all levels of engagement.

Two potential questions arise when considering futuring as an aspect of energy literacy: what does a sustainable energy transition look like, and who is invited to imagine our energy futures? Answering the question of who gets to decide our futures should also be considered through integrative energy literacy frameworks. While the de facto response to these inquiry questions might initially fall on decision makers, such as leaders, policy makers, or politicians, another response is to position energy futuring through public citizen literacy. The ways people learn about energy (knowing), consider how it affects their lives (being), and what to do about it (doing) greatly influences the imaginative and actionable aspects of energy transition.

The conceptual framework of energy literacy offers a holistic way of experiencing and understanding energy through education (K-12, higher education, continuing education, public literacy, etc.), citizen engagement, policy development, and government leadership. As elaborated in the Affirming the Conceptual Framework section, this proposed process allows deeper connections to be fostered around the complex energy systems, and further invites questions that may shape our futures. For example, this framework can inform and impact how environmental and sustainability education may grapple with energy as a more holistic interconnected topic to contend within the climate emergency.

There are, however, some limitations depending upon the type of research being conducted. The utility of the conceptual framework has yet to be further validated because it is, by the very nature of exploring and theorizing concepts, rooted in qualitative research and analysis. The framework is also open to interpretation and therefore does not provide a prescriptive method on how to build or apply energy literacy in specific contexts. For instance, reproducibility remains dependent upon context and circumstance of various users. Regardless of these limitations, the merits of viewing energy systems through the lens of holistic energy literacy offer expansive possibilities to integrate the concepts of energy into other systems.

Conclusion

This article considers an integrated conceptual framework for energy literacy, building on extant complementary and multiple approaches to learning about and living with energy in our lives. Conceptualizing a holistic approach to energy literacy expands how we understand

and think about energy, while also learning about energy application. Energy literacy functions as an aspect of education beyond any one discipline or knowledge structure and into public and civic forms of literacy. Merging *what energy is* (epistemology; knowing), *what energy is about* (ontology; being), and *what energy does* (application; doing) in the context of sociocultural and technical structures underscores the nature of our existence as part of a complex system. It further supports environmental and sustainability education by providing ways of framing and addressing the climate crisis. Ultimately, energy literacy provides a method of translating knowledges and experiences to realize energy transitions and create sustainable energy futures.

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No potential conflict of interest was reported by the authors.

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