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# Mapping risk and benefit perceptions of energy sources: Comparing public and expert mental models in Indonesia, Malaysia, and Singapore

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ABSTRACT

Traditionally reliant on fossil fuels, Southeast Asian countries – Indonesia, Malaysia, and Singapore – plan to introduce cleaner energy (e.g., renewable energy) into their energy mix. To gauge public support, an understanding of their risk and benefit perceptions of energy technologies is necessary. In the absence of technical knowledge, lay people may form these perceptions based on existing mental models – these are individuals' internal representations of the external world that can affect how they perceive various issues. Using the mental models approach, the current study examines and compares the public's and energy experts' mental models in an attempt to understand how risks and benefits of energy technologies are perceived, as well as gaps in the public's understanding and information needs. We conducted online focus group discussions in Indonesia, Malaysia, and Singapore with 78 members of the public and 26 energy experts. The public and energy experts were found to have broadly similar considerations about energy security, economic and environmental impacts, and safety of energy technologies, but they differed in how they thought about them. While energy experts had relied on their topical expertise and existing evidence to form risk and benefit perceptions, the public had relied on other contextual factors to do so, such as their place-identities, religious beliefs, and personal values. Misleading analogies were also found to have played a role. The findings' implications on public policies and communication strategies are discussed.

## 1. Introduction

Global energy systems have come under scrutiny for their role in exacerbating climate change. The energy supply sector has been identified as the main contributor of greenhouse gas emissions [1]. To mitigate this, countries around the world are transitioning out of a reliance on carbon-laden fossil fuels and adopting cleaner technologies such as renewable energy and nuclear energy. As a key player on the world energy stage, Southeast Asia (SEA) is also gradually moving towards cleaner energy systems [2]. Traditionally dependent on fossil fuels, countries such as Indonesia, Malaysia, and Singapore have plans to include renewables (e.g., solar) in their energy mix [3,4]. While there are currently no nuclear power plants in these countries, Indonesia has plans to utilize nuclear power as a source of energy to power the country [5]. Malaysia has no plans to do so [6], and Singapore considers existing nuclear power technologies unsuitable for deployment in the country, although it is monitoring the progress of advanced nuclear technologies [7]. The introduction of new energy technologies can be met with varying levels of public support, such as in the case of nuclear energy [8], which can impact the implementation of these technologies [9]. For countries undertaking the mammoth task of overhauling their energy system, it is imperative to understand public support for energy technologies prior to their implementation, warranting an investigation of its underlying factors.

Of the myriad factors affecting public support for various energy technologies, scholars have found public risk and benefit perceptions to be the main predictors (e.g., [8,10,11]). Risk perceptions of energy technologies have been previously studied, for instance, using the psychometric paradigm [12], while benefit perceptions have been examined in relation to people's values [13]. Wallquist, Visschers and Siegrist [14] proposed to examine people's mental concepts to understand how they intuitively think about the risks and benefits of an energy technology. Public risk and benefit perceptions of a particular energy technology may be intuitively formed based on people's existing mental model, even in the absence of specific technical knowledge and familiarity to it [14]. Mental models refer to people's internal representations of the external world [15]. They can arise from people's beliefs, experiences, and previous knowledge on a relevant, albeit non-specific,

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subject [14], and can affect how people interpret and understand different issues [15,16].

With the introduction of novel energy technologies in Indonesia, Malaysia, and Singapore, it is worthwhile to understand how the public intuitively perceive the risks and benefits of these technologies. This can allow for the identification of key concerns that the public might have about energy technologies, as well as the deep-seated beliefs that they use to guide their considerations. Such insights can aid the formulation of appropriate communication strategies to help the public better understand various energy technologies. In this study, we examine the public's mental models of risks and benefits of various energy technologies, comparing them across Indonesia, Malaysia, and Singapore. We also examine energy experts' mental models, comparing them with the public's mental models to identify any gaps in the public's understanding and their information needs. Adopting a qualitative study design, we use focus group discussions to elicit the public's and energy experts' mental models.

### 1.1. Study context

Countries in the Association of Southeast Asian Nation (ASEAN) are signatories to the Paris Agreement on climate change, which mandates a reduction in greenhouse gas emissions, such as through the restructuring of energy systems within these countries [17]. As maritime SEA countries that are situated close to one another [18], Indonesia, Malaysia, and Singapore present an interesting study context. The countries have strong links with one another as members of ASEAN [19], and form the Indonesia-Malaysia-Singapore Growth Triangle, which facilitates mutual cooperation for economic development in the region [20]. Indonesia's, Malaysia's, and Singapore's energy contexts are intertwined. Historically, Singapore has relied on Indonesia and Malaysia for its natural gas supply [21]; in recent years, Malaysia has also started exporting electricity to Indonesia [22]. This energy interdependency is likely to continue into the future, for instance, as seen in Singapore's plans to import cleaner energy from Indonesia and Malaysia [23]. Considering these close ties, we conduct an in-depth examination of the public's perceptions of energy technologies in Indonesia, Malaysia, and Singapore.

#### 1.1.1. Indonesia

Comprising thousands of islands, Indonesia occupies a total area of 1,916,906.77 $km^2$ with an estimated population of 270.2 million [24]. Indonesia is the most populous Muslim-majority country in the world [25]. Despite possessing a secular constitution, Islamic influences have been observed in laws and policy for Indonesia in the past [26,27]. Most Indonesians regard Islam as playing an important role in society, though they believe it to be a private matter [28]. Indonesia has an abundance of primary energy sources (i.e. fossil fuels and renewable energy such as hydro, geothermal, bioenergy, solar energy, and wind energy), and rely on domestic energy production and fossil fuel imports [29]. Faced with declining fossil fuel reserves in the country, the utilization of renewable energy is encouraged [29]. However, the demand for coal has been on the rise, with Indonesia being the fifth-largest coal producer in the world [17]. Although there are currently no nuclear power plants in Indonesia, the government has plans to utilize nuclear power as a source of energy to power the country [5,30].

#### 1.1.2. Malaysia

Malaysia consists mainly of Peninsular Malaysia, and Sabah and Sarawak on the island of Borneo [31]. Occupying a total area of 330,524 $km^2$ [32], Malaysia has a population of 32.7 million [33]. While possessing a secular constitution, Malaysia adopts Islam – the predominant religion [34] – as the federation's religion to symbolise its importance to the country, and Islamic influences may be observed in its social fabric [35]. Rich in primary energy sources (i.e. fossil fuels and renewable energy sources such as hydro, biodiesel, and solar energy), Malaysia relies on domestic energy production and fossil fuel imports [36]. Various national policies have been implemented to reduce the country's reliance on fossil fuels to conserve the Malaysian oil [37], including the development of renewable energy [38]. However, the demand for coal has increased, with Malaysia being the eighth-largest net importer of coal in the world [17]. While nuclear energy was initially considered to be a potential energy source [38], this idea was later scrapped as it was deemed too risky [6].

#### 1.1.3. Singapore

Singapore occupies a land area of 725.7 $km^2$ [39] with an estimated population size of 5.7 million [40]. Amid its multireligious population [40], Singapore has self-declared to be a secular state, with the government employing secularism in its governance strategy [41]. As a city-state with scarce natural resources, the Republic relies on imports of fossil fuels, primarily natural gas from Indonesia and Malaysia [21,42]; about 95% of the electricity in the country is generated by natural gas [43]. Singapore's geographical constraints limit its access to renewable energy, consequently impeding a large-scale energy transition; nonetheless, solar energy is a promising source for its energy future [3,7]. While nuclear energy has been studied as a potential source of clean energy, existing nuclear power technologies are presently considered unsuitable for deployment in Singapore; nevertheless the country is monitoring the progress of advanced nuclear technologies [7].

## 2. Literature review: mental models

Mental models are people's internal, mental representations of the world, constructed based on an individual's experiences, knowledge structures, and personal insights of the external world [15,44]. They are shaped by sociocultural and environmental factors, and encompass an individual's assumptions, values, and beliefs [16]. While these simplified representations of a complex reality might be incomplete or inaccurate, they serve a functional purpose to help people interpret, understand, and navigate the world [15], such as in instances of uncertainty [45], decision-making, and forming perceptions [46]. Acting as an information filter, individuals use their mental models to interpret incoming information from the external world; congruent information is assimilated into an individual's mental model, while incongruent information either modifies it, or is rejected [16]. Such changes in mental models facilitate learning: existing mental models can be refined, modified, or completely restructured, the last of which entails a change in the deeply ingrained values and beliefs [16]. An individual's understanding of an issue can therefore continue to develop over time. However, the intuitive nature of mental models poses a threat to accurate interpretations of the world, as flawed mental models can lead people to erroneous conclusions [47], for instance, when misleading analogies in mental models are used to make inferences [46].

Past studies have used mental models to examine how the public understands various social issues, such as climate change [48], conservation planning [16], and climate risk management [49]. Sterman and Sweeney [48] investigated why there was public opposition to climate mitigation policies, despite public knowledge of climate change. Climate mitigation policies are based on the complex science of climate dynamics; an appreciation of these policies would therefore require an understanding of the underlying science. However, when the authors examined people's mental models of climate dynamics, they found that they were often oversimplified, inaccurate representations of the subject. Public mental models were incongruent with the ideas put forward by climate mitigation policies, resulting in a lack of support for these policies. In the same vein, Biggs, Abel, Knight, Leitch, Langston and Ban [16] attributed the failure to implement conservation plans (i.e., the planning-implementation gap) to an inadequate understanding of various stakeholders' perspectives. The authors argued that an examination of the stakeholders' mental models is useful for understanding their personal values and beliefs, as well as for identifying perspectives

that are different or shared between stakeholders. Once identified, a common framework of understanding can be developed to foster communication and joint action between the stakeholders, thereby facilitating the successful implementation of conservation plans [16]. On examining values in mental models, Bessette, Mayer, Cwik, Vezer, Keller, Lempert and Tuana [49] identified a set of 13 different values – such as fairness and nonhuman welfare – that people talk about when discussing climate risk strategies. The authors similarly emphasized the importance of understanding people's values by examining their mental models, so as to improve risk communication and encourage decision-making that are more value-aligned.

Other studies have used mental models to understand how people perceive the risks, for instance, of smallpox and its vaccine [50], nuclear waste disposal [51], dengue fever [52], and climate change [46]. Investigating public risk perceptions of nuclear waste disposal, Skarlatidou, Cheng and Haklay [51] found that participants' prior knowledge of the Chernobyl and Three Mile Island nuclear power plant incidents had informed their mental models of the risks of nuclear waste disposal, resulting in conflation of the risks of nuclear waste disposal with those of nuclear power plant accidents. Examining the public's mental models also allowed the authors to identify main perceptions and concerns that the public had about the risks of nuclear waste disposal. Similarly, Dhar-Chowdhury, Haque and Driedger [52] examined the public's mental models of dengue disease risks and found that the public had multiple misconceptions regarding dengue disease, such as the erroneous belief that dengue is a food-borne disease due to personal experiences of ailment following food consumption. Examining these mental models also revealed that the public had underestimated the risks of dengue disease, resulting in a neglect to take appropriate measures for controlling and preventing it. Consequently, public communication can be formulated accordingly to correct misconceptions and misperceptions, so as to encourage uptake of measures to tackle dengue disease.

### 2.1. Mental models and communication

The mental models approach has been used in risk communication [53]. It entails comparing public mental models with expert mental models – the latter comprise pooled knowledge and beliefs of a community of experts on the subject matter [53]. Such a comparison is based on the idea that experts' beliefs about the risks of an issue determine what the lay public should know, and that this information should be communicated from the experts to the public; consequently, this would reveal any areas of convergence (commonalities) and divergence (gaps) between the models [53]. Commonalities in the mental models of different stakeholders can enable mutual understanding and facilitate communication between these stakeholders, while gaps can be disruptive to these endeavors [16]. Comparing public and expert mental models can therefore identify public beliefs that need to be reinforced or corrected through communication efforts [53].

Conventionally, expert mental models are first constructed, and later used to guide the elicitation of public mental models [53]. However, experts tend not to think like the public [44]; using their mental models as a guide might therefore restrict the scope of eliciting the public's mental models. The concepts and contextual factors that are specific to the public, and which the public uses to understand various issues, might not be adequately captured as a result. Taking this into consideration, Dhar-Chowdhury, Haque and Driedger [52] proposed a modified mental models approach to retain the complexity and contextual richness of the public's mental models as much as possible. Instead of using expert mental models as a guide to elicit public mental models, the authors assumed both expert and public mental models to be on the same knowledge spectrum. Their mental models were therefore elicited independent of each other before they were compared to identify gaps in public's understanding.

## 3. Current study

As mental models help individuals to make inferences and predictions about the world, they play a key role in how people form perceptions and make decisions [46]. In the absence of technical or scientific knowledge, people attempt to make sense of various issues based on their existing mental models [14,51]. Examining mental models is therefore useful to understand how people perceive an issue, as well as reveal underlying concepts that inform these perceptions.

The extant mental models literature is largely focused on examining the public's mental models of risk perceptions to inform risk communication strategies. However, there is also value in examining mental models of benefit perceptions, so that information on both risks and benefits of an issue can be communicated to the public, allowing for more considered opinions to be formed. This is especially pertinent to the study of public perceptions of energy sources, considering that benefit perceptions are a strong predictor of public support for various energy technologies (e.g., [8,11]).

With these in mind, the primary objective of this study is to examine the public's mental models of risk and benefit perceptions of various energy technologies. These include conventional sources of energy, such as fossil fuels (e.g., coal, natural gas), which currently are the main sources of energy in Indonesia, Malaysia, and Singapore, as well as alternative energy sources, such as renewable energy (e.g., solar, wind) and nuclear energy. To identify any gaps in the public's understanding and their information needs, we also aim to examine energy experts' mental models, seeking to compare them with the public's mental models. Areas of divergence in the public's and energy experts' mental models would indicate gaps in understanding that can be bridged through communication efforts, while areas of convergence would indicate a shared understanding that can be reinforced. To understand how the mental models of risk and benefit perceptions of energy technologies might differ across countries, we aim to compare them across Indonesia, Malaysia, and Singapore.

To the best of our knowledge, no studies have attempted to examine and compare the public's and energy expert's mental models of risk and benefit perceptions of various energy technologies, not least across SEA countries. As such, we ask the following research questions (RQ):

RQ 1: What are the public's and energy experts' mental models of risk and benefit perceptions of energy technologies in Indonesia, Malaysia, and Singapore?
RQ 2: How do the public's and energy experts' mental models compare?

## 4. Method

Our study was based on a modified mental models approach. Similar to Dhar-Chowdhury, Haque and Driedger [52], we elicited public and expert mental models separately. We conducted online focus group discussions (FGD) with members of the public and energy experts separately, in Indonesia, Malaysia, and Singapore. FGDs enable participant-led discussions and interpersonal interactions [54], making it an ideal choice for exploring social attitudes around complex topics [55], such as energy technologies. Like face-to-face FGDs, online FGDs are effective in eliciting information from FGD participants; they additionally allow participants to join from anywhere [56], allowing a wider range of participants and consequently capturing more diverse viewpoints.[1]

[1] This approach is especially well-suited for this study, which was conducted during the COVID-19 pandemic, where there were movement restrictions and border closures globally.

### 4.1. Sampling and recruitment

Upon receiving ethics approval from our University's Institutional Review Board, we conducted a total of nine online FGDs with the public and three online FGDs with energy experts in Indonesia, Malaysia, and Singapore, as detailed in Table 1. The online FGDs were conducted between November 2020 and February 2021. Group sizes ranged between eight and ten participants. Each online FGD lasted approximately 2 h, and participants were compensated at the end of each session. All participants had given informed consent before participating.

#### 4.1.1. Recruiting the general public

Public participants were recruited door-to-door and via word-of-mouth. A total of 78 participants were recruited, all of whom were either Indonesian, Malaysian, or Singaporean citizens of legal voting age[2] ($n_{Indonesia} = 24$; $n_{Malaysia} = 24$; $n_{Singapore} = 30$). To overcome technological limitations (e.g., internet access), only people residing in the capital city of each country were recruited (i.e., Jakarta in Indonesia, Kuala Lumpur in Malaysia, and Singapore). While participants had varied professional and educational backgrounds, none had expertise in energy issues.

#### 4.1.2. Recruiting energy experts

Expert participants were recruited through email and telephone contact. We generated an initial sampling frame by using publicly available information to consolidate contacts with expertise in energy issues. Additional participants were identified via snowball sampling. A total of 26 participants were recruited, all of whom were either Indonesian, Malaysian, or Singaporean residents ($n_{Indonesia} = 9$; $n_{Malaysia} = 8$; $n_{Singapore} = 9$) from academia, research institutes, or the energy industry. Participants were Assistant Professors (or above) in academia, scientists (or above) in research institutes, and in managerial positions and above in the energy industry, with expertise in different areas of energy (Table 2).

### 4.2. Moderation and guide

The online FGDs were conducted in the lingua franca of each country (i.e., Bahasa Indonesia in Indonesia, Bahasa Melayu/English in Malaysia, and English in Singapore). An experienced moderator facilitated each online FGD to encourage free-flowing discussions among the participants, aided by an assistant moderator. Two faculty members who were part of the research team moderated the online FGDs in Singapore. Both moderators for the online FGDs in Indonesia and Malaysia were professional moderators who had vast experience conducting online FGDs in the respective countries; they were briefed by the research team prior to moderating the online FGDs with the general public and energy experts.

Moderators used semi-structured topic guides designed by the research team, based on research on public perceptions of energy issues. These were developed in English and translated into Bahasa Indonesia and Bahasa Malaysia by professional translators. Back-translation was done by native speakers of the respective languages for accuracy. The guides included a list of questions and prompts, beginning with a section gauging general perceptions of energy sources. After introductions, public participants were asked to talk about energy sources that they were aware of. This was not done with expert participants, given their expertise. Both public and expert participants were then shown a list of energy sources and asked to discuss their thoughts on them, particularly what their risks and benefits were (e.g., 'Which energy sources do you think have the most and the least potential benefits? Which energy sources do you think have the most and the least potential risks?'). Other questions in the guides explored participants' trust, and information and communication behaviors, which are not a focus of this study.

### 4.3. Analysis

The online FGDs were digitally recorded and transcribed verbatim; transcripts were translated into English by professional translators. We checked the English transcripts for discrepancies (e.g., typological errors), and clarified linguistic uncertainties with the translators (e.g., Bahasa Indonesia slang words). All transcripts were de-identified to conceal participants' identities for confidentiality reasons.

The transcripts were subjected to an iterative coding process using *NVivo 12 Plus*. A research team member and an independent coder (a doctoral student trained in qualitative research methods) each coded the transcripts line-by-line, generating a list of initial descriptive and emergent codes. Subsequent rounds of coding were more focused, generating a list of categories from similar codes. Guided by the research questions, we then partook in the second-level coding process to understand the codes and identify perceptions that had emerged, generating the categories and sub-categories for constructing the mental models.

## 5. Results

The participants in Indonesia, Malaysia, and Singapore discussed a range of energy sources in the online FGDs, including fossil fuels (e.g., coal, natural gas, crude oil), renewable energy (e.g., solar, wind, hydropower), and nuclear energy.

### 5.1. Mental models: risk perceptions of energy technologies

The public's and energy experts' mental models of risk perceptions, elicited from the online FGDs in Indonesia, Malaysia, and Singapore, are shown in Fig. 1.

#### 5.1.1. Public's mental models of risk perceptions

The mental models of the Indonesian, Malaysian, and Singaporean public in relation to energy and risks shared some similarities, mainly: a disrupted electricity supply, economic losses, environmental damage, and harm to humans. The Singaporean public additionally had concerns about geopolitical tensions; this had not emerged in the Malaysian and Indonesian public online FGDs.

Participants in all three countries considered if an energy technology could provide them with a constant and adequate supply of electricity. An energy source that could not reliably do so would risk a disruption to their electricity supply, thus severely disrupting their lives. For instance, some Singaporean participants were aware of the intermittency of solar energy, as well as current limitations of energy storage technologies, rendering it unreliable as a main source of energy for the country currently. In the same vein, they viewed solar energy as an unpredictable force of nature, such that there is no control over how disruptive it might be. Similarly, some Malaysian and Indonesian participants were aware that fossil fuels are a limited source of energy that will ultimately be depleted and are thus an unreliable source of energy in the long run.

The financial risks of an energy technology were a consideration for the participants in all three countries. As energy consumers, the participants would have to bear the costs of energy technologies; the adoption of a costly energy technology would therefore risk economic losses. The high, direct costs of using an energy technology were a concern for the participants, especially for renewable energies and nuclear energy. The use of fossil fuels might pose a risk as well, as in the instability of consumer oil prices due to the global oil crisis. Additionally, Singaporean participants also mentioned indirect costs in terms of a depreciation in property values and a loss of national income. For instance, building a nuclear power plant in Singapore might drive away

[2] We included individuals who are of legal voting age as their votes can influence public policy [57]. The legal voting age is 21 years old in Singapore and Malaysia, and 17 years old in Indonesia [58].

**Table 1**
Details of online focus groups.

| Focus group | Focus group composition in each country | | |
|---|---|---|---|
| | Singapore (n) | Malaysia (n) | Indonesia (n) |
| General public FGDs | 10 (6 males, 4 females) Aged 21–39 | 8 (4 males, 4 females) Aged 21–36 | 8 (4 males, 4 females) Aged 20–38 |
| | 10 (5 males, 5 females) Aged 40–55 | 8 (4 males, 4 females) Aged 43–52 | 8 (4 males, 4 females) Aged 40–52 |
| | 10 (5 males, 5 females) Aged 56–74 | 8 (4 males, 4 females) Aged 56–73 | 8 (5 males, 3 females) Aged 59–70 |
| Energy experts FGDs | 9 (7 males, 2 females) Aged ≥21 | 8 (5 males, 3 females) Aged ≥21 | 9 (8 males, 1 female) Aged ≥21 |

foreign investors, which would have economic impacts for a country that is reliant on international trade.

In assessing an energy technology, participants in all three countries considered how much harm it would cause to the environment. Participants also raised specific concerns regarding global warming, pollution, and destruction of the ecosystems. Generally, there was consensus across all three countries that fossil fuels are a pollutive energy source that harms the environment. A participant [S3P6, Singapore] further likened its use to "exploiting what belongs in the world and…polluting the world". Participants were also concerned about the environmental impacts of energy waste; Malaysian and Indonesian participants were particularly concerned about nuclear waste, associating it with radiation, while Singaporean participants were concerned about solar energy waste (i.e., used solar panels).

Participants in all three countries considered the risk of harm to humans, especially when assessing the adoption of nuclear energy in their countries. Of particular concern to the participants was the risk of a catastrophe, where there would be a massive loss of human lives. The mention of nuclear energy would bring past events to mind, especially the Fukushima and Chernobyl nuclear incidents, as well as the bombing of Hiroshima. This line of thinking often ended with participants emphasizing the risk of accidents, disasters, and explosions with the use of nuclear energy. Malaysian and Indonesian participants also associated nuclear energy with misuse or abuse of the technology, describing that "there are certain people who will take the opportunity to…produce…weapon." [M3P2, Malaysia]. This was echoed by an Indonesian participant [I1P5, Indonesia], who mentioned that nuclear energy is "identical with war…mindset just goes there."

Additionally, participants expressed a sense of inevitability about nuclear accidents, citing unavoidable human errors. This was especially salient in Singaporean participants; drawing comparisons with past events, participants remarked that "human error does exist no matter how good the government is [S3P5, Singapore]". Another participant [S2P4, Singapore] expressed this sense of inevitability as an "act of God". Singaporean participants also frequently mentioned the complete destruction of the country in the event of a nuclear accident due to its small size, such that "the whole of Singapore would be completely uninhabitable and… might just cease to exist [S1P10, Singapore]".

Geopolitical tensions were a consideration that Singaporean participants had when discussing nuclear energy as an energy source in the country. Participants were worried that a reliance on others to obtain materials for nuclear energy would put Singapore at risk of being held hostage by their energy needs, as a participant [S1P5, Singapore] remarked: "…vulnerable to…attacks because they can just cut off your resources". Others were concerned that having a nuclear power plant in Singapore would put a strain on its relationship with neighboring countries: "we are an island…where do you build your nuclear plant… go into somebody's waters? And then somebody will start quarrelling with you [S3P5, Singapore]".

#### 5.1.2. Energy experts' mental models of risk perceptions

The mental models of energy experts in Indonesia, Malaysia, and Singapore shared some similarities, mainly: a disrupted electricity supply, economic losses, and environmental damage. Energy experts in Singapore additionally had concerns about the risks of harm to humans.

Energy experts across the three countries were concerned about the risks of having the energy supply disrupted, primarily due to the non-availability of an energy source and the inability of an energy source to meet the country's energy needs. Having a constant and reliable supply of energy would ensure their country's energy security.

The cost of utilizing an energy source was a consideration for energy experts across the three countries. It would be unfeasible to implement an energy source that is costly and unaffordable for the masses, even if it satisfied the other requirements (e.g., clean). Some energy experts were of the opinion that energy development and economic development in their country are intertwined, and were concerned about the impacts of utilizing an energy source on the country's economy.

While energy availability and economics appeared to be the most important considerations, energy experts were also concerned about the potential of energy technologies to damage the environment. For instance, energy experts pointed out the importance of assessing the environmental impact of an energy source's life cycle, as a seemingly environmentally friendly energy technology might actually be environmentally-damaging.

The risk of harm to humans was a consideration for energy experts in Singapore. They were primarily concerned about human health impacts due to air pollution caused by burning fossil fuels: "whether it be burning coal or oil or [liquefied natural gas], more people are killed that way than nuclear power [S4P6, Singapore]". However, this had not emerged as a concern in the Malaysian and Indonesian FGDs.

### 5.2. Mental models: benefit perceptions of energy technologies

The public's and energy experts' mental models of benefit perceptions, elicited from the online FGDs in Indonesia, Malaysia, and Singapore, are shown in Fig. 2.

#### 5.2.1. Public's mental models of benefit perceptions

The mental models of the Indonesian, Malaysian, and Singaporean public related to energy and benefits shared some similarities, mainly: a stable energy/electricity supply, economic benefits, environmental friendliness, safety, and ease of use. Additionally, the Malaysian and Indonesian public also focused on the health benefits of energy technologies.

Participants in all three countries considered the ability of an energy technology to provide a stable supply of energy/electricity a benefit. Most of them saw the abundance of and ease of access to an existing energy source, as well as its longevity, as a key benefit – one that renewable energies have (e.g., sunlight and water). Additionally, some Indonesian participants considered these renewable sources to be provided by God – for instance, that "Allah has provided the sun [I3P8, Indonesia]" – and were thus assured that renewable energies would provide them with the supply of energy that they need.

The financial savings of energy technologies were a consideration for participants in all three countries. Most of them considered cheap and affordable technologies to be a benefit; they perceived renewable energies to be particularly beneficial in this aspect, since they are natural resources that are freely available. Particularly, some Malaysian participants considered these renewable energy sources to be free-to-use as they are provided by God: "water can get it free…Allah given [M3P5, Malaysia]". Some Malaysian participants also considered energy sources that can contribute to the country's economy as a benefit, such as fossil fuels, for which Malaysia is a major producer.

In assessing the benefits of an energy technology, participants in all

**Table 2**
Expert participants' areas of energy expertise.

| Country | Online FGD participants' areas of expertise |
|---|---|
| Singapore | Nuclear energy, solar energy, fossil fuels (natural gas, petroleum), bioenergy, wind energy, hydropower, geothermal energy |
| Malaysia | Nuclear energy, solar energy, fossil fuels (natural gas, coal, petroleum), bioenergy, wind energy, hydropower, hydrogen energy |
| Indonesia | Nuclear energy, solar energy, fossil fuels (natural gas, petroleum), bioenergy, hydropower, geothermal energy, ocean and wave energy |

three countries considered how environmentally friendly it is. Most of them perceived clean and non-pollutive energy sources, as well as the naturalness of an energy source, to be environmentally friendly; these were mostly renewable energies. A majority of participants also perceived nuclear energy to be a clean source of energy as it is not carbon intensive.

The safe use of an energy technology was a consideration for participants in all three countries. Aside from thinking about safety in broad terms, Malaysian participants also considered the certainty of using an energy technology. For instance, the long history of use of fossil fuels in Malaysia, as well as the understanding that there is advanced technology and relevant expertise in place to utilize this energy source, provided participants a sense of safety [M1P3, Malaysia].

Generally, participants in all three countries perceived the ease of use of an energy technology to be a benefit. Most of them saw the utilization of renewable energies to be beneficial in this aspect, as they perceived it to be a straightforward and user-friendly process, primarily because these energies are naturally occurring and easily-observable.

Some of the Malaysian and Indonesian participants considered the health benefits of energy technologies. They highlighted the medical benefits of nuclear energy, and recounted personal experiences of how it had been used in the treatment of cancer. Indonesian participants additionally highlighted the necessity of having energy sources derived from natural resources (e.g., solar energy and hydropower), as they had associated them with their natural elements (e.g., sun and water), which they believed to be essential for human life, such that humans "would find it hard to survive life [I2P6, Indonesia]" without them.

#### *5.2.2. Energy experts' mental models of benefit perceptions*

The mental models of energy experts in Indonesia, Malaysia, and Singapore were similar. The main shared themes that emerged in the FGDs were: a stable energy/electricity supply, economic benefits, environmental friendliness, and safety.

The experts' perceptions of benefits were straightforward. In assessing the ability of an energy technology to provide a stable supply of energy/electricity, energy experts considered how much of it can make up the baseload of the country, based on the current availability, accessibility, longevity, and energy intensity of the energy source. Low-cost and clean energy technologies were also significant considerations. In assessing the safety of an energy technology, energy experts often considered how advanced its technology is.

### *5.3. Comparing public's and energy experts' mental models*

Across the three countries, there were areas of convergence in the public's and experts' mental models of risk and benefit perceptions. These were mostly considerations that were related to the safety, environmental impacts, economic impacts, and ability of energy technologies to provide a reliable supply of energy/electricity. Notably, although the public and energy experts had similar broad considerations, they differed in the details; for instance, while economic loss was a common consideration, only the public were concerned about the spillover cost effects of using energy technologies (e.g., the country's economy).

There were also areas of divergence in these models. Most prominently, the public and energy experts differed in their concerns regarding risk of harm to humans. While the public gravitated towards thinking about catastrophic risks and had more affective reactions to these risks (e.g., frightening), the energy experts took a more evidence-based approach, referring to statistics and data when describing them (e.g., number of deaths per energy technology). The public also interpreted past events differently; for instance, they believed that the Fukushima and Chernobyl incidents were completely devastating, and had resulted in long-lasting radiation in the environment, causing massive deaths. In comparison, however, the energy experts had again assessed the damage done in these past events based on evidence, noting that these were not as catastrophic as they were made out to be. Most of the public also had general ideas about the causes of the Fukushima nuclear incident; on the other hand, the energy experts were more cognizant of the causes, and had a better idea of its inevitability. On a related note, the public had additionally expressed a sense of lack of control and inevitability in the use of an energy technology (e.g., human errors), while energy experts were more assured, placing faith in technological advancements.

Comparing the public's and energy experts' mental models also revealed misconceptions that the public had about energy technologies. Most of the public's misconceptions about risks revolved around the use of nuclear energy, specifically the risk of harm to human lives. The public had inflated the loss of lives in past nuclear incidents, and mistakenly assumed that they would be exposed to radiation should nuclear energy be used; these assumptions frequently arose from their personal interpretation of the Fukushima and Chernobyl incidents. The mention of nuclear energy also prompted some participants to recall the Hiroshima bombing incident; their interpretation of it often saw them conflating atomic bombs with nuclear energy, thus leading them to believe that nuclear energy would be weaponized.

Most of the public's misconceptions about benefits revolved around the use of renewable energy. Participants had assumed that renewable energy technologies are free to use, since these utilize freely available natural resources that are in abundance (e.g., limitless solar energy from the sun). As renewable energies are naturally occurring and observable (e.g., water in the sea), participants had an oversimplified view of renewable energy technologies, and thus had assumed that these would be easy to implement and use. Some participants had also adopted the belief that "what is natural is good", thus assuming that renewable energy is good. This was especially so for participants who had thought that renewable energy technologies were essentially natural elements (i.e., the sun, water, and air (wind)), erroneously assuming that such renewable energies are essential for survival.

## 6. Discussion

Examining mental models is useful for understanding how people perceive the risks and benefits of energy technologies. They also shed light on what shape these perceptions. We constructed and examined the public's and energy experts' mental models of risk and benefit perceptions of various energy technologies in Indonesia, Malaysia, and Singapore. While these mental models revealed risk and benefit considerations to be broadly similar across the public and energy experts in the three countries, there were notable differences in the breadth and emphasis of these considerations. Our results also revealed that the public had relied on analogies, some of which were misleading, to form risk and benefit perceptions. This had led participants to make inaccurate inferences about the risks and benefits of different energy technologies.

### *6.1. Public's mental models of risk and benefit perceptions of energy technologies*

Overall, the Indonesian, Malaysian, and Singaporean public's mental models showed that they mainly had considerations about energy security, economic impacts, environmental impacts, human impacts, technological complexity, and safety when perceiving the risks and

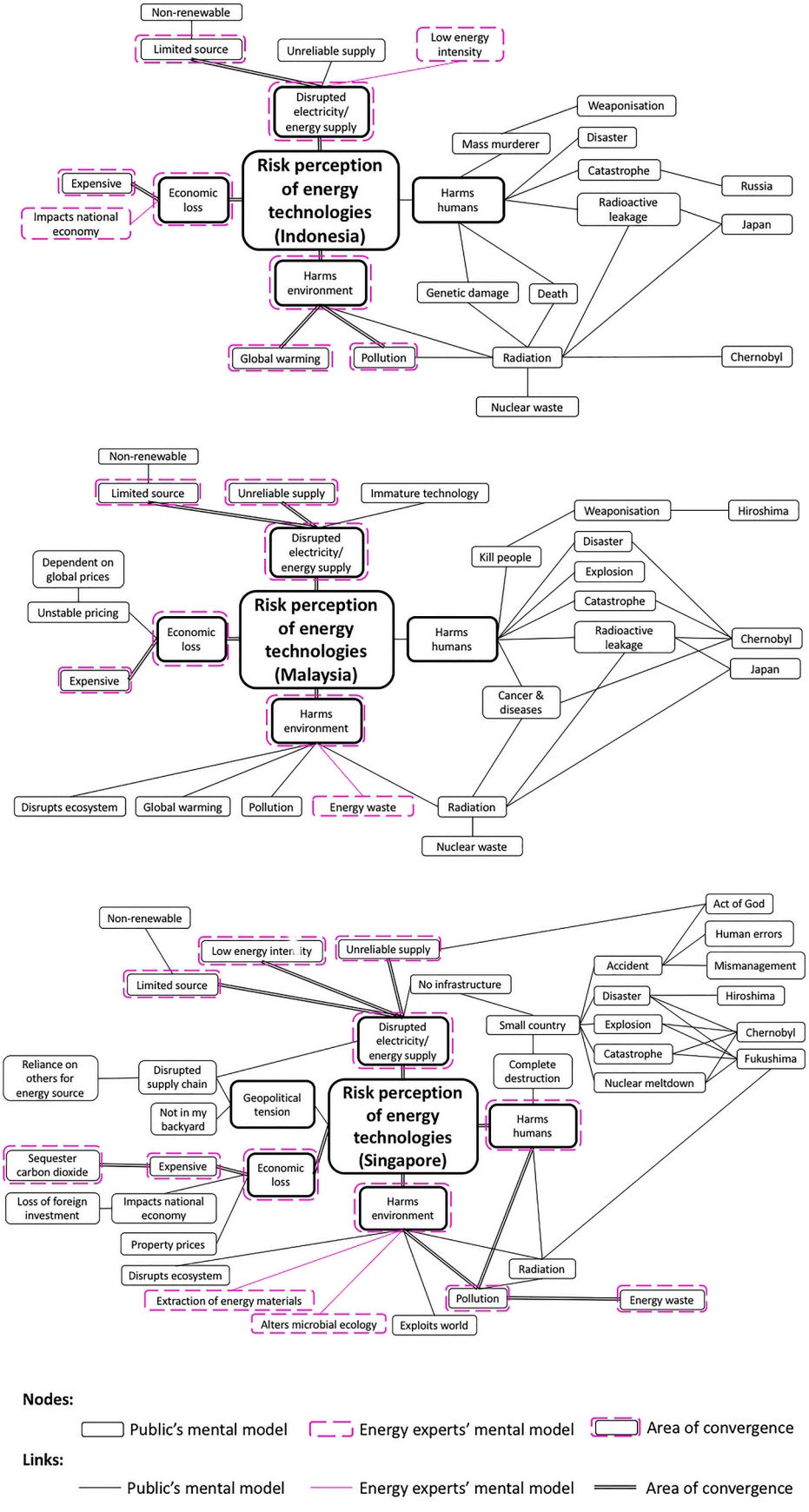


**Fig. 1.** Public's and energy experts' mental models in Indonesia, Malaysia, and Singapore: risk perceptions of energy technologies.

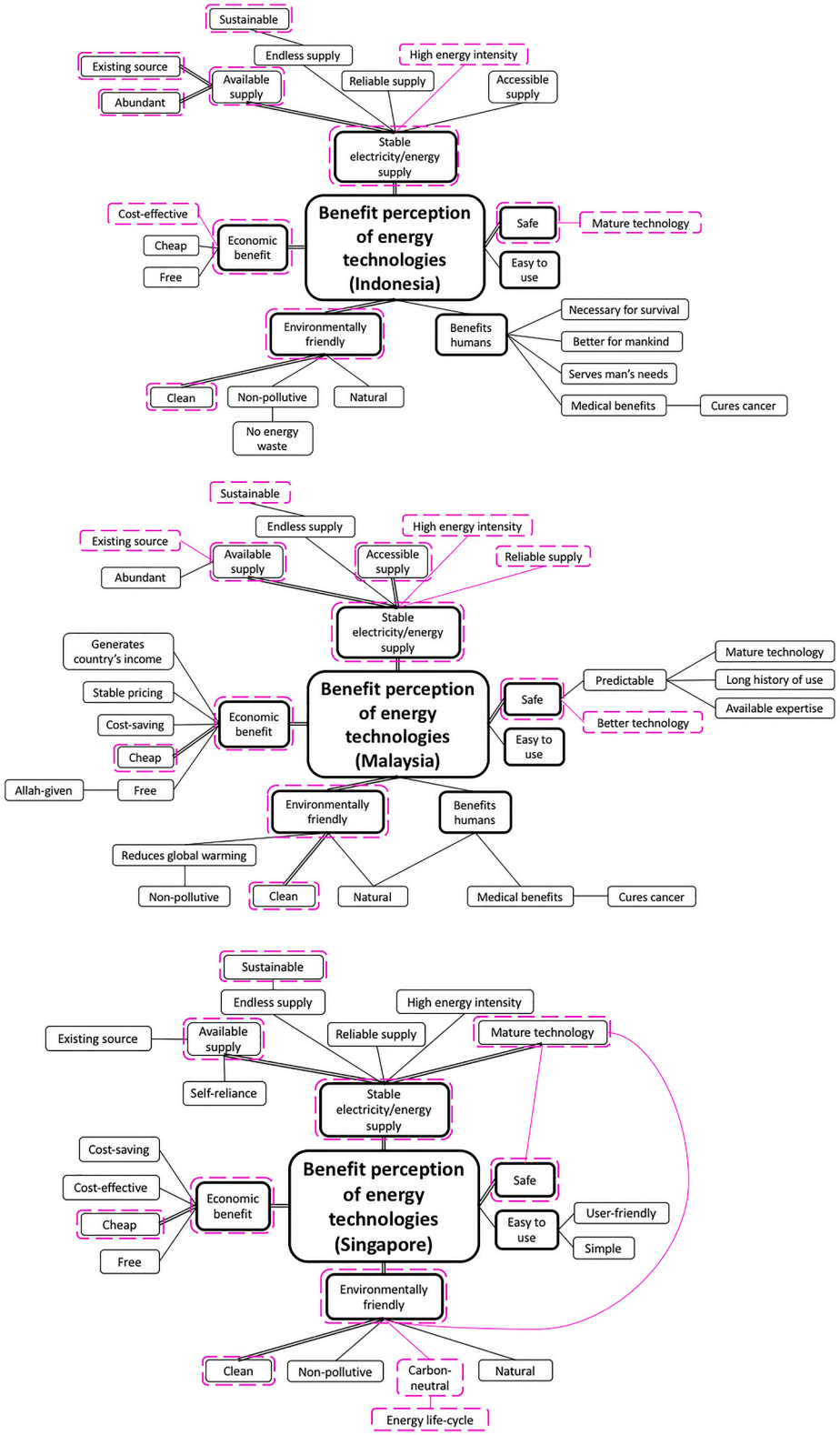


**Fig. 2.** Public's and energy experts' mental models in Indonesia, Malaysia, and Singapore: benefit perceptions of energy technologies.

benefits of an energy technology. The public's risk and benefit perceptions about energy security, economic impacts, and environmental impacts were centered around stable/disrupted energy supply, economic benefits/losses, and environmental friendliness/damage. The safeness of an energy technology was perceived to be a key benefit; on the same spectrum, the compromise of safety – in terms of harm to humans – was perceived to be a key risk. Notably, the mental models showed little variation in how people perceived safety; on the other hand, perceptions about the risk of harm to humans were elaborated, and mostly revolved around nuclear energy.

While broad considerations about energy are echoed in other parts of the world [9], our findings revealed nuances that are unique to each country studied. In Singapore, the public expressed concerns about the risk of geopolitical tensions that may arise with the deployment of nuclear energy – these concerns had not been brought up in discussions with the Indonesia and Malaysia public. We also observed that religious beliefs were mentioned in discussions on the benefits of renewable energy with the Indonesia and Malaysia public, as well as energy considerations that might have been shaped by personal values across the three countries. We discuss the following in more detail: the public's perceived risk of harm to humans, perceived risk of geopolitical tensions, and religious beliefs and personal values in risk and benefit perceptions.

#### 6.1.1. Perceived risk of harm to humans

When the public thought about the risks of an energy technology, their perceptions skewed towards how it might compromise the safety of humans, elaborating on the multiple ways that the technology can potentially cause direct harm to humans (e.g., explosions). This was particularly evident in discussions on nuclear energy, as participants drew on high-profile nuclear energy-related events that had happened in other countries – notably the Chernobyl and Fukushima nuclear accidents, and Hiroshima bombing – to articulate the risks that they perceived of it. Comparatively, discussions on how other energy technologies might similarly harm humans did not occur to the same extent, despite current evidence. For instance, there was little discussion surrounding the harms caused by fossil fuels, even though they have largely been linked to human deaths globally [59], and that the use of nuclear energy in some countries has prevented deaths that would have been caused by the use of fossil fuels [60].

The perceived risk of nuclear energy's harm to humans can be understood using the psychometric paradigm, which posits that lay people assess risks based on qualitative information, such as the perceived dreadfulness (dread risk, e.g., perceived lack of control, potential for a catastrophe, fatal consequences) and newness of a risk (unknown risk, e.g., unknown to science, unobservable) [61,62]; previous research has shown nuclear energy to be associated with these types of risks [9]. Since nuclear energy has not been implemented in Singapore and Malaysia, and is in the nascent stages in Indonesia, nuclear technology might be relatively unknown in the public sphere. Lay people's awareness of this novel and unobservable technology might have been informed by their existing knowledge and evaluation of past nuclear-related events, specifically the Chernobyl and Fukushima nuclear accidents. Particularly, past studies have shown that media coverage of such events tended to emphasize the potential detrimental effects of nuclear energy, while downplaying its benefits [63]. Using these as points of reference could have led participants to perceive nuclear energy to be a dreadful risk with potential for catastrophic and fatal consequences, prompting them to view nuclear energy technology as a particularly risky technology.

#### 6.1.2. Perceived risk of geopolitical tensions

Our results also showed that Singaporean public were concerned about potential geopolitical tensions should nuclear energy be used, as they were concerned that having to rely on others for the source of nuclear energy would compromise the country's energy security. As a small country situated near Indonesia and Malaysia, Singaporeans had concerns about strained relationships with neighboring countries. Their awareness that Singapore is a small country also seemed to have amplified their concerns about nuclear energy's potential to harm humans as well. These concerns could have arisen from place-based considerations, such as place-identity. Place-identity can be understood in terms of how a place influences a person's identity, or how a person ascribes meaning to a place based on its characteristics and constructs identity of a place (e.g., physical characteristics, historical associations); essentially, it encapsulates people's relationship with a place [64]. Changes to a place, whether physically or symbolically, can influence a person's identity and perceived identity of a place [64]. Previous research has shown that place-related factors, such as a place's historical associations with particular energy technologies and a community's need for economic development, can influence public perceptions of an energy technology [9]. The Singaporean participants' awareness of the country's geographical location and dependence on being well-connected to the rest of the world might have influenced their sense of vulnerability, thus shaping their perceptions of the risks of nuclear technology.

#### 6.1.3. Personal values and religious beliefs in risk and benefit perceptions

Some of the considerations that the participants had expressed reflect their value orientations. Values serve as people's guiding principles for their beliefs, attitudes, and behaviors [65], and have previously been studied in mental models [49]. Egoistic, altruistic, and biospheric values are of relevance in the energy context [13,66]. Those who have an egoistic value orientation tend to be concerned about their own interests, those with an altruistic value orientation are concerned about the welfare of others, while those with a biospheric value orientation are concerned about the biosphere [66]; people with different value orientations would consider the risks and benefits of an energy technology differently, relative to themselves (egoistic values), other people (altruistic values), or the environment (biospheric values) [13].

For instance, participants across the three countries consistently mentioned their concerns about whether an energy technology would harm (risk) or not harm (benefit) the environment, reflecting their biospheric values. Some Malaysian and Singaporean participants were also concerned about the impacts of an energy technology on their country's national economy, suggesting the role of altruistic values in their assessment of risks and benefits of an energy technology, as their concerns transcended their personal, immediate needs. Some Indonesian and Malaysian participants might have also been guided by egoistic values, as they had considered how an energy technology might benefit themselves as humans, serving their needs. Pertinent to the Indonesian and Malaysian contexts, where Islam plays an important role in the social fabric, the public had also intuitively relied on their religious beliefs to assess the risks and benefits of energy technologies. Islam views nature as providing for mankind, and activities that would destroy nature and mankind are forbidden [67]. This could have shaped public's perceptions of energy technologies, suggesting that their religious values had guided their understanding of risks and benefits in uncertainty, which, in this case, is novel energy technologies.

### 6.2. Comparing public's and energy experts' mental models

The public's mental models were extensive and diverse, while those of energy experts were comparatively more focused. In perceiving the risks and benefits of energy technologies, the public had relied on contextual factors and perceptions of past events, while energy experts had primarily relied on their topical knowledge and current evidence, such as the death statistics of nuclear-related events. This is in line with previous findings on how lay people and experts perceive risks [68].

Although the public's and energy experts' mental models showed that they had similar broad, overarching considerations related to energy security, economic and environmental impacts, and safety, they

differed in how they thought about each consideration (i.e., their mental representations). For instance, while economic loss was a common concern for the public and energy experts in terms of how expensive an energy technology might be, only the former was concerned that the nation's economy would be impacted by the adoption of particular energy technologies. Similarly, while environmental friendliness was a common consideration in terms of how clean an energy technology might be, the public had additional considerations, such as the naturalness of the technology. Divergences in the public's and energy experts' mental models might impede public communication, as there might be omission of crucial information to assuage public concerns in the process of communicating information from experts to the lay public, or that the public may not be receptive of the information communicated to them. Public communication on energy technologies should therefore be informed by the public's mental models, so that their concerns can be sufficiently addressed.

### 6.3. Analogies and misconceptions

The public's mental models revealed their use of analogies to infer risks, based on their existing knowledge. This is where misconceptions might arise, as their existing mental concepts might be flawed. As noted by Bostrom [50], using analogies to infer risks can be misleading. For example, the public in our study had used erroneous knowledge of Hiroshima bombing as an analogy for nuclear energy, resulting in concerns that nuclear energy might be weaponized. Nevertheless, the use of analogies can be a simple way to communicate risk. This was exemplified by the expert participants, who had used analogies based on their knowledge of current evidence to illustrate risks, for instance, by comparing radiation exposure from living near a nuclear plant to that from common, relatable events, such as taking a trans-continental flight or undergoing an X-Ray scan. Mental models are useful for identifying any flawed mental concepts and resultant misleading analogies.

### 6.4. Study limitations and implications

Our study is not without limitations. Its exploratory nature limits our ability to draw firm conclusions that can be generalized to the wider, national population. Moreover, our study participants resided in urban areas (i.e., Jakarta in Indonesia, Kuala Lumpur in Malaysia, and Singapore) – their perceptions of energy technologies might therefore differ from people who reside in rural areas. Nevertheless, the small group and organic discussions during the FGDs enabled us to gain in-depth, qualitative insights into how the Indonesian, Malaysian, and Singaporean public perceive the risks and benefits of energy technologies. Additionally, these findings could be extended to countries that are similar to Indonesia, Malaysia, and Singapore, in terms of culture, geography, economy, and other characteristics.

Future studies should attempt to include members of the public from more diverse backgrounds, age groups, and geographical regions to capture a broader range of viewpoints; with this wider diversity, additional focus groups could be conducted to allow for meaningful comparisons to be made, for instance, between age groups. To further the understanding of perceptions elicited in the current study, future studies should also employ quantitative research methods to examine them on a larger scale (e.g., national population), as well as to explicate the underlying mechanisms and factors that formed these perceptions. On a bigger scale, given the energy context in the whole of SEA and the increasing need for countries in the region to cooperate on energy issues [69], future studies should additionally examine public perceptions of energy technologies in other SEA countries.

Our study has important implications. Theoretically, our findings contributed to the current literature on sociocultural and psychological considerations in people's mental models, such as personal values and religious beliefs. The comparison of the public's mental models across Indonesia, Malaysia, and Singapore allowed us to examine these considerations across unique contexts, thereby broadening our understanding of the role they play in how people perceive energy technologies. Practically, the findings from our comparison of public and expert mental models can inform the design of communication strategies that the public can relate to, as well as the design of targeted communication to address important public concerns. First, the comparison of the public's and energy experts' mental models showed that the public had varied and diverse considerations when assessing the risks and benefits of an energy technology, and relied on more than just technical information about various energy technologies. Public policies and communication strategies should therefore also be informed by the public's mental models, incorporating sociocultural and psychological considerations, such as their personal values and acknowledging their place-identities. Second, our findings highlighted the existence of flawed analogies in the public's mental models, and how they had influenced their risk and benefit perceptions of various energy technologies. Since these analogies were based on past events, public communication strategies should also aim to correct misconceptions that the public have of past events.

## 7. Conclusion

Using mental models, our study shed light on how the public and energy experts in Indonesia, Malaysia, and Singapore perceived the risks and benefits of energy technologies. Although the public had broadly similar considerations, the mental models revealed that they had extensive and diverse risk and benefit perceptions, while the energy experts were more focused in these aspects. The public also emphasized an energy technology's risk of harm to humans, particularly for nuclear energy; this emphasis was not observed with the energy experts. Comparison of the public's and energy experts' mental models also revealed that contextual considerations, such as religious beliefs, had shaped the former's risk and benefit perceptions, while the latter had largely relied on an evidence-based approach. The public's misconceptions of energy technologies and information needs were also highlighted through this comparison. All in all, our findings can aid the design of effective public communication that can address public concerns and information needs appropriately.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2022.102500.

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