FROM AWARENESS TO ACTION: ENERGY LITERACY AND HOUSEHOLD ENERGY USE

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1. Introduction

Energy is a vital resource that powers the modern world and enables economic growth. With the increasing demand for energy, it becomes clear that the current approach to energy production, distribution, and consumption must change. Energy literacy has emerged as one key concept in the effort to transition to more sustainable energy systems (Martins et al.,2020). In fact, it has the potential to change energy consumption in households; either by reducing it or by adapting it to the needs of the power system. In this literature review, we examine the current state-of-the-art literature on energy literacy's impact on energy consumption in households.

Energy literacy is a complex multidimensional concept that still lacks a common assessment scale. In fact, each author evaluates it according to the data they collect and the domains they focus on. Nevertheless, the results of several studies conducted in Europe, North America, and Southeast Asia, have shown that energy literacy is considerably low everywhere, and while knowledge of energy concepts is variable, it is evident that people do not demonstrate sufficient energy saving, efficient, or flexible behaviours (Martins et al., 2020).

By increasing consumers' energy literacy, they can become more active participants in the energy market. When customers are well informed about energy costs, demand response programs, time-of-use tariffs, and renewable energy options, they may make decisions that are both cost-effective and consistent with their preferences and values. From an economic standpoint, increasing customer energy literacy goes beyond simply helping them understand their energy bills. By providing additional information about energy consumption and its economic implications, consumers can make more informed decisions, actively engage in energy saving behaviours, contribute to overall energy efficiency, and become flexible customers. These changes finally result in improved demand side management, greater demand side flexibility, lower energy bills, and reduced greenhouse gas emissions.

Despite the growing body of literature on energy literacy, several gaps remain in state-of-the-art publications. Other reviews on the topic focus either on distinguishing different types of energy literacy (van den Broek, 2019), or on the factors that impact energy literacy (Martins et al., 2020). These concepts are discussed in more detail in Section 3. However, the effect of energy literacy on household energy consumption is still unclear. For these reasons, we choose to focus on the different outcomes which are potentially influenced by energy literacy. We opted for the term "outcome" to include not only energy-related behaviours but also rational decision-making, providing a more comprehensive representation of how energy literacy can impact energy use. Multiple disciplines, including economics, psychology, and sociology, have driven the energy literacy literature, giving an independent examination of the outcomes. We aim to give a holistic view on the discussions and conclusions in the respective fields and to suggest avenues for future research.

Our contribution lies in categorising three distinct groups of outcomes that are potentially influenced by energy literacy. Energy Saving Behaviours, Energy Efficiency Investments, and Flexibility Provision. Additionally, we establish three levels of energy literacy (low, moderate, high) that cover the necessary skill sets or actions needed to perform the outcomes belonging to one or more of the different groups. We highlight the increasing knowledge and skills that people need in relation to energy-saving behaviour, investments in energy-efficient appliances, and flexibility provision. The first level relates to the simplest group of energy literacy, which is defined by understanding and performing energy-saving behaviours. The second level includes people with a higher degree of understanding of energy literacy who can successfully invest in energy-efficient improvements. The third level represents the most advanced level of energy literacy, where individuals possess comprehensive energy literacy to make informed energy choices and eventually provide flexibility.

In Section 2, we describe in detail the methodology we followed to perform the literature review and the approach to identify the groups (Energy Saving Behaviours, Energy Efficiency Investments, and Flexibility Provision). In the third section, we provide general information about energy literacy, its definitions, determinants, and

measurements. In the fourth, fifth, and sixth sections, we elaborate on the three groups and their corresponding levels, and in the concluding section we wrap up the results and suggest further research avenues on energy literacy.

2. Methodology

We conducted a literature review of peer-reviewed scientific articles from various disciplines, including economics, psychology, education, and engineering. Given the multidisciplinary nature of the topic, and our goal of understanding and critically analysing the various studies on energy literacy and its outcomes, we considered an integrative literature review to be the most appropriate way to perform our study. The purpose of an integrative literature review is to provide an overview of the knowledge base on a topic, to critique it, and potentially to create new theoretical knowledge in regard (Snyder, 2019). We based our approach on the methodology proposed by Torraco (2005), using it as a set of guiding principles. In our case, the review of the literature resulted in the identification of three groups of outcomes of energy literacy and a proposed research agenda on the topic of energy literacy.

We searched the academic databases Google Scholar and Scopus, proceedings of energy related conferences (IAEE, IEEE), in addition to other search engines (Google, Semantic Scholar, Publish or Perish) and online resources (U.S. Department of Energy, IEA). We used the following search string "("energy literacy" AND ("flexibility" OR "demand response" OR "demand side management" OR "energy efficiency" OR "energy consumption" OR "electricity bill" OR "emissions" OR "households"))" to inquire the chosen databases.

After removing duplicates, the combined search resulted in 137 documents. We carried out a staged review, including the papers which respected all the following criteria:

- The paper mentions energy literacy;
- The paper relates to energy consumption and related decision-making;
- The paper analyses energy literacy in households and individuals, not in school students;
- The only object of the paper is not a pilot to increase energy literacy;
- The paper is not a project report.

The first stage of the review consisted of the analysis of titles, which resulted in the elimination of 22 documents; for the second stage, we read the abstracts, and removed further 19 documents; the final stage of the revision consisted of reading the entire papers, after this phase, we removed 49 documents. Then this literature review is then comprehensive of 47 papers.

We collected the literature in a spreadsheet and used it to identify the following characteristics of the articles: year of publication, geographic location, methodology (quantitative or qualitative), how the authors define energy literacy, if it is paired with financial literacy, if they assess the effect on energy consumption, if yes, what are the results obtained, and finally what are the outcomes associated with energy literacy.

As in van den Broek (2019), we followed an inductive approach to identify the different groups of outcomes linked to energy literacy. This means that the categories are derived from the existing body of knowledge on energy literacy rather than being determined by a pre-established framework. This method allows a better and more concrete understanding of how energy literacy has been studied in relation to energy-related outcomes in the different disciplines.

3. Defining Energy Literacy

One of the first research studies on energy literacy dates to 1983, when Gaskell and Pike assessed the relationship between energy literacy and self-reported energy conservation. They found that those who saw themselves as 'savers' were more knowledgeable, keen to save money, and less concerned about comfort, compared to 'non-savers'. They defined energy literacy as a combination of knowledge of how to save energy at home and personal beliefs regarding financial savings, health, and energy consumption. Today, that definition has been enriched and refined, and one of the most cited is that by the U.S. Department of Energy (2017) which defines energy literacy as "an understanding of the nature and role of energy in the world and daily lives accompanied by the ability to apply this understanding to answer questions and solve problems".

The subsequent discussion will revolve around two influential articles that significantly contribute to shaping the understanding of energy literacy. The first one, written by Dewaters and Powers (2013), defines energy literacy as a multidimensional construct that consists of knowledge, attitude, and behaviour. The knowledge dimension encompasses understanding about scientific concepts, energy transfer processes, and the role of energy in ecosystems. The attitude dimension examines people's perception of how much energy is produced, how it affects the environment, and how their own ideas affect their decisions. The behaviour dimension focuses on personal awareness of energy-related actions, global citizenship responsibility, and commitment to energy-saving practices. They also establish connections between these three dimensions, stressing the value of information, while also emphasising its application in real-world settings for successful behaviour modification. According to Martins et al. (2020), a paper that builds on the findings of Dewaters and Powers, understanding data on energy consumption and linking actions to energy use can be challenging for consumers. In their literature review, they highlight the importance of applying knowledge to real-life scenarios as a fundamental component of energy literacy.

The second article, by van den Broek (2019), focuses on energy literacy within the domestic context, specifically with respect to households' consumption of electricity and gas. Her literature review identifies four types of energy literacy: device energy literacy, action energy literacy, financial energy literacy, and multifaceted energy literacy. She then proceeds to connect these types with the effect they have on energy saving and conservation.

Device energy literacy refers to knowledge about the energy consumption of household appliances. Research on device energy literacy has produced mixed findings, and participants often underestimate the energy use of high-consuming devices and overestimate the energy use of low-consuming appliances.

Action energy literacy implies an understanding of energy-saving actions at home. Research indicated that people typically have low action energy literacy, lacking knowledge of certain energy-saving habits, and the relative effectiveness of various conservation measures. Action energy literacy is linked to energy conservation, and providing information on the impact of energy-saving actions can promote energy-saving behaviours. However, measuring action energy literacy is controversial, since individuals will be less severe in their judgment in situations that are not fully exploited (reference point biases).

Financial energy literacy is the ability to assess the financial impact of energy consumption, particularly focusing on the financial savings associated with energy-saving investments. It includes information on the financial effects of energy use, such as understanding energy costs and having the skills to analyse investments. The association between financial energy literacy and energy usage is not clear, even though those with strong financial energy literacy are better at spotting cost-effective appliances. While some research did not find an effect on curtailing energy saving actions, others find that financial energy literacy encourages better management of energy-saving practices.

Multifaceted energy literacy comprises a thorough grasp of energy concepts that includes knowledge of energy in general, as well as device, action, and financial literacy. This type expands beyond domestic energy knowledge to encompass energy production, supply, environmental and social impacts, and active engagement in energy conservation. Researchers have adopted this conceptualization and developed a questionnaire to measure energy literacy (Dewaters & Powers, 2013). This questionnaire incorporates cognitive aspects (knowledge, cognitive skills), affective aspects (values, attitudes, personal responsibility), and behavioural aspects (intentions, participation, and actions). While environmental education improves knowledge and attitudes toward energy, its impact on energy-saving behaviour is mixed, potentially due to a lack of focus on practical energy-saving practises. van den Broek (2019) concludes that studies consistently demonstrated low insights of multifaceted energy literacy among students, both in terms of scientific understanding and awareness of energy's impacts.

The studies analysed in our literature review followed a common research approach, using surveys and interviews as primary data collection methods. With the use of a broad hypothesis framework, these surveys serve as useful instruments to evaluate knowledge of energy consumption, actions, and financial literacy in relation to energy literacy.

Although the reviewed research papers use both quantitative and qualitative methods, each study has its own unique perspective based on the researcher's background and approach. This allows for a thorough examination of the impact of various factors on energy consumption from different perspectives. Additionally, researchers aim to capture the multidimensional nature of energy literacy and provide a more thorough understanding by

applying a variety of measurement instruments and techniques. However, this variety has revealed the need for a shared baseline in this area and drew attention to the lack of defined criteria for assessing energy literacy.

4. Outcomes and levels of energy literacy

Building on previous research, we classify the outcomes of energy literacy. The first group "energy saving outcomes", involves individuals who possess basic energy knowledge and know how to save energy at home with their behaviour. The second group relates to energy efficiency investment outcomes, encompassing individuals who have acquired the knowledge and skills to make energy-efficient behaviour changes and investment decisions. The third and final group represents flexibility provision outcomes, including individuals with the ability to understand new energy concepts and provide flexibility in their energy consumption patterns. The following table summarises the papers reviewed and provides information regarding the methodology used, location, and the group we assigned it to.

Table 1. Papers included in the literature review and groups of outcomes they encompass

No.	Reference	Country	Method	Group of Outcomes
1	(Andor et al., 2019)	Germany	Quantitative	Energy efficiency investments
2	(Asmare et al., 2022)	Lithuania	Quantitative	Energy efficiency investments
3	(Baikowski, 2018)	EU	Quantitative	Energy efficiency investments
4	(Blasch et al. 2017)	Netherlands	Quantitative	Energy saving behaviours
5	(Blasch et al., 2019)	Switzerland	Quantitative	Energy efficiency investments
6	(Blasch et al., 2021)	EU	Quantitative	Energy efficiency investments
7	(Blasch et al., 2022)	Switzerland	Quantitative	Energy efficiency investments
8	(Boogen et al., 2021)	EU	Quantitative	Energy efficiency investments
9	(Brent & Ward, 2018)	Australia	Quantitative	Energy efficiency investments
10	(Brounen et al., 2013)	Netherlands	Quantitative	Energy saving behaviours
11	(Chadwick et al., 2022)	OECD	Review	Energy efficiency investments
12	(Cornago, 2021)	Multi-country	Review	Energy saving behaviours
13	(Crawley et al. 2021)	UK	Qualitative	Flexibility provision
14	(Damigos et al., 2021)	Greece	Quantitative	Energy efficiency investments
15	(de Leon Barido et al., 2018)	Nicaragua	Quantitative	Flexibility provision
16	(Dewaters & Power, 2013)	USA	Quantitative	NA
17	(Dharshing and Hille., 2017)	Switzerland	Quantitative	Energy efficiency investments
18	(Dütschke & Paetz., 2013)	Germany	Mixed	Flexibility provision
19	(Ebrahimigharehbaghi et al., 2022)	Netherlands	Quantitative	Energy efficiency investments
20	(El Gohary et al., 2022)	Sweden	Quantitative	Flexibility provision
21	(Filippini et al., 2020)	Nepal	Quantitative	Energy efficiency investments
22	(Gaskell & Pike, 1983)	UK	Quantitative	Energy saving behaviours
23	(Gobiowska, 2020)	Poland	Quantitative	Energy saving behaviours
24	(He et al., 2022)	China, Netherlands	Quantitative	Energy efficiency investments
25	(Joshi & Sen, 2021)	India	Quantitative	NA
26	(Kalmi et al., 2021)	Finland	Quantitative	Energy efficiency investments
27	(Kantenbacher & Attari, 2021)	USA	Qualitative	Energy saving behaviours
28	(Kempton & Layne, 1994)	USA	Quantitative	Energy saving behaviours

29	(Kowalska-pyzalska & Byrka, 2019)	Poland	Quantitative	Energy saving behaviours
30	(Li et al., 2017)	Netherlands	Quantitative	Flexibility provision
31	(Mangso & Sheau-Ting, 2021)	Multi-Country	Review	Energy saving behaviours
32	(Martins et al., 2020)	Portugal	Review	NA
33	(Mills & Schleich, 2012)	EU	Quantitative	Energy saving behaviours
34	(Neves & Oliveira, 2021)	Spain	Quantitative	Energy efficiency investments
35	(Olsthoorn et al., 2023)	Germany	Quantitative	Energy efficiency investments
36	(O'Sullivan and Viggers, 2021)	New Zealand	Qualitative	Energy efficiency investments/Flexibility provision
37	(Rahman et al., 2019)	Bangladesh	Quantitative	Energy saving behaviours
38	(Reis et al., 2021)	Portugal	Quantitative	Flexibility provision
39	(Ruokamo et al., 2019)	Finland	Quantitative	Flexibility provision
40	(Satre-Meloy, 2019)	USA	Quantitative	Energy saving behaviours
41	(Sayarkhalaj & Fatemi Khesal, 2022)	Iran	Quantitative	Energy saving behaviours
42	(Schubert, 2017)	Multi-country	Review	Energy efficiency investments
43	(Schwartz et al., 2013)	Germany	Qualitative	Energy efficiency investments
44	(van den Broek & Walker, 2019)	UK	Quantitative	Energy saving behaviours
45	(van den Broek, 2019)	Multi-country	Review	Energy saving behaviours/ Energy efficiency investments
46	(Walker & Hope, 2020)	UK	Qualitative	Flexibility provision
47	(Zanocco et al., 2022).	USA	Quantitative	Energy saving behaviours

To delve deeper, in this study we use these groups as foundational components for the identification of three distinct levels of energy literacy. The first level corresponds to the initial group, focusing on energy-saving behaviour as a short-term outcome. The second level incorporates both the first and second groups, enabling individuals to not only engage in energy-saving behaviours, but also make informed investments in energy efficiency, leading to long-term outcomes. Finally, the third level encompasses all three groups, providing individuals with the ability not only to achieve energy-saving behaviours and make informed investments but also to provide flexibility to the energy system. Therefore, we define the levels of energy literacy as follows:

- The first (low) level of energy literacy implies the occurrence of the first outcome: energy-saving behaviours. This level includes individuals who are aware of the most effective energy-saving behaviours to achieve maximum energy savings. In addition, individual`s knowledge on the energy consumption of domestic devices and the ability to estimate energy usage values compared to other devices is included in this level.
- The second (moderate) level of energy literacy, along with energy saving behaviours as in the first level, includes investing in energy-saving appliances and devices as part of energy literacy. By acquiring relevant knowledge, going beyond the basic knowledge of the first level, this level emphasises the importance of investment literacy, which enables people to evaluate the long-term benefits as well as the costs of making investments in energy-efficient technologies.
- The third and highest level covers the first two levels and adds to it the requirement of understanding new energy concepts (including electricity tariffs) and actively managing home energy usage (provision of flexibility). This level includes understanding the structure and dynamics of utility tariffs, such as peak and off-peak rates, time-of-use pricing, or demand response programmes. With this knowledge, people can deliberately adjust their energy consumption and be open to new energy concepts to maximise energy efficiency and flexibility.

Figure 1 provides a visualisation of the structure we propose and shows the progression of the three levels of energy literacy.

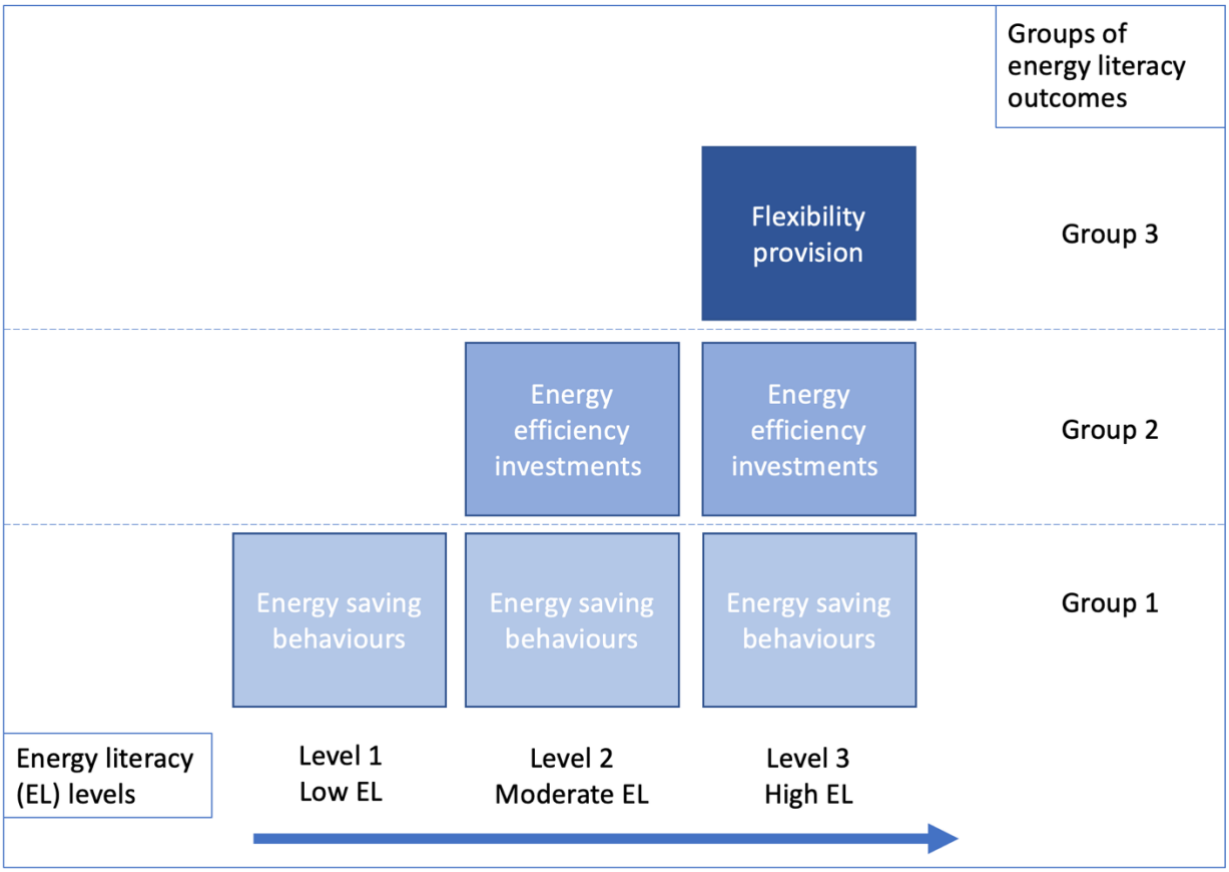

Figure 1. Energy literacy levels and the corresponding energy literacy outcome groups

Identifying and highlighting the outcomes of energy literacy and setting them into levels helps to understand the evolution and cumulative nature of energy literacy. Equipping individuals with the necessary knowledge and skills enables them to make informed choices, adopt energy-saving technologies, optimise energy usage, and opt for more flexibility. In the following three sections, we explain the three groups of outcomes identified from the literature. In addition, we discuss the necessary skills that individuals within each group need to acquire to effectively engage with these groups.

5. Energy saving behaviours group and building the first level of energy literacy

The first group identified in literature, explains the relationship between enhanced energy literacy and energy saving behaviours. Individuals who possess a basic understanding of energy sources and conservation techniques are more likely to adopt energy-saving behaviours, thereby reducing their energy consumption and environmental impact. Thus, the first level of energy literacy consists of the capability of identifying and performing energy saving behaviours, and it can be associated to the device and action energy literacy types identified by van den Broek (2019). Energy saving behaviours are deliberate attempts to reduce energy use, including adopting practices and making behavioural changes that result in decreased energy use while still meeting desired needs and maintaining sufficient comfort levels (Cornago, 2021). It also involves recognizing the role of individual actions and habits in energy consumption patterns.

This section examines a diverse range of studies that shed light on the nature of energy literacy and its implications for sustainable energy practices of the first group. We identify different outcomes that emphasise the importance of energy saving behaviours that can result from higher energy literacy awareness. To start with, a study in California on the awareness of daily consumption by citizens revealed that 50% of the respondents correctly identified their load curves prior to COVID-19. However, only 31% of respondents knew how to identify their load curve during the lockdown period, when they spent more time than usual at home. Thus, people find it hard to estimate the different energy consumption that results from a change in lifestyle (Zanocco et al., 2022). This

low-energy knowledge represents an obstacle towards achieving the needed energy saving behaviours. Sayarkhalaj & Fatemi Khesal (2022), investigated the relationship between knowledge of energy use, attitudes, and energy-related behaviour among 384 Mashhad residents in Iran. When assessing energy saving behaviours, this study considers individuals' behaviour and actions regarding energy saving and usage. Results reveal that most respondents have a moderate degree of knowledge about energy use, with 49.2% of the respondents having a very moderate degree of knowledge, 18.5% low, and 8.9% with an extremely low degree. Further results suggested that increased knowledge of energy consumption is correlated with savings-oriented energy consumption behaviours. Additionally, Kowalska-pyzalska and Byrka (2019) claim that households in Poland who are aware of how much energy they consume are more likely to reduce it. Furthermore, the study by Gobiowska (2020) shows that energy literacy in households helps influence energy-saving behaviours. To sum up, Mangso & Sheau-Ting (2021) reviewed 24 different studies from a variety of different countries that indicate a positive and significant relation between energy knowledge and energy saving behaviours.

Residential energy consumption plays a crucial role in energy conservation, presenting a significant opportunity to promote sustainability. To effectively develop and enhance the energy saving behaviours of residential households, it is essential to have a comprehensive understanding of the key factors driving energy use in households. An abundant number of studies on attitudes and values have suggested that socio-economic factors like higher education acquirements, higher income, and larger households have a significant effect on energy saving behaviours. Education has a wide range of effects on household energy behaviour, knowledge, and attitudes. The adoption of energy conservation practices is strongly positively correlated with higher levels of education, whereas knowledge of energy use and savings options is less strongly correlated, suggesting that education may be more effective in influencing behavioural changes than raising awareness of energy-saving opportunities (Mills and Schleich, 2012). Energy experts are also better than average people at estimating the energy use in their homes, confirming that knowledge on energy topics is needed to analyse and act on own consumption (Kantenbacher & Attari, 2021). Brounen et al. (2013) also studied the choice of thermal comfort (i.e., thermostat settings) during the night and how the tendency of people to lower their energy usage settings at night can be used to quantify energy behaviour. The findings demonstrated that older residents choose higher comfort settings when their salaries are higher, and that age has a negative relationship with lowering the thermostat at night. In the evening, the more cost-conscious respondents choose a lower comfort temperature. Furthermore, Satre-Meloy (2019) reveals that household electricity consumption is influenced by a combination of sociodemographic factors and physical characteristics of the house. The size of the house, the number of occupants, the presence of an electric vehicle (EV), and the use of air conditioning (AC) are significant predictors of an increase in electricity consumption. Consequently, a statistically significant correlation was observed between habitual energy saving behaviours and decreased usage was observed (Satre-Meloy, 2019).

Furthermore, according to Kempton and Layne (1994), consumers' ability to conserve energy is hindered by limited access to their consumption data. As a matter of fact, some have asserted that more information on energy use can serve as a helpful "nudge" to promote energy saving behaviours among private consumers. An important area of research examines the relationship between energy literacy and nudges to promote energy saving behaviours. Energy-literate individuals are more likely to understand energy concepts, leading to a positive response to nudges and informed decisions regarding energy use. Rahman et al. (2019) explained the contrast between direct and indirect feedback: direct feedback occurs at the time of usage, such as with energy monitors or smart meters, whereas indirect feedback occurs sometime after consumption has occurred, such as on households' energy bills. Rahman et al. (2019) also indicated that direct feedback outweighs indirect feedback in terms of resulting energy savings behaviours. It has also led to an increase in interest in buying energy-saving products or renewable energy technologies, as well as improved energy literacy.

On the contrary, several studies we encountered did not identify a direct correlation between energy literacy and energy saving behaviours. These findings suggest that having a higher knowledge of energy literacy does not necessarily lead to a significant increase in energy saving behaviours among individuals. Among these studies, Satre-Meloy (2019) mentions previous studies on individuals that advocate for a better environment, including lower energy consumption, but do not act according to their beliefs. The results do not indicate a conclusive link between their beliefs and actual power use. Similarly, van den Broek and Walker (2019) focused on young people who had just started using energy as independent consumers and the factors that influence their energy use were qualitatively evaluated. Although they expressed a favourable opinion about energy conservation, participants did not frequently express a strong urge to conserve energy based on environmental concerns. Also, Brounen et al.

(2013) conducted a study on 1721 Dutch households showing no connection between energy awareness and conservation behaviour.

In summary, the relationship between energy literacy and energy-saving behaviours has several dimensions. Many studies have shown a positive correlation between the adoption of energy-saving behaviours and knowledge of energy consumption. However, other research indicates that having a higher degree of energy literacy does not always translate into significant changes in individual energy saving behaviours. Factors such as socioeconomic aspects, physical characteristics of households, and the availability of direct feedback on energy consumption play a role in shaping energy behaviours. There are two main ways to reduce energy use while maintaining the same degree of comfort. It can be achieved by improving input utilisation efficiency, such as by using appliances more effectively, and by implementing energy-saving technologies, such as by buying energy-efficient appliances or making energy-saving renovations, which is discussed in the next section. (Blasch et al. 2017).

6. Energy efficiency investment group and building the second level of energy literacy

Moving beyond behavioural changes, the second group investigates how energy literacy empowers people to make informed decisions regarding investments in efficiency improvements. To be able to invest properly, one must have knowledge about how to achieve energy-efficient savings. Therefore, the energy efficiency investment group together with the energy saving group constitutes the second or moderate level of energy literacy. In other words, skills from the first level (knowledge on the energy consumption of various appliances and actions) combined with a financial aspect constitute the second level of energy literacy.

While changing individual behaviour helps saving energy, increasing the overall energy efficiency of the household by investing in better equipment has a much higher impact on reducing energy consumption (Satre-Meloy, 2019). In this paper, the term energy efficiency improvement is defined as the investment in new and more efficient appliances or the investment in overall household efficiency, such as isolating the outer shell of the building. Despite being economically optimal, meaning that it would help save money and energy in the long run, many private households do not choose to increase the efficiency of their houses (Chandler and Brown, 2009; EPRI, 2009; National Academy of Sciences, 2009; Granade et al., 2009; McKinsey & Company, 2009; Creyts et al., 2007). Insufficient information and lack of knowledge are among the main barriers to rational decision making in general, i.e., people are not aware of the long-term economic outcomes of their purchases and do not spend time gathering this information (Schubert, 2017).

Lately, researchers have been studying the combination of investment and energy literacy, called energy-related financial literacy. It is defined as “the combination of energy cost-specific knowledge, financial literacy and cognitive abilities that are needed in order to take decisions with respect to the investment for the production of energy services and their consumption” by Blasch et al. (2021). People with high levels of energy related financial literacy have the skills needed to spot and purchase energy-efficient appliances, maximising energy savings while lowering their energy bills in the long term. They can choose appliances that support their energy goals by being aware of the energy consumption characteristics and efficiency ratings of various devices.

Blasch et al. (2021) found that higher levels of energy-related financial literacy are linked to an increase in the adoption of energy efficient lighting and that the interaction between the energy and financial components is important, since financial literacy alone has no effect. This is in line with the findings from Filippini et al. (2020), whose results show that higher levels of energy-related financial literacy are associated with more rational attitudes toward appliance replacement in households in Nepal, and with Blasch et al. (2019), who prove that energy and investment literacy reduce cognitive biases when choosing household appliances. Additionally, Asmare et al (2022) found that the willingness of individuals to invest in energy retrofits for multi-apartment buildings is positively correlated with their overall financial literacy, energy literacy, and energy related financial literacy. Investing in energy efficiency successfully can lead to saving energy, in fact, higher energy literacy is also linked to lower energy consumption controlling for factors such as household characteristics (Kalmi et al., 2021). Energy and investment literacy is also associated with a better response to interventions aimed at facilitating the choice of efficient appliances. (Blasch et al., 2022)

We found more publications indicating energy literacy as one of the determinants of investments in energy efficiency in households. Individuals with a higher level of energy literacy are more likely to successfully perform cost minimisation when buying appliances (He et al., 2022). In fact, energy literacy is also among the factors improving the implicit discount rate, also called IDR (the subjective discount rate used to translate future savings

in energy expenditures into present values) of people, making the IDR closer to the real return on investment (Damigos et al., 2021). Furthermore, energy literacy can increase the likelihood of buying more efficient and durable household appliances when replacing old ones (Schwartz et al., 2013; Schubert, 2017; Olsthoorn et al., 2023). This skill can be useful even in situations of energy poverty, where it can be an instrument to help choose more efficient appliances, if there are resources (O'Sullivan and Viggers, 2021). However, it is always important to consider the trade-off between energy consumption and the purchase of new and more efficient appliances: overusing electricity may prevent households from spending more on better appliances (Baikowski, 2018). Finally, energy literacy is among the factors affecting the adoption of energy technologies, including solutions for energy efficiency (Chadwick et al., 2022). Being aware of the household energy consumption can also influence the decision to insulate the walls and roof of one's residence (Ebrahimigharehbaghi et al., 2022).

Other studies do not find evidence of the relevance of energy literacy. Dharshing and Hille (2017) found that neither energy literacy, nor numeracy, nor being an environmentalist influence efficiency decision-making. Furthermore, for Brent and Ward (2018), financial literacy is a determinant of investments in energy efficiency, but they did not find any significant influence of energy literacy. Similarly, Boogen et al. (2021) do not find any effect of energy related knowledge on the levels of energy efficiency in a household, while they find that stronger cognitive abilities positively affect investments.

The importance of cognitive abilities is confirmed by Andor et al. (2019), who found that a higher level of cognitive reflection (the propensity to reflect on and override intuitive solutions) in consumers corresponds to a higher valuation of energy efficiency, however, lower levels of cognitive reflection are linked with a stronger response to the provision of efficiency classes through labels. Other characteristics which are related to energy literacy and have an impact on energy efficiency decision making include engagement and interest in energy topics, which implies a positive attitude towards switching to more efficient appliances (Neves & Oliveira, 2021), and the perception of electricity prices: if households perceive them as higher than market prices, they tend to reduce their energy consumption and also increase their expenditure on appliances, increasing efficiency (Baikowski, 2018)

In conclusion, energy literacy plays a crucial role in empowering people to make informed decisions and invest in energy efficiency. While changing individual behaviours is important for energy savings, investing in better equipment and improving overall household efficiency has a greater impact on reducing energy consumption. The lack of information and knowledge are significant barriers to rational decision-making, as people may not be aware of the long-term economic outcomes of their purchases. People with moderate levels of energy literacy possess the skills needed to identify and purchase energy efficient appliances, maximise energy savings, and make cost-effective choices. However, investing in efficient technologies may not be enough in the next years. The recent developments in the energy field, (first among them, the growing share of renewables in the energy mix), require new behavioural changes and the adoption of new technologies, which leads us to the third group: flexibility provision.

7. Flexibility provision group and building the third level of energy literacy

The paradigm of power system operations is in the process of dramatic change: while the power systems in the past were led by the principle of "demand leads, generation follows", the power systems in the future will be led by the opposite principle of "generation leads, demand follows". The main equation in the power system operation is the balance of electricity generation and demand, if this balance is not maintained, the power system can suffer from major issues and even collapse. In the past, the demand was inflexible or uncontrollable, meaning that there were no ways to use it to maintain this balance. But this was not a problem, since the generation side had a great deal of flexibility coming from the controllable operation of thermal (fossil-fuelled) and hydropower plants. In the future power system, the decarbonisation of the generation side leads to decommissioning of controllable thermal power plants and the integration of uncontrollable renewable energy sources. Therefore, we lose traditional flexibility providers and we need to find new ones. Here, demand can step in and provide the flexibility to maintain the fragile balance. But for the time being, the demand still does not provide sufficient flexibility to the power system (ENTSO-E, 2021). This is why it is of outmost importance that households and other consumers are literate about flexibility provision.

Following the previous paragraph, the third and last group of outcomes of energy literacy refers to the ability of end-users to provide flexibility to the power system. This can be done either by shifting consumption, by adopting flexibility-enabling technologies, or by responding to signals like dynamic tariffs. "Generally, flexibility as a

term refers to an energy system's ability to maintain continuous service during rapid and significant changes in energy supply and demand. Demand side flexibility is an essential part of the overall system-level flexibility" (Ruokamo et al., 2019). Households can provide flexibility by participating in direct load control of electricity and heating devices, by shifting energy consuming activities towards off-peak times, by producing and storing their own electricity, by adopting and responding to aggregators signals or dynamic tariffs.

The third or high level of energy literacy refers to the ability to provide demand-side flexibility to the electricity system. This involves a combination of skills coming from the first two levels, including recognising the specific appliances and activities that can be adjusted and having financial knowledge to invest in appliances that enable flexibility. The additional skills involve an understanding of emerging energy concepts, such as dynamic tariffs, energy communities, energy mix.

Many countries in the European Union have adopted some type of static time-of-use (TOU) electricity tariff, and dynamic pricing will acquire more importance since it enables sending a real-time signal regarding the availability of energy and other events which may require demand-side response. In some countries, such as Finland, customers have the possibility to choose a real-time price for their electricity, however, only 7% of them have done so (Finnish Energy Authority, 2018). Energy literacy could play a role in understanding and adopting dynamic tariffs, as shown in a survey by Reis et al. (2021). They found that higher energy and graphical literacy was associated with a higher willingness to adopt a time-differentiated tariff (TDT). Unfortunately, most respondents were unable to correctly read graphs and to calculate the energy costs associated with a TDT. Similarly, the study on dynamic tariffs by Dütschke & Paetz (2013) suggests that consumers are more willing to adopt a dynamic tariff if they are familiar with it or have already experienced it, which is not likely, given their scarce implementation. They also highlight that the economic advantages of this kind of tariffs most of the times are unclear, and thus make them undesirable. Similarly, Ruokamo et al. (2019) suggest that the difficulties in understanding the contracts, combined with risk aversion, is one of the reasons why customers do not participate in real-time pricing schemes. To the authors best knowledge, none of the other state-of-the-art papers deals directly with the link between energy literacy and willingness to adopt dynamic tariffs. However, it is worth noting that tariff understanding and awareness regarding own energy bills is a component of energy literacy scales in several papers (O'Sullivan & Viggers, 2021, Joshi & Sen, 2021, El Gohary et al., 2022).

Flexibility also depends on the ability to shift consumption when needed, which becomes easier if there are smart technologies in the household. The lack of energy literacy has been identified as one of the barriers to the shifting of routine activities, since consumers underestimate the energy consumption of short, daily activities, such as taking a shower (Walker & Hope, 2020; O'Sullivan & Viggers, 2021). Our literature review reveals a current scarcity of studies examining the inclusion of energy literacy as a determinant in the analysis of potential flexibility provision. However, there are papers where the need for a higher energy literacy is hinted at. To start with, familiarity with the smart grid is also a factor that could favour household flexibility: it was found to have a positive influence on the willingness to change energy use patterns such as postponing the start time of appliances and turning off the heating or air conditioning for a short time (Li et al., 2017). It also favours the adoption of flexibility enabling devices, such as smart metres or storage batteries (Chadwick et al., 2022). This is not a one side relation, in fact, in some articles, energy literacy emerges as a side effect of flexibility pilots. This happens because of the information campaigns that most of the time are combined with pilots (de Leon Barido et al., 2018; Crawley et al. 2021).

The literature review suggests that energy literacy could improve the acceptance of dynamic tariffs and the provision of flexibility. Given the growing importance of demand-side flexibility provision, we believe that the impact of energy literacy on flexibility is under researched. Educating households is a relatively inexpensive tool to achieve a change in energy use, and we believe its potential and costs must be explored more regarding demand-side flexibility.

8. Conclusions

Energy literacy is a complex area of research that has generated a significant body of knowledge across a variety of disciplines. Throughout this review, we found evidence that with an increase in energy literacy comes a potential change in energy consumption outcomes.

Our contribution consists of the identification of three main outcomes in terms of energy consumption that are influenced by energy literacy: energy saving behaviours, investment in energy efficient technologies, and flexibility provision. Each group represents one of the building blocks of three levels of energy literacy. The first group of outcomes directly corresponds to the low level of energy literacy: it consists of performing energy saving behaviours at home. The moderate level of energy literacy includes outcomes from the first group together with the ability to perform cost minimisation for the long term when deciding on efficiency improvements for the household (second group). The final and most advanced level is represented by the capability to provide flexibility; this in fact requires a combination of the identification of appliances and activities to shift from the first group, the financial literacy to invest in flexibility enabling appliances from the second group, plus the understanding of dynamic tariffs, energy community, energy mix, and other new energy concepts, together with the desire to become a proactive participant in the energy system.

Although this grouping brings more clarity to the multidisciplinary domain of energy literacy, it also highlights two important research gaps. The first one consists of the need for more coherence over a standard definition and measurement of energy literacy in households. While the questionnaire by Dewaters and Power (2013) is widely used in schools worldwide to measure the energy literacy of young students, a similar tool is missing for households. We invite the diverse research community around energy literacy to work toward such standards, as it will allow for a better comparison between the results obtained in research.

The second gap that emerges from our review is that despite the growing importance of flexibility of electricity demand in households, it has not been sufficiently explored in energy literacy research. In this paper, we would like to stress the importance of improving the understanding of the relation between energy literacy and demand-side flexibility in households, since energy education has the potential to be a relatively inexpensive tool for strengthening our energy systems.

While wrapping up, it is appropriate to mention limitations. The first is the absence of a unified measurement standard for energy literacy. With some exceptions, each of the papers analysed adopts a different scale or even definition of energy literacy; some focus more on the cognitive component, others on the behavioural or the financial one, and others try to measure everything at the same time. It is certain that this represents an obstacle to a clear assessment of the impact of energy literacy. This also prevents any study aimed at quantifying its impact, such as a meta-analysis.

Another limitation we acknowledge is publication bias, where studies with insignificant or contrary results are often not published (DeVito & Goldacre, 2019). Researchers tend to avoid sharing such outcomes as they may be considered failed research or receive negative feedback from scientific outlets (Nair, 2019). While this bias is typically more relevant for systematic reviews and meta-analyses (Stanley, 2005), we believe it could affect our review as well. Despite using neutral keywords, we have found a significant number of papers supporting the idea that energy literacy influences energy consumption and decision-making. The goal of our review is not to strongly prove any causality between the two, however, a more systematic review may shed light on such question.

The scope of this research can even extend beyond households; in fact, every energy-consuming actor can provide flexibility. While large companies may have energy departments where energy experts work, this does not happen for small and medium enterprises (SMEs). In practice more than in research, it emerges that SMEs are not aware of the possibility to provide flexibility and its potential in terms of economic advantages for them and for the stability of our power systems. If a higher energy literacy can bring about a change in energy consumption in households, similar knowledge could have the same effect in other contexts.

With this paper, we want to contribute to the discussion on energy literacy by highlighting its potential and the gaps that exist between the current state-of-the-art research on energy literacy and the new energy concepts (primarily, flexibility) that emerge over time. We hope that more research on the topic will help improve the way we use energy in all its aspects.

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References

Andor, M. A., Frondel, M., Gerster, A., & Sommer, S. (2019). Cognitive reflection and the valuation of energy efficiency. Energy Economics, 84, 104527.

Asmare, F., Giedraitis, V., Jaraitė, J., & Kažukauskas, A. (2023). Energy-related financial literacy and retrofits of Soviet-era apartment buildings: The case of Lithuania. Energy Economics, 120, 106583.

Baikowski, M. (2018). Impacts of consumers' electricity price misperceptions (No. 105). CAWM Discussion Paper.

Blasch, J., Boogen, N., Filippini, M., & Kumar, N. (2017). Explaining electricity demand and the role of energy and investment literacy on end-use efficiency of Swiss households. Energy Economics, 68, 89-102.

Blasch, J., Filippini, M., & Kumar, N. (2019). Boundedly rational consumers, energy and investment literacy, and the display of information on household appliances. Resource and Energy Economics, 56, 39-58.

Blasch, J., Boogen, N., Daminato, C., & Filippini, M. (2021). Empower the consumer! Energy-related financial literacy and its implications for economic decision making. Economics of energy & environmental policy, 10(2), 149-181.

Blasch, J. E., Filippini, M., Kumar, N., & Martinez-Cruz, A. L. (2022). Boosting the choice of energy-efficient home appliances: the effectiveness of two types of decision support. Applied Economics, 54(31), 3598-3620.

Boogen, N., Cattaneo, C., Filippini, M., & Obrist, A. (2021). Energy efficiency and the role of energy-related financial literacy: evidence from the European residential sector. Energy Efficiency, 14, 1-17.

Brounen, D., Kok, N., & Quigley, J. M. (2013). Energy literacy, awareness, and conservation behavior of residential households. Energy Economics, 38, 42-50.

Chadwick, K., Russell-Bennett, R., & Biddle, N. (2022). The role of human influences on adoption and rejection of energy technology: a systematised critical review of the literature on household energy transitions. Energy Research & Social Science, 89, 102528.

Chandler, S. J. A., & Brown, M. A. (2009). Meta-review of efficiency potential studies and their implications for the south.

Cornago , E. (2021). The potential of behavioural interventions for optimising energy use at home – analysis. IEA. https://www.iea.org/articles/the-potential-of-behavioural-interventions-for-optimising-energy-use-at-home

Crawley, J., Johnson, C., Calver, P., & Fell, M. (2021). Demand response beyond the numbers: A critical reappraisal of flexibility in two United Kingdom field trials. Energy Research & Social Science, 75, 102032.

Damigos, D., Kontogianni, A., Tourkolias, C., & Skourtos, M. (2021). Dissecting subjective discount rates and investment literacy for energy-efficient investments. Energy Efficiency, 14(3), 31.

Dharshing, S., & Hille, S. L. (2017). The energy paradox revisited: analyzing the role of individual differences and framing effects in information perception. Journal of Consumer Policy, 40, 485-508.

de Leon Barido, D. P., Suffian, S., Kammen, D. M., & Callaway, D. (2018). Opportunities for behavioral energy efficiency and flexible demand in data-limited low-carbon resource-constrained environments. Applied Energy, 228, 512-523.

DeVito, N. J., & Goldacre, B. (2019). Catalogue of bias: publication bias. BMJ Evidence-Based Medicine, 24(2), 53-54.

DeWaters, J., & Powers, S. (2013). Establishing measurement criteria for an energy literacy questionnaire. The Journal of Environmental Education, 44(1), 38-55.

Dharshing, S., & Hille, S. L. (2017). The energy paradox revisited: analyzing the role of individual differences and framing effects in information perception. Journal of Consumer Policy, 40, 485-508.

Dütschke, E., & Paetz, A. G. (2013). Dynamic electricity pricing—Which programs do consumers prefer?. Energy Policy, 59, 226-234.

Ebrahimigharehbaghi, S., Qian, Q. K., de Vries, G., & Visscher, H. J. (2022). Identification of the behavioural factors in the decision-making processes of the energy efficiency renovations: Dutch homeowners. Building Research & Information, 50(4), 369-393.

El Gohary, F., Nordin, M., Juslin, P., & Bartusch, C. (2022). Evaluating user understanding and exposure effects of demand-based tariffs. Renewable and Sustainable Energy Reviews, 155, 111956.

Filippini, M., Kumar, N., & Srinivasan, S. (2020). Energy-related financial literacy and bounded rationality in appliance replacement attitudes: evidence from Nepal. Environment and Development Economics, 25(4), 399-422.

Finnish Energy Authority (2018). National Report 2018 to the Agency for the Cooperation of Energy Regulators and to the European Commission. Ref, 1411(480), 2018.

Gołębiowska, B. (2020). Energy literacy in Poland. Ekonomia i Środowisko-Economics and Environment, 73(2), 23-23.

Granade, H. C., Creyts, J., Derkach, A., Farese, P., Nyquist, S., & Ostrowski, K. (2009). Unlocking energy efficiency in the US economy. McKinsey & Company.

He, S., Blasch, J., van Beukering, P., & Wang, J. (2022). Energy labels and heuristic decision-making: The role of cognition and energy literacy. Energy Economics, 114, 106279.

Hossain, S., Hasan, S., & Uddin, S. (2019). Behavioural economics in energy consumption: Rational or habitual. Research Gate.

Joshi, G., & Sen, V. (2021). Residential Consumer Understanding of Electricity Bills: The Case of the Indian Consumer. International Journal of Asian Business and Information Management (IJABIM), 12(3), 1-16.

Kalmi, P., Trotta, G., & Kažukauskas, A. (2021). Energy-related financial literacy and electricity consumption: Survey-based evidence from Finland. Journal of Consumer Affairs, 55(3), 1062-1089.

Kantenbacher, J., & Attari, S. Z. (2021). Better rules for judging joules: Exploring how experts make decisions about household energy use. Energy Research & Social Science, 73, 101911.

Kempton, W., & Layne, L. L. (1994). The consumer's energy analysis environment. Energy Policy, 22(10), 857-866.

Li, R., Dane, G., Finck, C., & Zeiler, W. (2017). Are building users prepared for energy flexible buildings?—A large-scale survey in the Netherlands. Applied Energy, 203, 623-634.

Martins, A., Madaleno, M., & Dias, M. F. (2020). Energy literacy: What is out there to know?. Energy Reports, 6, 454-459.

Mills, B., & Schleich, J. (2012). Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: An analysis of European countries. Energy Policy, 49, 616-628.

Nair, A. S. (2019). Publication bias-Importance of studies with negative results!. Indian journal of anaesthesia, 63(6), 505.

Neves, J., & Oliveira, T. (2021). Understanding energy-efficient heating appliance behavior change: The moderating impact of the green self-identity. Energy, 225, 120169.

Olsthoorn, M., Schleich, J., Guetlein, M. C., Durand, A., & Faure, C. (2023). Beyond energy efficiency: Do consumers care about life-cycle properties of household appliances?. Energy Policy, 174, 113430.

O'Sullivan, K., & Viggers, H. (2021). Six ways to help fix energy hardship in New Zealand. Policy Quarterly, 17(4), 65-72.

Reis, I. F., Lopes, M. A., & Antunes, C. H. (2021). Energy literacy: an overlooked concept to end users' adoption of time-differentiated tariffs. Energy Efficiency, 14(4), 39.

Ruokamo, E., Kopsakangas-Savolainen, M., Meriläinen, T., & Svento, R. (2019). Towards flexible energy demand–Preferences for dynamic contracts, services and emissions reductions. Energy Economics, 84, 104522.

Satre-Meloy, A. (2019). Investigating structural and occupant drivers of annual residential electricity consumption using regularization in regression models. Energy, 174, 148-168.

Schubert, C. (2017). Green nudges: Do they work? Are they ethical?. Ecological economics, 132, 329-342.

Schwartz, T., Denef, S., Stevens, G., Ramirez, L., & Wulf, V. (2013, April). Cultivating energy literacy: results from a longitudinal living lab study of a home energy management system. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 1193-1202).

Sayarkhalaj, H., & Khesal, M. F. (2022). Investigating energy literacy and its structural model for citizens of Mashhad. Heliyon, 8(11), e11449.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. Journal of business research, 104, 333-339.

Stanley, T. D. (2005). Beyond publication bias. Journal of economic surveys, 19(3), 309-345.

Torraco, R. J. (2005). Writing Integrative Literature Reviews: Guidelines and Examples. Human Resource Development Review, 4(3), 356–367.

van den Broek, K. L. (2019). Household energy literacy: A critical review and a conceptual typology. Energy Research & Social Science, 57, 101256.

van den Broek, K. L., & Walker, I. (2019). Exploring the perceptions of drivers of energy behaviour. Energy Policy, 129, 1297-1305.

Walker, I., & Hope, A. (2020). Householders' readiness for demand-side response: A qualitative study of how domestic tasks might be shifted in time. Energy and Buildings, 215, 109888.

Zanocco, C., Sun, T., Stelmach, G., Flora, J., Rajagopal, R., & Boudet, H. (2022). Assessing Californians' awareness of their daily electricity use patterns. Nature Energy, 1-9.