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Understanding Human Behavior to Improve Demand-side Energy Management

by Wipa Loengbudnark

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of Professor Alexey Voinov, Associate Professor Kaveh Khalilpour, and Dr Gnana Bharathy

University of Technology Sydney
Faculty of Engineering and Information Technology

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Wipa Loengbudnark, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abstract

Energy is crucial for all the fundamental aspects of our life. However, converting conventional energy resources into usable energy releases carbon dioxide and other greenhouse gases (GHGs) and pollutants into the atmosphere, leading to climate change and impacts on health and environment. Much effort has been spent on developing alternative technologies with a smaller carbon footprint and less detrimental to the climate. Several technologies have been invented to increase the efficiency of energy use and therefore minimize the energy demand. The idea is that every kilowatt of energy that is not used is not any different than a kilowatt of energy produced. Not using energy is an equally, perhaps even more, effective way to reduce climate change. However, energy demand reduction is very much related to human choices and preferences and cannot be achieved if people do not support it. The behavior of energy users plays an important role in minimizing carbon emissions. This behavior matters both for saving energy, reducing energy demand as well as switching to renewable and less polluting sources of energy.

This thesis seeks to understand factors that influence energy-related behavior in two levels, namely individual and collective, using three contexts as case studies: transportation, household, and work environments. More specifically,

- In case of transportation, this thesis examines factors that influence electric vehicle (EV) purchase intention among Australian consumers. Further, it examines which factors influence the preferences for one of the two types of EVs: battery-powered EVs, and hydrogen fuel cell EVs (Chapter 2). This represents lifestyle choices that can be considered individual behaviors.
- Next, examining factors influencing EV purchase intention, we expand to consumers in other locations in addition to Australia, including the UK, Germany, Poland, Greece, Singapore, and two US states: California and Mississippi. This allows us to understand the impact of contextual factors in influencing consumers' attitudes (Chapter 3).
- In terms of residential human behavior, this thesis examines factors influencing Australian consumer attitudes to community renewable energy. It also seeks to understand the impact of situational factors that vary across Australian states and territories in influencing attitudes to community renewable energy (Chapter 4). This chapter represents collective behaviors that can result in structural or system changes and can benefit the entire community.
- In the context of work environments, this thesis seeks to design behavioral intervention strategies that can decrease energy consumption without compromising user satisfaction. It analyzes how occupants' controllability over energy-consuming equipment in their working areas can affect their satisfaction, perceived productivity, and building energy demand. It also

examines the energy-saving potential of allowing occupants to control their lights instead of the automatic control (Chapter 5).

The findings of this thesis provide a better understanding of the factors behind particular energy-related behaviors. They also emphasize heterogeneity that exists among energy users at various levels.

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1 INTRODUCTION

"Engineers do innovative things, and that's still continuing,

but engineers are not great at understanding human behavior.

They'd make these rational arguments about saving money or energy,

and people would say, 'That's great!' But people didn't change."

Susan Mazur-Stommen

Director of the Behavior and Human Dimensions Program,

American Council for an Energy-Efficient Economy

1.1 Motivation for the research

Although energy may not be the answer to every issue in the world, it is undeniable that energy plays a significant role in all the fundamental aspects of our life. Energy provides water, produces food, facilitates transportation, houses people, maintains health, enables education, and promotes welfare (Ulgiati et al., 2022). Since the start of the industrial revolution, significant societal transformations have occurred, while the population has been growing exponentially. A significant amount of energy is required to power various modern-day amenities, including heating and cooling, electronic gadgets, lighting systems, home appliances, and transportation (Pasten & Santamarina, 2012). So far most of it has been provided primarily by fossil fuels. In fact, it is fossil fuels that have made much of our technological progress possible. The capability of extracting, transforming, and utilizing energy from different sources has ensured the survival and progression of human civilization (Ulgiati et al., 2019). However, these processes release carbon dioxide and other greenhouse gases (GHGs) into the atmosphere. These gases trap heat from the sun and cause the Earth's temperature to rise. The rising temperature leads to climate change which causes a range of negative impacts, including sea level rise, more frequent and intense heatwaves, more severe weather events such as hurricanes and droughts, and changes in precipitation patterns. These changes are having significant impacts on human societies and ecosystems.

In order to address climate change, several attempts have been made to minimize the reliance on fossil fuel-based energy. This can be accomplished by transitioning to cleaner energy sources, such as renewable energy sources, like solar and wind, and improving energy efficiency in buildings, transportation, and industry. All these require innovations in energy generation (e.g., photovoltaics (PV), solar thermal, and wind turbine), storage (e.g., stationary batteries or those in electric vehicles), and consumption (e.g., more efficient lighting and appliances). However, without energy users' support, engagement, and optimal use, technology cannot reduce energy demand. The Intergovernmental Panel on Climate Change (IPCC) acknowledges that human behavior, including consumption patterns and lifestyle choices, plays a significant role in climate change (IPCC, 2022). The IPCC has also stressed that changes in societal norms and human behavior are crucial in achieving the objectives of the Paris Agreement and mitigating the consequences of climate change. Thus, it is crucial to understand the factors and policies that can motivate, encourage, and facilitate energy users to support, engage, and optimally use a wide range of sustainable energy technologies. To address this challenge, this thesis investigates the influential factors of energy-related behavior in a wide range of contexts: on the road, at home, and in the office.

1.2 Background

Energy systems can be divided into two different perspectives, namely supply-side and demand-side. The supply-side perspective focuses on the production and distribution of energy resources to meet demand, which is taken as a given. It emphasizes expanding and diversifying the sources of energy supply, increasing their efficiency, optimizing their performance to ensure a reliable and resilient energy infrastructure. In contrast, the demand-side perspective centers on the end-users of energy and aims to optimize energy consumption, decrease demand, and promote conservation and savings.

This section provides an overview of the energy conversion chain, the connection between supply-side and demand-side perspectives, the technology that are used to conserve energy, the roles of end-users to minimize demand for energy, and the science behind end-users' behavior.

1.2.1 Energy conversion chain

Although it is widely known that energy is used to fulfill human well-being, it is not energy itself that humans desire but the services it provides (Fell, 2017). Before energy can provide services to humans, there are several processes involved. These processes span from extracting primary energy resources, converting them into utilizable energy forms, delivering them to the users, and converting them into energy services (Figure 1).

Like any other system, all energy conversion processes are not possible to be 100% efficient. There are losses throughout the process. Figure 2 illustrates an example of losses in the energy conversion chain from coal (primary energy) to illumination (service provided to humans). Initially, 100 units of energy were inputted, but 65 units were wasted at the source due to generation inefficiencies and heat loss. In addition, five units were lost during the transmission and distribution process through the high-voltage power grid. Therefore, only 30 units were available for end-use. However, due to an inefficient end-use and conversion process of incandescent lamps, 28 units were wasted. As a result, only three units of energy service were provided at the end-use, meaning that 97 units were wasted.

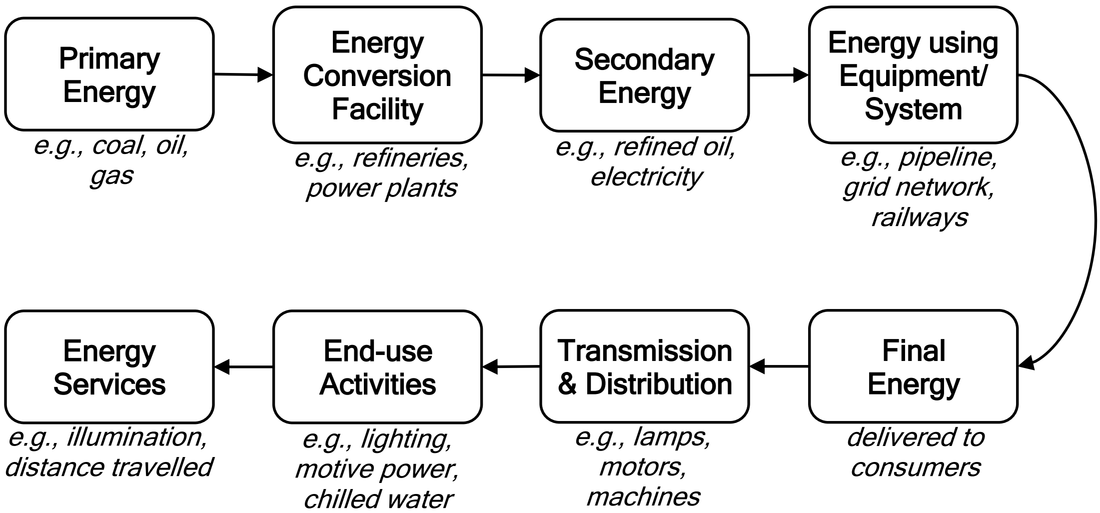

Figure 1 The energy conversion chain from supply to end-use (adapted from Mohanty (2012))

It can be seen that to provide small units of energy service at the consumer side, a larger amount of primary energy is required. How much primary energy is required depends on the efficiency of all the machines, equipment, or systems involved in the conversion chain. Conversely, saving small units of energy at the end-user can save a considerable amount of primary energy. Therefore, when end-users conserve energy, it significantly saves production, transmission, and distribution, regardless of the resource system (Mohanty, 2012).

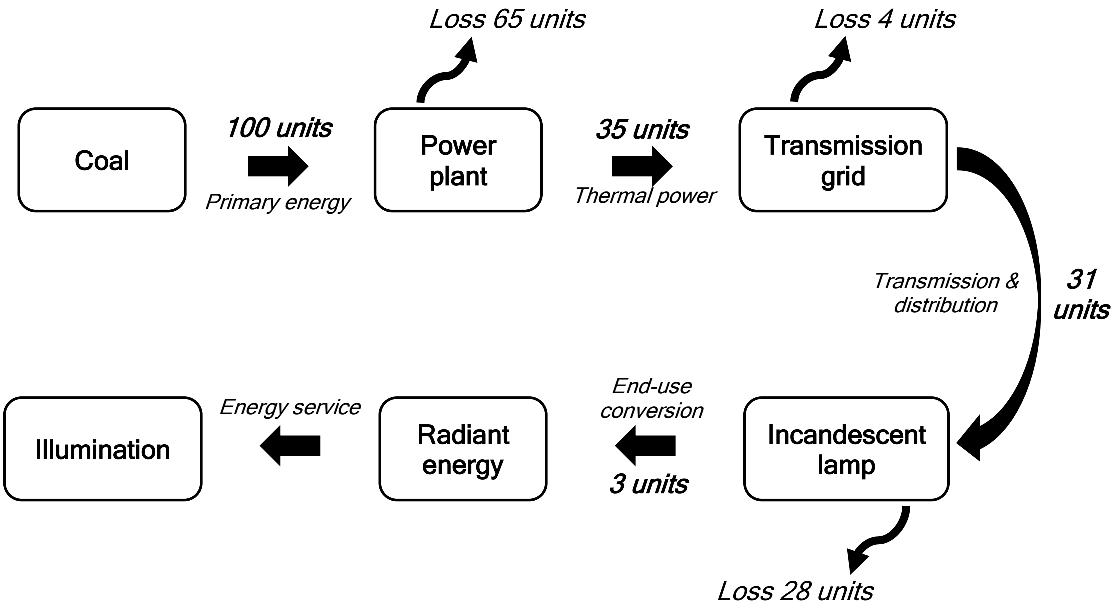

Figure 2 Example of losses in the energy conversion chain from coal (primary energy) to illumination (service provided to humans) (adapted from Mohanty (2012))

1.2.2 Low-carbon energy technology

Low-carbon energy technology is the technology that emits little or no CO_2 and pollutants (IEA, 2020). It could be the technologies that convert energy from renewable sources into other forms of energy or the technologies that improve the efficiency of converting energy into end-used services.

Renewable energy technologies offer technological alternatives to fossil fuel-based primary energy. One of the well-known renewable energy technologies is PV which converts sunlight into electrical energy. Solar energy can also be applied to the thermal application using solar thermal collectors to collect heat from sunlight. Another widely used renewable energy is wind energy. Wind turbines are used to transform the motion energy of air into mechanical energy and then convert it into electrical energy (Halkos & Gkampoura, 2020).

Renewable energy potential varies across locations. Solar and wind energy are considered variable renewable energy sources because they are not constant and cannot be controlled. The local weather and geological conditions affect power generation from these sources, leading to unpredictable fluctuations (Xu et al., 2022). Prolonged periods of unpredictable weather can result in an energy shortage (Halkos & Gkampoura, 2020). This led to challenges in grid management and energy storage system (Marocco et al., 2023). As a result, demand for energy storage systems is expected to increase in the coming years.

In addition to renewable energy technology, there is also a range of technologies with improved energy efficiency. These improved technologies consume less energy while not compromising services provided to humans. For example, a huge improvement in the light bulb. From 60-watt incandescent to 14-watt compact fluorescent, and recently 7-watt light-emitting diode (LED) with the same amount of light. Another example is the transition from internal combustion engine vehicles to hybrid and fully electric vehicles. Hybrid vehicles combine an electric motor with a gasoline or diesel engine, resulting in better fuel efficiency and lower emissions than traditional vehicles. Electric vehicles run solely on electricity and emit no tailpipe emissions. Both vehicles can significantly reduce the amount of fuel consumed and emissions produced compared to traditional gasoline or diesel vehicles.

1.2.3 Energy-related behavior

As discussed earlier, energy-saving (or wasting) behavior at the end of the energy conversion chain (the end-users) will result in a decrease (or increase) in the larger amount of primary energy required. The innovative energy technologies discussed in the previous section can reach their maximum energy efficiency only if there is support from energy users and they are used properly. According to the International Energy Agency, energy-related behavior is defined as any human activity that affects the utilization of various fuels (electricity, gas, petroleum, coal, etc.). These activities include the procurement or disposal of energy-related materials and technologies, how they are used, and the cognitive processes involved in those actions (IEA-DSM, 2015).

Energy-related behavior can be at both individual and collective levels. Individual energy behavior refers to action taken by one individual, including when people purchase new energy-consuming products or services, decide whether to repair, maintain, or upgrade energy-consuming devices, or how they use buildings, transportation, and equipment (Ando et al., 2010; Lacroix et al., 2022). Consumers' decision to purchase energy-efficient technologies may be associated with several drivers and barriers. The deployment of these technologies needs to facilitate drivers and address barriers. Furthermore, there may be the energy rebound effects once the efficiency is improved. A decline in energy cost due to improved efficiency leads to changes in consumer behaviors, followed by an increase in energy consumption. William Stanley Jevons argued that when energy efficiency increases by 1%, a reduction in energy consumption is often less than 1% (Zhang & Peng, 2017). Therefore, there is room for non-technical options to improve the energy conversion chain. For example, in the case of energy use in buildings, previous research shows massive energy-saving opportunities through a greater understanding of how buildings are used (Naylor et al., 2018).

While individual actions play a significant role in mitigating climate change, it is important to foster collective actions to encourage such behaviors among the wider society (Ando et al., 2010). Collective energy behavior refers to actions that aim to influence others' behavior by joining existing actions that others are already engaged in or convincing others to take action (Lacroix et al., 2022). Compared to individual actions, collective behaviors involve more complex social dilemma aspects as they require participants' time, effort, and emotional investment. Nevertheless, the benefits of such behaviors extend to the entire community (Ando et al., 2010). In the long run, individual-level behaviors are similar to changes in one's lifestyle, while collective-level behaviors are a part of structural or system changes (Lacroix et al., 2022).

1.2.4 Behavioral theories

To understand energy-related behavior and how it can be changed, it is crucial to know the science of human behavior. The literature on factors influencing energy-related behavior can be categorized into two groups with some overlapping. One stems from social sciences, which provides insights into human behavior. The other one stems from the economics of human behavior, which emphasizes that human behavior deviates from the standard economics notion of rationality (Kok et al., 2011).

In social sciences, one of the most frequently used theories to explain human behavior is the theory of reason action (TRA). Fishbein and Ajzen (1975) proposed TRA, which suggests that an individual's behavior is determined by their intention to carry out that behavior. This intention, in turn, is influenced by their attitude towards the behavior and the subjective norms surrounding it. Later, Ajzen (1991) extended TRA to develop the theory of planned behavior (TPB). TPB proposed that desired behavior is derived from an intention to perform that particular behavior. An intention is driven by three key elements: attitude, subjective norm, and perceived behavioral control. Attitude is a personal belief toward a particular behavior. At the same time, the subjective norm is a perception that significant others, people who are important to them, expect that individuals should (or should not) choose that particular behavior. Perceived behavioral control is defined as the level of ability, which individuals have to perform a behavior.

Another theory that extends TRA is the technology acceptance model (TAM) proposed by Davis (1989). TAM describes how the opinions of potential users influence the acceptance of particular technologies. User attitudes and intentions to adopt a new technology are impacted by two psychological factors: perceived usefulness and ease of use. Attitude, in this context, refers to the evaluation of a specific technology that can either positively or negatively influence the intention to accept and use the technology.

In addition, there is the rational choice theory (RCT) originated from Smith (1776). A fundamental aspect of RCT is that individuals possess perfect information regarding the benefits and costs of their decision, enabling them to make optimal choices that maximize their utility (Welsch & Kühling, 2011). Furthermore, RCT also based on fundamental principles that choices are consistent and transitive. Transitivity of choice implies that if an individual likes choice A more than choice B, and choice B more than choice C, then they would also prefer choice A over choice C (Browne et al., 2010). Consistency of choice can be described as the act of selecting the same choice throughout all instances of repetition (Alós-Ferrer & Garagnani, 2021). However, RCT faced criticism and refinement overtime. One of the criticisms is that there have been evidences of behavior failures which systematically deviate from the core of RCT, as explored and categorized by behavioral economics (Welsch & Kühling, 2011).

The behavioral economics model emphasizes that human behavior deviates from the standard economics notion of rationality. One important highlight is the idea of bounded rationality, which argues that humans rarely make decisions rationally (Frederiks et al., 2015). There are biases that stem from culture, tradition (the rule of thumb), heuristics, and mental shortcuts. Even people with sufficient knowledge and motivation to act in pro-environmental ways may not do what their knowledge and motivation would imply. As can be seen in many domains of human behavior, there are knowledge-action gaps (Knutti, 2019), value-action gaps (Chai et al., 2015), attitude-action gaps (Zhang et al., 2021), and intention-action gaps (He et al., 2023), which all distance the actual actions of humans from their various inclinations and stimuli.

1.3 Research goal

The main goal of this research is to understand and quantify factors influencing energy-related preferences and behaviors in order to inform decision-making and management. While energy is primarily viewed through an engineering and technology angle, understanding human behavior is mainly explored by social sciences. Linking these two disciplines is challenging but essential to improve demand-side energy management.

1.4 Objectives

There are three specific objectives of this research, which we intend to achieve by answering the respective research questions.

1. Identify factors that influence individual energy behavior. We focus on analyzing individual purchase behavior for electric vehicles (EV), seeing them as an example of a change in energy related behavior. To address this objective, we consider the following research questions:

1.1 What behavioral theories can conceptualize individuals' decision-making process regarding EV purchasing?

1.2 What is the relative contribution of different factors on EV purchase decisions? What factors are most important?

1.3 What contextual factors play a role in EV purchase decisions?

2. Identify factors that influence collective energy behavior. In this case we choose to look at how renewable energy projects are considered in a community level, looking at Community Renewable Energy (CRE). To address this objective, we consider the following research questions:

2.1 What behavioral theories can conceptualize the formation of attitudes toward CRE projects? What are the prevailing attitudes in different communities?

2.2 What is the relative contribution of different factors on attitude toward CRE projects? What factors are most important?

2.3 What situational factors affect attitude toward CRE projects?

3. Design behavioral intervention strategies that can decrease energy consumption without compromising user satisfaction. This time our case study is building environments, looking at results from a survey and experiments in university buildings. To address this objective, we consider the following research questions:

3.1 To what extent controllability over energy-consuming systems in buildings influences building users' satisfaction and perceived productivity?

3.2 What are the ways that user behavior can be modified?

3.3 To what extent does the changed behavior impact energy use?

1.5 Overall methodology

This thesis is aligned with the post-positivism research paradigm. It is based on the ontology (nature of reality) that there exists a social reality that is stable and patterned enough to be known (Bisel & Adame, 2017). This social reality is viewed as cohesive, whole, and singular. Furthermore, based on epistemology (nature of knowledge), social reality can be understood and quantified through measurement, although it may be challenging to access (Bisel & Adame, 2017). Post-positivism recognizes that knowledge is not generalizable to all cases and situations universally (Clark, 1998). Findings are considered to be linked to their context and can be applied with reference to similar cases elsewhere.

This thesis follows an abductive research approach. That is, we modified theories with some relevant factors and went for empirical testing. The methodological approach of this thesis is quantitative. The advantage of the quantitative approach is that quantitative data can be interpreted using statistics, which can be considered scientifically objective (Hackett, 2018). It also increases the validity of decision-making preparation (Csutora et al., 2021).

The research design of this thesis is the multiple-method design. However, the primary research strategy of this thesis is the survey approach. The survey approach is a proper methodology for this thesis as it allows us to discover various social, contextual, or group interactions that influence behavior and motivate individuals (D'Oca et al., 2016; Hong et al., 2017). The primary analysis technique is Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS software (Ringle et al., 2015). The rational for choosing PLS-SEM is that SEM provides the capability to create latent variables based on observed variables (Chin & Marcoulides, 1998). The PLS approach is appropriate when focusing on prediction rather than theory testing (Reinartz et al., 2009).

In addition to the survey approach, there is also experimentation involved. The experiment collects behavioral data by observing participant choices, which are “revealed preference”. While the surveys are “stated preferences” methods where participants are asked to express their opinions and preferences on a particular topic, the revealed preference approach involve observing people's behavior in naturally occurring situations or natural settings.

The overall methodology of this thesis is summarized in Figure 3.

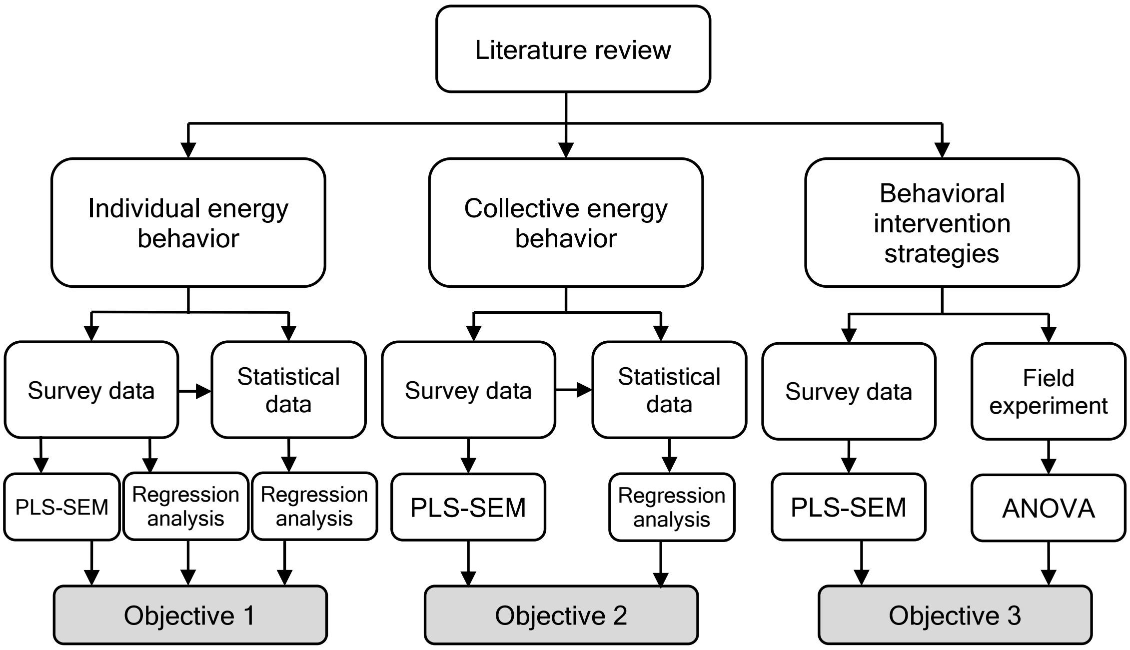

Figure 3 Overall methodology

1.5.1 Key characteristics and limitations of the methodological approach used

Stated preference and revealed preference approach have different characteristics and limitations. The stated preference approach depends on hypothetical questions that directly ask people about their values or that ask them about how they might act or decide under different circumstances (Mendelsohn, 2019). The advantage of asking hypothetical questions is that it allows asking about any value or behavior in new or unusual scenarios that are otherwise challenging to measure. However, there are circumstances where the stated preferences of participants do not align with their actual preference (Wardman, 1988) or actual behavior (Ajzen, 2005). This may be because of systematic bias in the responses (Wardman, 1988). It can also be because people may not be aware of how they would react in unfamiliar hypothetical scenarios (Mendelsohn, 2019). Besides, sometimes, they do not want to share their genuine intention.

On the other hand, revealed preference measures the value people place on something based on their observed behavior. Observational data is relatively unbiased compared to stated preference, as it is not influenced by factors such as the desire to be socially accepted, or the emotional state of the respondents (Nock & Kurtz, 2005). Nevertheless, challenge of revealed preference studies is that data are from uncontrolled settings. Since many factors could potentially be correlated with the thing being studied, the studies may be biased (Mendelsohn, 2019). Furthermore, studies based on revealed preferences are vulnerable to the influence of researchers, given the numerous assumptions required in each empirical analysis (Mendelsohn, 2019).

1.6 Outline of the thesis

The thesis comprises six chapters and is structured as a compilation of papers (Figure 4). Apart from the introduction (Chapter 1) and conclusion (Chapter 6), four chapters are stand-alone papers in different states of publication (Chapter 2 to Chapter 5). These four chapters have their own introduction, literature review, methodology, and discussion.

Chapter 1 introduces an overview of the thesis, including the motivation, background, research objectives, and overall methodology.

Chapter 2 and Chapter 3 deal with individual energy-related behavior in transportation. Chapter 2 presents an empirical analysis of factors influencing the EV purchase intention of Australian consumers. Chapter 3 expands to consumers from seven locations in addition to Australia, including the UK, Germany, Poland, Greece, Singapore, and two US states: California and Mississippi.

Chapter 4 looks at collective residential energy-related behavior. This chapter empirically analyzes factors influencing Australian consumers' attitudes toward community renewable energy. Unlike the previous chapters that represent the personal lifestyle choices, the collective behavior involves broader aspects and can result in structural or system changes that can benefit society as a whole.

In Chapter 5 we look at practical solutions that can be implemented to change consumer behavior and save energy, without compromising user satisfaction. Here we focus on behavioral intervention strategies in workplace environments. This chapter analyzes the impact of occupants' controllability on satisfaction, productivity, and energy-saving potential. We describe a related experiment conducted at University of Technology Sydney.

Chapter 6 summarizes the findings, clarifies the contributions, identifies implications, and points out the recommendations for future research.

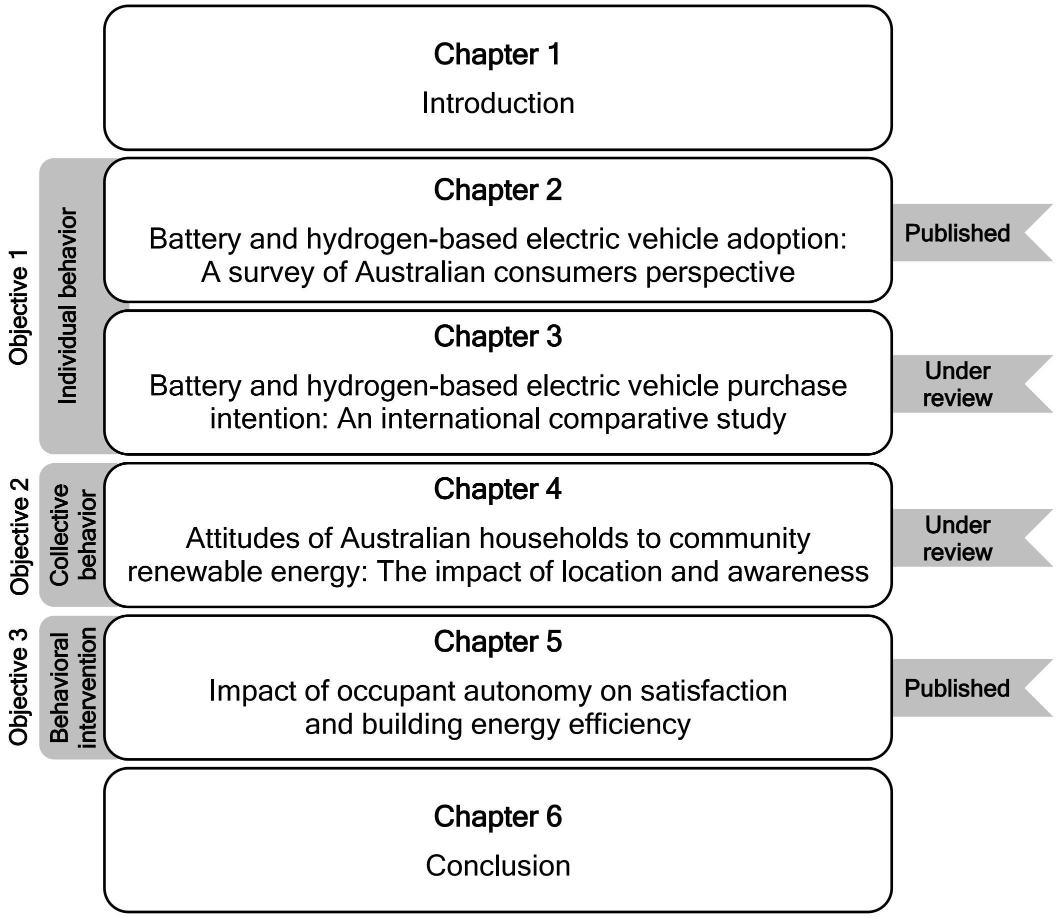

Figure 4 The layout of the thesis

2 BATTERY AND HYDROGEN-BASED ELECTRIC VEHICLE ADOPTION: A SURVEY OF AUSTRALIAN CONSUMERS PERSPECTIVE

[Production note: This picture is not included in this digital copy due to copyright restrictions.

Frits Ahlefeldt

(Ahlefeldt, 2019)

2.1 Preamble

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Abstract

Electric vehicles (EV) are a promising alternative for the current fossil-fuel-based vehicles. However, as of 2020, the share of EV sales was only 4.6 % globally, and 1 % in Australia. It is important to identify factors that promote or hinder consumer intentions of EV adoption. In addition, there are a few types of EVs, each with different advantages and disadvantages creating consumer segmentation. This study considered battery-powered EV and hydrogen fuel cell EV and sought to understand which factors influence the preferences for one of the two types of vehicles. We designed a survey on individual perceptions toward EV and collected data of 1735 consumers in Australia. Participants had a mean age of 44.9 years (SD = 16.71) and 41 % of them were males. The median daily traveling distance was 8.7 km, and 74 % of them reported using a personal car for commuting. The results show that the safety concern has a stronger impact on adoption intention than the purchase cost and perceived benefits. Age and consumers' current mode of transportation play a significant role in EV adoption intentions. In addition, the results indicate that preference for BEV is significantly affected by BEV range sufficiency, tolerability in battery charging time, and fear of hydrogen explosion, whereas the key preference factors for FCEVs is their longer driving range, and fear of battery explosion. Besides, the results reveal

that part-time employees are more likely to prefer BEV than full-time workers. On the other hand, apartment residents tend to prefer FCEV more than people living in a house. Furthermore, female is more likely to still undecided than males whether they prefer BEV or FCEV.

Findings

In the previous chapter,

The motivation for the research, the background, the research objectives, and the overall methodology were introduced. The background information describes the energy conversion chain from supply to end-use, highlighting how end-users are essential in reducing energy demand.

In this chapter,

The focus is on individual energy behavior in the road context, specifically on EV, which are more energy efficient than conventional internal combustion vehicles, and can be run on renewable energy. This chapter analyzes which factors promote or hinder Australian consumers' preference for EV over conventional internal combustion vehicles. Separately, it analyzes which factors affect the preferences for one of the two types of EV: battery-powered EV and hydrogen fuel cell EV. It should be noted that the question about preferences between BEV and FCEV is presented to all respondents, regardless of whether they indicated a preference for EVs or conventional vehicles. This is our intention to comprehend respondents' preferences under the scenario where only EVs are available as options.

To help respondents better visualize the concept, three car models were selected to represent three different engine types, namely (1) Toyota Corolla Sedan 1.6 represents internal combustion engine vehicle, (2) Nissan Leaf S represents battery-powered EV, and (3) Toyota Mirai represents hydrogen fuel cell EV. The rationale for selecting the Toyota Corolla Sedan 1.6 to symbolize internal combustion engine vehicles stems from the fact that Toyota is the most favorite car in Australia (ABS, 2021c) and the Corolla Sedan 1.6 is categorized as a medium-sized car (as classified by the European Commission). This choice mitigates the potential influence of luxury. Similarly, in the realm of battery-powered EVs, the Nissan Leaf S was chosen over alternatives with longer ranges and faster charging times (such as Tesla Model S) because we want to avoid luxury-related factors. Furthermore, the price of Nissan Leaf is more affordable than Tesla Model S. As a result, it is more comparable to conventional vehicle than Tesla. Regarding hydrogen fuel cell EV, Toyota Mirai was chosen as a representative because it is the only sedan-style hydrogen fuel cell EV that commercially available in the market at the time of the study (Asif & Schmidt, 2021). Honda Clarity was available but for lease only (Asif & Schmidt, 2021). Meanwhile, Hyundai offers Hyundai Tucson and Hyundai Nexo (Asif & Schmidt, 2021), both of which fall into the category of Sport Utility Vehicle. Thus, to ensure comparability across the three engine types, Toyota Mirai was chosen as a hydrogen fuel cell EV representative.

The main findings of this chapter are

1. Safety concerns have a stronger impact on adoption intention than the purchase cost and perceived benefits. These findings are consistent with She et

al. (2017) which found that safety is the most important barrier to the adoption of zero-emission vehicles. They are also consistent with Orlov and Kallbekken (2019) which found that financial and environmental benefits of EV are not the main drivers for the adoption. The strong impact of safety concern on EV adoption intention can be understood from two aspect. First, our study not only focuses on BEV, but also includes FCEV, which may be less familiar to most of the respondents. This broader inclusion highlights that EVs are less developed compared to conventional vehicles. According to Rogers et al. (2014), most of the population (which are the majority adopters) are more cautious about risks and are hesitant to buy innovative products that significantly deviate from the prevailing designs. Second, while there are only a few financial incentive policies in place (Electric Vehicle Council, 2020), measures addressing safety concerns are absent. Thus, safety issues related to EVs are likely to be met with more skepticism compared to financial considerations.

2. Age and consumers' current mode of transportation play a significant role in EV adoption intentions.

3. Preference for BEV is affected by BEV range sufficiency, tolerability in battery charging time, and fear of hydrogen explosion.

4. Preference for FCEVs is affected by the longer driving range and fear of battery explosion.

5. Part-time employees tend to prefer BEV more than full-time workers.

6. Apartment residents tend to prefer FCEV more than people living in a house.

7. Females tend to be more undecided than males about whether they prefer BEV or FCEV.

In the next chapter,

The analysis of factors that influence EV purchase intention is expanded to consumers in other locations besides Australia, namely the UK, Germany, Poland, Greece, Singapore, and two US states: California and Mississippi. The attitude toward EV of consumers from eight different locations is compared. We explore the differences in influential factors of EV purchase intention between participants who intend to purchase EVs and those who do not. Furthermore, the impact of contextual factors, namely gasoline affordability, environmental values, and road traffic death rate, are examined.

Author Contributions

Wipa Loengbudnark: Conceptualization, Methodology, Formal analysis, Investigation, Data Curation, Writing – original draft, Visualization. **Kaveh Khalilpour:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Gnana Bharathy:** Methodology, Writing – review & editing, Supervision. **Firouzeh Taghikhah:** Conceptualization, Writing – review & editing. **Alexey Voinov:** Conceptualization, Writing – review & editing, Supervision.

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Battery and hydrogen-based electric vehicle adoption: A survey of Australian consumers perspective

Wipa Loengbudnark [a,*], Kaveh Khalilpour [a], Gnana Bharathy [a], Firouzeh Taghikhah [c], Alexey Voinov [b]

[a] Faculty of Engineering & IT, University of Technology Sydney, Australia
[b] Faculty of Engineering Technology, University of Twente, Netherlands
[c] Discipline of Business Analytics, University of Sydney, Australia

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Adoption intention

ABSTRACT

Electric vehicles (EV) are a promising alternative for the current fossil-fuel-based vehicles. However, as of 2020, the share of EV sales was only 4.6 % globally, and 1 % in Australia. It is important to identify factors that promote or hinder consumer intentions of EV adoption. In addition, there are a few types of EVs, each with different advantages and disadvantages creating consumer segmentation. This study considered battery-powered EV and hydrogen fuel cell EV and sought to understand which factors influence the preferences for one of the two types of vehicles. We designed a survey on individual perceptions toward EV and collected data of 1735 consumers in Australia. Participants had a mean age of 44.9 years (SD = 16.71) and 41 % of them were males. The median daily traveling distances was 8.7 km, and 74 % of them reported using a personal car for commuting. The results show that the safety concern has a stronger impact on adoption intention than the purchase cost and perceived benefits. Age and consumers' current mode of transportation play a significant role in EV adoption intentions. In addition, the results indicate that preference for BEV is significantly affected by BEV range sufficiency, tolerability in battery charging time, and fear of hydrogen explosion, whereas the key preference factors for FCEVs is their longer driving range, and fear of battery explosion. Besides, the results reveal that part-time employees are more likely to prefer BEV than full-time workers. On the other hand, apartment residents tend to prefer FCEV more than people living in a house. Furthermore, female is more likely to still undecided than males whether they prefer BEV or FCEV.

* Corresponding author.
E-mail address: Wipa.Loengbudnark@student.uts.edu.au (W. Loengbudnark).

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3 BATTERY AND HYDROGEN-BASED ELECTRIC VEHICLE PURCHASE INTENTION: AN INTERNATIONAL COMPARATIVE STUDY

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Frits Ahlefeldt

(Ahlefeldt, 2021)

3.1 Preamble

Status

Paper Status

Under review, *Energy Policy*

Abstract

A cross regional survey was conducted to understand how various factors can influence the intention to purchase electric vehicles (EVs), distinguishing between battery and hydrogen powered EVs. Data were collected from 4985 respondents from Australia (n = 1735), UK (n = 475), Germany (n= 475), Poland (n = 500), Greece (n = 500), Singapore (n = 500), and two US states: California (n = 500), and Mississippi (n = 300). We found that Greece has the highest preference for EVs, whereas Mississippi has the lowest. We compared participants who intend to purchase EVs and those who do not. The results show that participants who intend to purchase EVs are sensitive to the benefits of EVs, while those who do not intend to purchase care more about the cost. Regardless of cultural background and purchase intention, safety concerns play a significant role in EVs purchase intention. We found a consistent cross-national pattern that consumers who do not mind longer battery charging time are more likely to prefer battery-powered EVs, while people who are concerned with hydrogen tank safety are less likely to prefer fuel cell EVs. Mississippi shows major differences with other places which can be explained by the contextual differences. We estimated the impact of contextual factors, such as gasoline affordability, environmental values, and road traffic death rate, on EVs purchase intention. The empirical results provide policy implication.

Findings

In the previous chapter,

The factors that influence Australian consumers' intention to purchase EV, and the factors that influence preference for battery-powered EV and hydrogen fuel cell EV were examined. Several factors, both attitudinal and socio-economic, were influential on consumer preferences.

In this chapter,

The main emphasis is still on people's willingness to purchase EV. However, the research will now cover a broader range of consumers across different locations and cultural backgrounds, including Australia, the UK, Germany, Poland, Greece, Singapore, and two states in the US: California and Mississippi. This chapter examines the differences between participants who intend to buy EVs and those who do not and compares their responses across the eight locations. Additionally, the chapter will investigate how contextual factors in different locations, such as the affordability of gasoline, environmental values, and road traffic death rates affect people's willingness to purchase EVs.

The main findings of this chapter are

1. Safety concerns play a significant role in EVs purchase intention regardless of cultural background, location, and purchase intention.
2. Participants who intend to purchase EVs are sensitive to the benefits of EVs.
3. Participants who do not intend to purchase EVs care more about the cost.
4. Participants who do not mind longer battery charging time are more likely to prefer battery-powered EVs. At the same time, people who are concerned with hydrogen tank safety are less likely to prefer fuel cell EVs.
5. Gasoline affordability in different locations is inversely correlated with the preference for EVs over conventional vehicles.
6. Environmental values are correlated with the perceived benefits of EVs.

7. Road traffic death rates in different locations are correlated with safety concerns.

In the next chapter,

The focus will be on collective energy-related behavior in household context which involves broader aspects and can result in structural or system changes that can benefit society as a whole. The chapter investigates the impact of climate change concern, attitude to renewable energy, sense of community, and perceived community benefits in influencing attitude to community renewable energy. In addition, it also examines the role of location and renewable energy awareness in influencing a positive attitude to community renewable energy.

Author Contributions

Wipa Loengbudnark: Conceptualization, Methodology, Formal analysis, Investigation, Data Curation, Writing – original draft, Visualization. **Kaveh Khalilpour:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Gnana Bharathy:** Methodology, Writing – review & editing, Supervision. **Alexey Voinov:** Conceptualization, Writing – review & editing, Supervision.

3.2 Introduction

Transportation is one of the important indicators of life quality (Rao & Min, 2018). Availability of motorized transport provides mobility to people to work away from their home or access markets and services. Without that, people would be restricted to limited areas around their homes. On the other hand, transportation was responsible for up to 37% of CO_2 emissions globally in 2021 (IEA, 2022). Although alternative fuel vehicles have started to appear, such as electric vehicles (EVs), their uptake remains limited and gasoline[1] is likely to still be the predominant energy source within the transportation sector for the next decades (Rosales Carreón & Worrell, 2018).

EVs are technically different from the internal combustion engine (ICE) vehicles (Jena, 2020). EVs are driven partly or solely by one or more electric motors (Boriboonsomsin, 2021). There are several types of EVs, depending on the source of electricity used to power the motors, including: plug-in hybrid, hybrid EVs, battery EVs (BEVs), and hydrogen fuel cell EVs (FCEVs) (Transport for NSW, 2019). Among several types of EVs, BEVs and FCEVs are the two that are powered by electric motors only, with no ICE involved. As a result, there are no tailpipe emissions from BEVs and FCEVs (Rosales-Tristancho et al., 2022), while plug-in hybrid and hybrid EVs could emit when they run on the ICEs (Boriboonsomsin, 2021).

In our former work we focused on the Australian context (Loengbudnark et al., 2022). However, from the cross-national perspective, trends in energy use by

[1] In this paper we interchangeably use “gasoline” and “petrol” when referring to the fuel of internal combustion engine vehicles.

transport, as well as transport related behavior, vary substantially amongst countries and states due to contextual differences, such as gasoline price, and cultural values. The objective of this study is to examine the differences between locations with respect to people's perception of EVs and the influence of perceived benefits, purchase cost and safety concerns on the intention to buy, as well as the influence of car performance on the choice between BEVs and FCEVs. We also examine whether there are any differences in these factors between participants who intend and do not intend to purchase EVs. The eight locations included in this study are Australia, UK, Germany, Poland, Greece, Singapore, and two US states: California, and Mississippi. On the one hand, all these locations are high-income economies (World Bank, 2022). On the other hand, these locations are different in their geography and background. To answer the questions raised, we conducted a survey among consumers in these locations asking them about their attitudes to EVs in general, and BEVs and FCEVs in particular.

3.3 Background

3.3.1 Factors influencing EVs purchase decision

Consumers make everyday decisions to select products that maximize their returns and minimize losses (Featherman et al., 2021). For new products, the benefits perceived by the consumers must be appealing enough to outweigh the disadvantages to achieve market success (Carley et al., 2019). The decision to purchase EVs can be influenced by various factors. One of the most frequently mentioned barriers to the decision to purchase an EV (be it a BEV or an FCEV) is the higher purchase cost compared to conventional vehicles (Rosales-Tristancho et al., 2022). Furthermore, safety concerns are identified as another major barrier (Browne et al., 2012; Hardman et al., 2017; Tarigan, 2019). Below we look at these factors in some detail, based on the literature reviewed.

Perceived benefits

EVs offer advantages in terms of both societal and individual benefits. Regarding the individual benefits, EVs offer financial benefits to consumers in two ways. Since EVs are more energy efficient, they require less energy to run over a given distance (Carley et al., 2013). The second most appealing feature is that EVs require less maintenance than conventional vehicles (Egbue & Long, 2012). They have fewer moving parts and fluids, which results in lower maintenance-related costs (Hagman et al., 2016). The lower operation cost compared to conventional vehicles has been confirmed as an important driver of EVs purchase intention in several studies (Rezvani et al., 2015; Simsekoglu & Nayum, 2019). This is confirmed by Kwon et al. (2020) who found that the cheaper operation cost is the strongest factor influencing BEVs user satisfaction.

Regarding the societal benefits, EVs emit less pollution than conventional vehicles that burn petroleum. This results in better air quality and, in turn, human health (Choma et al., 2020; Gireesh Kumar et al., 2021; Malmgren, 2016), and in climate change mitigation since no greenhouse gases are emitted (Carley et al., 2013; Egbue & Long, 2012; White & Sintov, 2017). Furthermore, EVs also produce less noise pollution than conventional vehicles (Bakker & Jacob Trip, 2013; Bühler et al., 2014) because electric motors are quieter than ICEs. It is unarguable that EVs are environmentally friendly (Jena, 2020; Rezvani et al., 2015; Yang et al., 2020) and have less impact on the environment (Rezvani et al., 2015), however this very much depends on how electricity that powers them is produced.

Purchase cost

Besides the advantages, challenges to EVs purchase decision also exist. High purchase cost has been identified as a major barrier to the decision to purchase EVs in many publications (Chhikara et al., 2021; Coffman et al., 2017; Egbue & Long, 2012; Ghadikolaei et al., 2021; Hardman et al., 2016; Hardman et al., 2017; Hidrue et al., 2011; Krishna, 2021; W. Li et al., 2020; Park et al., 2018; Rezvani et al., 2015; Rosales-Tristancho et al., 2022; Tarigan, 2019; Wang et al., 2018). The tradeoff between high purchase cost and the long-term operating cost savings is involved in consumer decision to purchase EVs (Parker et al., 2021; Sovacool et al., 2019). People often have problems with discounting and a high upfront price to pay often turns out to be more important than the savings in the future. Even though financial incentives have a positive influence on the adoption of BEVs (Ghasri et al., 2019; Hackbarth & Madlener, 2013; Jenn et al., 2020; Jenn et al., 2018; Kim et al., 2019; Wee et al., 2018), it is expected that even with subsidies, consumers still need to pay more out-of-pocket for most BEVs models than for comparable ICE vehicles (Parker et al., 2021). Even taking into account the financial benefits of lower maintenance and fuel costs, BEVs can be cost-competitive with ICE vehicles only if there are substantial subsidies (Parker et al., 2021). A similar situation has been observed in the case of FCEVs. According to Hardman et al. (2017), FCEVs are expensive mainly due to the lack of economies of scale for their parts, such as fuel cells, and hydrogen tanks. In Japan, a world leading country in hydrogen and fuel cell technology (Khan et al., 2021), the government has set the target for FCEVs to reach the same level of economy and convenience as conventional vehicles by 2030. Even after substantial subsidies, the price for a Toyota Mirai is still high (Khan et al., 2022b). However, based on IEA (2007) assumptions about the fuel cell technological improvement rate, Offer et al. (2010) estimated that fuel cells will be cost competitive with ICEs by 2030.

Safety concern

Safety is another important factor considered by consumers when purchasing new cars (Daziano, 2012). Safety concerns have been found to negatively influence the support of alternative fuel vehicles in several studies (Browne et al., 2012; Hardman et al., 2017; Tarigan, 2019).

One of the safety issues related to BEVs is the so-called 'thermal runaway' (Barelli et al., 2021; Held et al., 2022), a phenomenon of rapidly increasing temperature inside lithium-ion battery cell when the rate of heat generation is faster than the rate of heat dissipation (Held et al., 2022). This phenomenon can lead to fire and explosions (Barelli et al., 2021). In recent years, there have been reports about BEV batteries fires and explosions while charging or parking (Barelli et al., 2021; Cui et al., 2022). For example, in China (Ruffo, 2021), and in United States (Ruffo, 2020). Besides, there were also reports on the fires due to the re-ignition of damaged batteries caused by road traffic accidents (Christensen et al., 2021). However, this only occurs because of some form of abuse, such as poor ventilation, high ambient temperature, road traffic accident, or failure of the battery management system (Christensen et al., 2021).

Compared to BEVs, FCEVs are still quite rare and, thus, there are only limited reports about FCEV failures (Smaragdakis et al., 2020). Using hydrogen as vehicle fuel in FCEVs requires proper safety measures to prevent possible hazards (Foorginezhad et al., 2021). Otherwise, it can also cause fire and explosion incidents (Wu et al., 2021). In 2019, there were fire incidents at hydrogen refueling stations in United States, Norway, and South Korea (Khan et al., 2022b; Wu et al., 2021). These incidents increase consumers' skepticism about FCEV safety (Wu et al., 2021). However, this may be easily avoided, like in Japan, where at hydrogen stations only trained staff refuels FCEVs for the customers, and there were no accidents reported so far (Khan et al., 2022b).

In addition to the incidents related to the energy source of the vehicles, people perception about accident risk has an influence on their transport behavior (Nordfjærn et al., 2014). However, there is limited research on the impact of perceived accident risk on BEV adoption (Simsekoglu & Nayum, 2019). While the absence of noise from EVs can be seen as a positive, it also creates a potential risk to other road users, such as pedestrians and bicyclists who do not hear the approaching vehicles (Aravena & Denny, 2021; Fabra-Rodriguez et al., 2021; Krishna, 2021; Pardo-Ferreira et al., 2020). The European Union and USA require EVs to be equipped with artificial noise generators in order to improve detectability at low speed (Pardo-Ferreira et al., 2020). However, Cocron and Krems (2013) and Pardo-Ferreira et al. (2020) argue that adding artificial sounds may not be the most appropriate solution and other options should be considered.

3.3.2 BEVs vs. FCEVs

Vehicle attributes are important features that consumers consider when deciding to buy it or not. Therefore, misperceptions about EV attributes potentially can be a barrier to adoption (Hardman et al., 2017; Hardman & Tal, 2018; Khan et al., 2020; Trencher et al., 2020). BEVs and FCEVs have unique advantages and disadvantages (Trencher et al., 2020). Therefore, they have different barriers for their market penetration (Rosales-Tristancho et al., 2022).

BEVs' main parts are a battery, an electric motor, and a controller (Jena, 2020). The batteries are rechargeable from the electricity supply via a plug. The extent to which BEVs are near carbon neutral depends on the source of electricity used to power them. The barriers that prevent consumers from replacing conventional vehicles with BEVs are the limited range, long charging time, and limited charging infrastructure (Bühler et al., 2014; Kwon et al., 2020; Rosales-Tristancho et al., 2022; Sheng et al., 2021; Simsekoglu & Nayum, 2019). However, the range anxiety may not be a concern among consumers who intend to use BEVs for urban transportation (Rezvani et al., 2015).

In FCEVs, a fuel cell is used to separate hydrogen into hydrogen ions and electrons (Sheng et al., 2021). The electrons are then used to power the electric motors. Meanwhile, hydrogen ions are combined with oxygen and become water, which is the clean exhaust from FCEVs. Like BEVs, the extent to which FCEVs are truly environmentally friendly depends on how hydrogen is produced. FCEVs driving range and refueling are different from BEVs

(Manoharan et al., 2019). As FCEVs do not rely on batteries, they can provide a longer driving range and need less time for refueling (Hardman et al., 2017). Prior studies revealed that after experiencing an FCEV, people perceived driving and refueling it to be similar to conventional vehicles (Hardman et al., 2016; Schneider, 2017), and the performance exceeded their expectations (Lipman et al., 2018). Despite the comparable performance with ICE vehicles, one of the major barriers for FCEVs penetration is the lack of hydrogen infrastructure (Hardman et al., 2016; Hardman et al., 2017; Khan et al., 2021, 2022b).

3.3.3 Study context

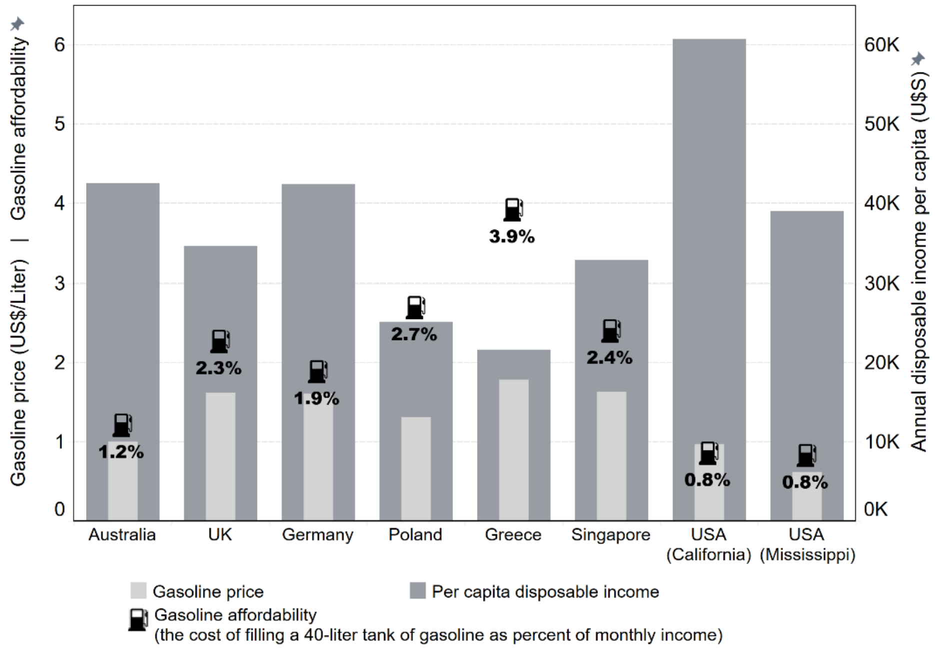
Apart from psychological and technical factors discussed above, the decision to purchase EVs could be influenced by contextual factors. To achieve cross-national comparison objectives, the following contextual factors are included in this study.

Gasoline affordability

ICE vehicles have long been dominating the street over the past decade. Fuel cost has a significant share in the total cost of ownership for ICE vehicles (Hasan et al., 2021; Suttakul et al., 2022). EVs can improve transportation energy efficiency and lower energy costs (Kontou et al., 2017). However, there are conflicting results regarding the impact of gasoline prices on EVs adoption in the literature. While Vergis and Chen (2015), Li et al. (2017), Haidar and Aguilar Rojas (2022), and Bushnell et al. (2022) found positive correlation between gasoline prices and BEVs adoption, fuel price was not a significant predictor of BEVs market share in a cross-national study by Sierzchula et al. (2014).

From energy justice perspective, there is a concept of ‘energy affordability’ which is defined as household’s energy burden, operationalized by the percentage of income spent on energy purchases (Gafa et al., 2022). In the context of transportation, gasoline price has a direct impact on household transportation expenses (Vaidyanathan et al., 2021). In Vermont, for example, transportation fuel expenditures accounted for approximately 3.2% of annual income for high-income households in 2019 but accounted for 7.35% for low-income households (Sears & Luci, 2019).

We calculated gasoline affordability based on gasoline price and disposable income per capita. Figure 5 presents gasoline price, disposable income per capita, and gasoline affordability in the various locations chosen for this study in 2019. Fuel affordability varies greatly across different locations. This is because of the differences in gasoline prices, as well as in personal income. Of each selected regions, gasoline is least affordable in Greece, followed by Poland. The cost of filling a 40-liter tank of gasoline accounted for 3.9% and 2.7% of monthly income, respectively. In the case of Greece, this is because gasoline is relatively expensive, and monthly income ranks the lowest among the compared regions. For Poland, although the cost of gasoline is not so high, but the monthly income is lower than in most of the other locations in this study. In contrast, gasoline is most affordable in the USA, both in California, and Mississippi, followed by Australia. The money spent to refill a gasoline tank is less than 1% of the typical salary in California, and Mississippi, while only 1.2% in Australia. For Germany, 1.9% of monthly income is needed to refill a tank of gasoline. Meanwhile, gasoline affordability is similar in the UK (2.3%) and Singapore (2.4%).



Sources: 1. Gasoline price (Trading Economics, 2022)
2. Disposable income per capita (OECD, 2022)
3. Singapore disposable income and population (Singapore Department of Statistics, 2022a, 2022b)
4. California and Mississippi disposable income per capita (U.S. Bureau of Economic Analysis, 2022)
5. California and Mississippi gasoline price (U.S. Energy Information Administration, 2022a, 2022b)

Figure 5 Gasoline price, disposable income per capita, and gasoline affordability in 2019

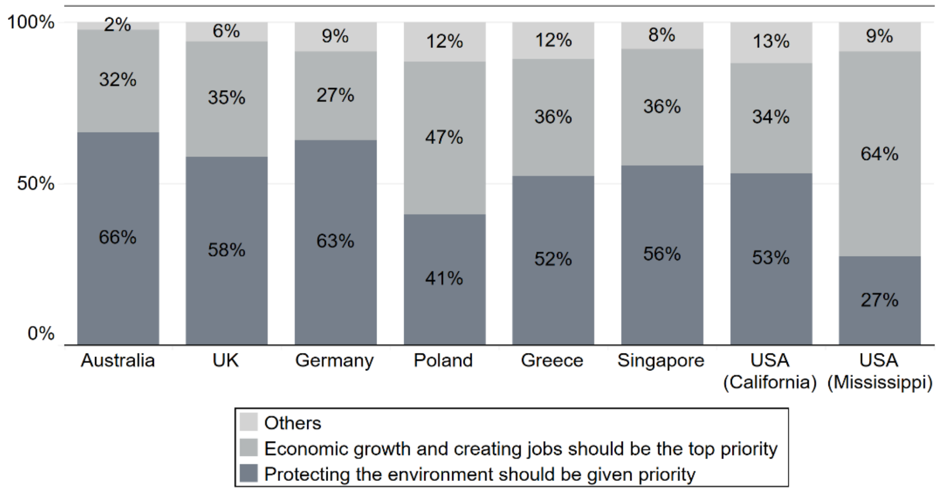
Environmental values

Values are regarded as guiding principles in peoples' lives. Different people may prioritize specific values over others differently (Bouman et al., 2018). These differences result in differences in the choices people make. The more people endorse a certain value, the more they tend to think and behave in accordance with this value. Environmental values are one of the ten values within the Value Theory (Schwartz, 1992) that guide human behavior (Salari, 2022). Salari (2022) found that environmental values relate to consumers' willingness to pay a higher price to purchase an EV than for a conventional vehicle.

Individual values are also influenced by the society or groups in which an individual is a member (Kwak et al., 2021). National cultural values define what decisions and behaviors are appropriate in a society (North, 1990). Several studies confirmed that culture shapes their member's attitude toward the environment. Schultz (2002) found that people from collectivistic culture place greater emphasis on a biospheric attitude than those from individualistic cultures, reflecting their concern for plants, animals, other people, and nature in general. Similarly, Sarigöllü (2009) suggested that there are significant differences in environmental attitudes between people from collectivistic and individualistic, past-oriented and future-oriented, materialist and postmaterialist, and externally and internally controlled cultures. Likewise, Dangelico et al. (2020) confirmed the effect of national culture on a country's environmental performance, though the effects may vary depending on the specific cultural dimensions and the environmental performance indicators.

Average environmental values at the national level are based on individual responses to the World Values Survey Wave 7 and the European Values Study 2017 that ask such questions as: *"Here are two statements people sometimes make when discussing the environment and economic growth. Which of them comes closer to your own point of view? A. Protecting the environment should be given priority, even if it causes slower economic growth and some loss of jobs B. Economic growth and creating jobs should be the top priority, even if the environment suffers to some extent"*.

Figure 6 visualizes the prioritization between economic values versus environmental values at the eight locations in this study. Australia and Germany strongly prioritize protecting environment over economic growth. In these two countries, the proportion of individuals who value the environment is twice that of those who value economic growth. In contrast, Mississippi prioritizes economic growth over protecting the environment.



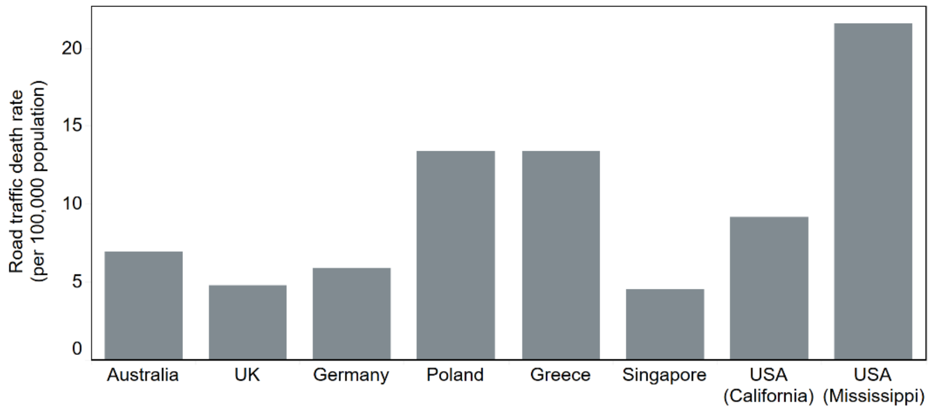
Sources:EVS/WVS (2022)

Figure 6 Economic values versus environmental values

Road traffic death rate

People's risk perception is related to familiarity with the risk source (Lund & Rundmo, 2009). Lichtenstein et al. (1978) found that risk perception toward rare events, such as aviation accidents, tend to be overestimated. In contrast, risk perception of high frequency events, such as traffic accidents, tends to be underestimated. Perception of risk decreases once one gets familiar with the risk by being exposed to it repeatedly (Gleitman, 1995). If this were the case, we could assume that people in localities with frequent accidents have a lower risk perception than people in locations with rare accidents.

Figure 7 shows road traffic death rate (per 100,000 population) in each selected location in 2019. Among the eight locations in this study, Mississippi has significantly higher road traffic death rate than other places. Road traffic death rate in Poland and Greece are the second high. Even though California is in the same country with Mississippi -USA, road traffic death rate in California is less than half of that in Mississippi. UK and Singapore have almost equal road traffic death rate and are the lowest among different places in this study.

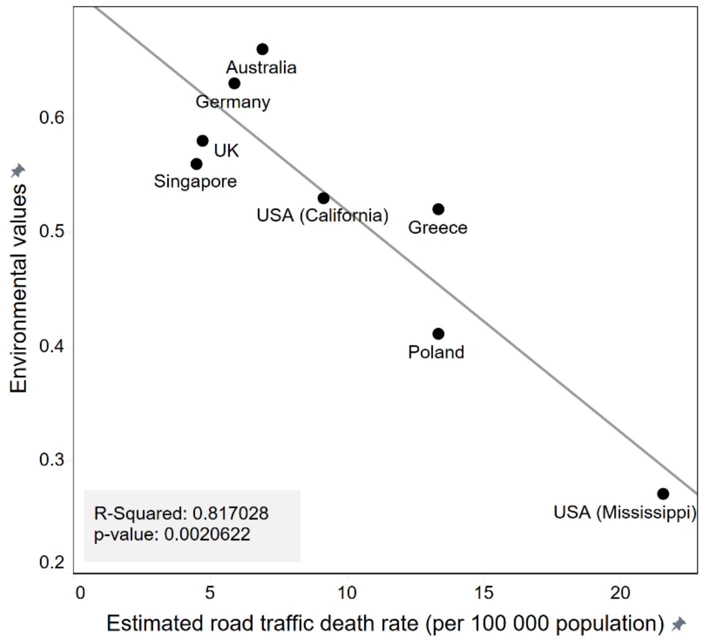


Sources: U.S. National Highway Traffic Safety Administration (2022); World Health Organization (2022)

Figure 7 Road traffic death rate in 2019

Environmental values vs. road traffic death rate

To give a better idea about the study context, road traffic death rate was plotted against environmental values (Figure 8). While most of the locations in this study are with high environmental caring and safe road traffic places, Mississippi is low in both environmental concerns and road safety. Meanwhile, Greece and Poland are similar in their road safety level, but different in environmental values.



Sources: EVS/WVS (2022); U.S. National Highway Traffic Safety Administration (2022); World Health Organization (2022)

Figure 8 Relationship between environmental values and road traffic death rate

3.4 Research Methodology

3.4.1 Participants and procedure

Data used in this study come from an online survey. We used a professional survey company, Qualtrics (2020), to conduct the survey. Before beginning data collection, human ethics protocols and data privacy protection were approved by the university's research ethics committee, approval number ETH19-4469. The estimated questionnaire administration time is 10 minutes. The participants recruited were older than 18 because the minimum age for driving in the countries in this study ranges from 16 to18 years. Furthermore, three criteria were set: (1) geographical IP location must be the respective localities in this study (2) time to response the survey must not less than 180 seconds (3) the same IP address can only take the survey once. After completing the survey, participants could earn rewards from Qualtrics.

A pilot survey of 380 samples (30 from Mississippi and 50 each from the rest) was conducted in June 2020 to check for the reliability and feasibility of the questionnaire design. After revising the questionnaire, a final survey conducted in July 2020 with a total sample size of 4985 from Australia (n = 1735), UK (n = 475), Germany (n = 475), Poland (n = 500), Singapore (n = 500), Greece (n = 500), California (n = 500), and Mississippi (n = 300). Respondents' demographic characteristics can be found in Table 1. We have formerly investigated the perspective of Australian respondents (Loengbudnark et al., 2022).

Most of respondents in this study travel less than 10 km a day. Among the eight locations, Mississippi, Germany, Poland, and California have considerable percentage of respondents who travel more than 20 km a day. Personal car is the mode of transportation used by most of the respondents in almost all locations, except Singapore. The majority of Singaporean participated in this study indicated they use public transportation for their regular commute. Regarding the type of accommodation, the respondents are living in, most of the respondents from Germany, Greece, and Singapore live in an apartment. Meanwhile, most of the respondents from Australia, UK, California, and Mississippi live in either a house with or without solar panels. It could also be observed that Australia comprises of the highest share of respondents live in a house with solar panels. For Poland, percentage of respondents living in a house and in an apartment are almost equal.

Table 1 Socio-demographic characteristics of survey participants

	Australia	UK	Germany	Poland	Greece	Singapore	USA (California)	USA (Mississippi)
N	1735	475	475	500	500	500	500	300
Age (%)								
18-35	35	44	35	52	45	55	43	52
36-55	34	38	45	41	49	40	36	35
More than 55	31	18	21	7	6	5	21	13
Gender (%)								
Male	41	42	50	47	57	52	39	30
Female	59	57	49	53	43	46	60	68
Intersex or prefer not to answer	1	1	0	0	0	2	1	2
Highest education level (%)								
Lower than bachelor’s degree	56	60	53	46	36	45	45	57
Bachelor's degree	29	24	22	16	39	38	37	25
Higher than bachelor’s degree	15	16	25	38	25	17	18	18
Current working employment status (%)								
Working full time	35	48	56	72	52	66	47	45
Working part time	19	16	16	8	12	10	13	12
Others	46	36	28	20	36	24	39	43
Approximate annual personal income[a] (%)								
Group 1	67	79	74	73	87	80	65	55
Group 2	33	21	26	27	13	20	35	45
Daily travelling distances (%)								
Less than 10 km	57	70	53	49	65	62	47	43
11 - 20 km	19	16	18	23	16	21	22	19
More than 20 km	24	14	28	28	19	18	31	39
Usual mode of transportation (%)								
Personal car	74	52	64	64	53	28	78	77
Public transportation	11	15	11	14	16	56	3	1
Walk	8	17	11	8	18	5	7	5
Others	7	15	14	14	14	11	12	17
Type of accommodation (%)								
A house with solar panels	32	12	14	24	17	9	21	12
A house without solar panels	50	65	30	31	24	25	52	62
An apartment or others	18	23	56	46	59	66	28	26

[a] Approximate annual personal income: Australia (Group 1 = Up to A$60,000, Group 2 = More than A$60,000), UK (Group 1 = Up to £35,000, Group 2 = More than £35,000), Germany (Group 1 = Up to €55,000, Group 2 = More than €55,000), Poland (Group 1 = Up to 65,000zł, Group 2 = More than 65,000zł), Greece (Group 1 = Up to €20,000, Group 2 = More than €20,000), Singapore (Group 1 = Up to S$80,000, Group 2 = More than S$80,000), California (Group 1 = Up to US$70,000, Group 2 = More than US$70,000), Mississippi (Group 1 = Up to US$30,000, Group 2 = More than US$30,000)

3.4.2 Questionnaire

The questionnaire is composed of three parts. In the first part, we asked participants about their socio-demographic information (Table 1). In the second part, the explanations about differences between petrol cars, BEVs, and FCEVs are presented (Figure 9). In these explanations, Toyota Corolla Sedan 1.6L, Nissan Leaf S, and Toyota Mirai were chosen to represent petrol cars, BEVs, and FCEVs, respectively. Charging time for BEVs is assumed to be 50 kW fast charging at station, while it is assumed to be 7 kW standard charging at home. The rational for choosing these three models as representatives have been described in Chapter 2. In addition to an explanation in Chapter 2, it should be noted that Toyota not only be the most preferred car in Australia (ABS, 2021c), but also in the world (Statista, 2023).

The last part of the questionnaire, we measured the respondents' opinions toward EVs in different aspects through 22 statements. This questionnaire uses a rating scale ranging from 0 to 100, where 0 represents high disagreement and 100 represents high agreement. Some questionnaire items were adopted from previous studies and modified to the context of this study (Ghasri et al., 2019; Linzenich et al., 2019; Schmalfuß et al., 2017).

Table 2 Corresponding factors of the EVs purchase intention model

Variables	Constructs	Statements
Dependent	EVs purchase intention	Overall, I prefer petrol cars over EVs
		I am currently considering buying an EV
Independent	Perceived benefits	EVs have lower fuel cost
		EVs have lower maintenance cost
		EVs are more environmentally friendly
	Purchase cost	EVs are more expensive
		EVs are not economically feasible
	Safety concerns	EVs increase the risk of road accidents
		EVs explosion risk is a concern to me

Table 3 Corresponding factors of the EVs choice model

Variables	Statements
Dependent variable	
EVs choice	Among EVs, I prefer BEVs over FCEVs
Independent variable	
EVs choice awareness	Before reading the provided explanations, I knew the difference between BEVs and FCEVs
Batteries cost	The cost of batteries will always be too high
BEVs range	The range of a Battery EV is sufficient for my daily needs
BEVs charging time	I do not mind that it takes longer to charge the battery than to refuel petrol or hydrogen cars
Battery explosion	Batteries can explode, this is a concern to me
Attitude toward hydrogen-based cars	I have a positive view about hydrogen-based cars
Hydrogen infrastructure	I have no problems using hydrogen in my car if there is the infrastructure to provide it
Hydrogen cost	I have no problems using hydrogen in my car if the hydrogen cost is low
FCEVs range	I prefer FCEVs to BEVs because of the longer driving range
Hydrogen explosion	Hydrogen is dangerous for use, it can explode
Hydrogen tank safety	Hydrogen tank is more dangerous than Compressed Natural Gas (CNG) tank, and I am not fine to use it in my car

Section 2: Explanations about BEVs and FCEVs

EVs are vehicles with electric motors and include:

Battery electric vehicles (BEVs) have an electric motor and a large battery that recharges by connecting to external power supply. BEVs are fully electric and have zero tailpipe emissions. Because of their simplicity and reliability of the electric motor, they have lower running costs. Examples of BEVs are Renault Zoe, BMW i3, Tesla Model S, Nissan Leaf.

Hydrogen fuel cell vehicles (FCEVs) convert compressed hydrogen into electricity to power an electric motor and, like BEVs, have zero tailpipe emissions. FCEVs are not yet on sale in Australia and are only a small proportion of EV fleets in other countries. They are generally more expensive but offer the advantages of longer operating ranges, lighter weight and rapid refuelling capability, which may suit long distance freight operation, once available. Examples of FCEVs are Toyota Mirai, Hyundai ix35 Fuel Cell, Honda Clarity Fuel Cell.

(Source: NSW Electric and Hybrid Vehicle Plan, Future Transport 2056)

	Petrol	Battery EV	Hydrogen Fuel Cell EV
	TOYOTA Corolla Sedan 1.6L	NISSAN Leaf S	TOYOTA Mirai
Buying price		1.6x of petrol car	3x of petrol car
Driving range	700 km	270 km	550 km
Refueling/charging price		-62% compared to petrol	-34% compared to petrol
Refueling/charging time at station	5 min	60 min	5 min
Refueling/charging time at home (when available)	5 min IF AVAILABLE	8 hour IF AVAILABLE	5 min IF AVAILABLE
CO_2 emission	125 g/km	0 g/km	0 g/km

Figure 9 The explanations about the difference between petrol cars, BEVs, and FCEVs provided at the beginning of the survey (Loengbudnark et al., 2022)

3.4.3 Analyses

The responses to the survey questions were analyzed by two methods. The questions related to the factors affecting EVs purchase intentions (Table 2) were analyzed through partial least squares structural equation modeling (PLS-SEM). On the other hand, the questions related to the choices between BEVs and FCEVs (Table 3) were analyzed through multiple linear regression.

Partial least squares structural equation modeling (PLS-SEM)

PLS-SEM was performed using SmartPLS software version 3.3.3 (Ringle et al., 2015). Model evaluation is described in the following sections, including common method bias assessment, measurement model assessment, and structural model assessment.

Common method bias: To check for common method bias, Harman's one factor test was performed through exploratory factor analysis without rotation using IBM SPSS Statistics version 28.0. The test was formed separately for each of the locations in this study. Test results indicated 16.7% of the variance is explained by the measurement items for Australia, 17.1% for UK, 19.7% for Germany, 20.2% for Poland, 15.6% for Greece, 21.9% for California, 22.9% for Mississippi, and 20.2% for Singapore. The test results for all the locations are less than the benchmark value of 50%, indicating the common method bias was not an issue in this study (Harman, 1976).

Measurement model assessment: All the constructs in this study are reflective constructs. To ensure the measurement models are reliable, Hair et al. (2017) recommend assessing internal consistency reliability, convergent validity, and discriminant validity. These assessments consist of the following criteria: (1)

Cronbach's alpha of all constructs should be greater than 0.6 (2) composite reliability of all constructs should be greater than 0.6 (3) factor loading of all items should be statistically significant and higher than 0.7 (4) average variance extracted (AVE) of the constructs should be greater than 0.5, (5) items should load higher on their intended constructs than on other constructs, and (6) following the Fornell-Larcker criterion, square root of the AVE should be greater than the highest correlation with any other constructs.

The measurement models for each region in this study are assessed separately and are reported in Appendix B. Models for Australia, Germany, Poland, Greece, Mississippi, and Singapore met the reliability requirements in the initial assessment, while models for UK and California need further modification. Therefore, we will discuss the measurement model assessment for the former and the latter groups separately.

For Australia, Germany, Poland, Greece, Mississippi, and Singapore models, internal consistency reliability was assessed using Cronbach's alpha and composite reliability. The results showed that composite reliability of all constructs in all models are greater than the threshold value of 0.6. However, Cronbach's alpha of the 'Purchase cost' construct in all models, and of the 'EVs purchase intention' construct in Australia and Mississippi models are smaller than the threshold value of 0.6. According to Chin and Marcoulides (1998) and Hair et al. (2017), Cronbach's Alpha tends to underestimate the internal consistency reliability. Since the composite reliability of 'Purchase cost' and 'EVs purchase intention' are satisfactory, thus their internal consistency reliability is valid.

Next, factor loading and AVE were used to identify convergent validity. The AVE value of all constructs is greater than the recommended value of 0.5. On the other hand, factor loading of all items are statistically significant. However, their values range from 0.537 to 0.963, while all of them should be larger than 0.7. To maintain content validity, items with weaker factor loading (< 0.7) can be retained, while items with very low factor loading (< 0.4) should be eliminated (Hair et al., 2017). Therefore, we retained the items to maintain content validity.

Lastly, discriminant validity was evaluated based on cross-loadings and the Fornell-Larcker criterion. The results of cross-loading assessment showed that all item's loadings on associated constructs were larger than their cross-loading on other constructs. The results of Fornell-Larcker criterion assessment indicated that square root of the AVE was greater than the highest correlation with any other constructs. Therefore, the reliability of measurement models for Australia, Germany, Poland, Greece, Mississippi, and Singapore are established.

For UK and California models, an evaluation of factor loadings revealed that item 'PB2' (EVs have lower maintenance cost) are not significant in both UK and California models. In addition, the item 'PB1' (EVs have lower fuel cost) is not significant in California model, which probably because of the high level of gasoline affordability in this region. The non-significant items were therefore removed from the models, resulting in acceptable factor loadings in both models. It should be noted that the 'Perceived benefits' construct of California model unavoidably became single-item construct.

After removing non-significant items, the models were re-evaluated. First, the values of composite reliability of all constructs in the two models are greater than the threshold value of 0.6. Cronbach's alpha of the 'Purchase cost' construct in the two models, and of the 'EVs purchase intention' construct in California models is smaller than the threshold value of 0.6. Like the former group, internal consistency reliability is therefore valid. Next, the AVE values of all constructs are satisfactory. All factor loadings are significant and meet an acceptable threshold of 0.4. As a result, convergent validity of both UK and California models are confirmed. Finally, an evaluation of cross-loadings and the Fornell-Larcker criterion indicated that the discriminant validity of the measurement models is valid. Therefore, the reliability of adjusted measurement models for the UK and California is confirmed.

Structural model assessment: After ensuring the reliability of measurement models, structural models can be evaluated. The structural model assessment criteria included: (1) Variance inflation factor (VIF) which is used to assess collinearity, (2) the coefficient of determination (R^2 value), which indicates a measure of in-sample predictive power, (3) the f^2 effect size, which represents the relative impact of a predictor construct on a target construct, and (4) the predictive relevance Q^2, which indicates the out-of-sample predictive power of the model. Results of structural model assessment are reported in Appendix B.

First, an assessment of collinearity showed that all VIF values of the items are below threshold value of 5, indicating no collinearity issues. Second, the R^2 value ranges from 0.205 to 0.306, indicating a moderate level of predictive accuracy in behavioral research (Cohen, 1992). Regarding the f^2 effect size, the values of 0.02, 0.15, and 0.35 represent small, medium, and large effects, respectively (Hair et al., 2017). The f^2 value of a significant relationship in this study ranged from 0.015 to 0.165. It should be noted that a small effect size does not necessarily mean an unimportant effect (Chin et al., 2003). Finally, Q^2 of all constructs were above zero, indicating that items are well reconstructed, and the models have predictive relevance (Hair et al., 2017; Henseler et al., 2009).

Multiple linear regression

Multiple linear regression was performed using SPSS version 28.0. Outliers are identified and removed before performing a multiple regression analysis. A standardized residual higher than 3.0 or lower than -3.0 is considered an outlier. Besides, a Cook's distance higher than 1.0 is considered an influential outlier.

3.5 Results

3.5.1 EVs purchase intention

Petrol cars vs. EVs

Percentage of respondents' preference between petrol cars and EVs by region is presented in Figure 10. This percentage is derived from the responses to the statement "Overall, I prefer petrol cars over EVs". A rating scale was used from 0 (representing high disagreement) to 100 (representing high agreement). For visualization purposes, the scale was converted into 3 categories, namely: Prefer EVs (0-33), Undecided (34-66), and Prefer petrol cars (67-100).

Overall, the most percentage of respondents in all locations, except for Australia, are being undecided. In addition, except for Greece, there is a higher percentage of respondents who prefer petrol cars than those who prefer EVs.

Among the eight locations, Greece shows the highest positive attitude toward EVs. To be more precise, 37% of the respondents from Greece prefer EVs. In contrast, Mississippi and Singapore show the least preference for EVs (14%). On the other hand, Australia has the highest preference for petrol cars, while Greece shows the lowest (23%). Furthermore, Poland and Singapore have the highest percentage of undecided respondents (53% and 52%, respectively).

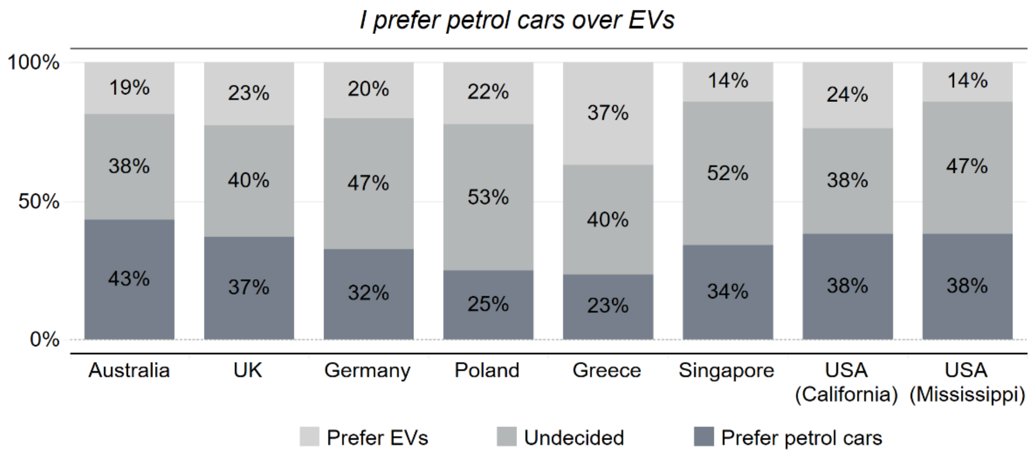


Figure 10 Respondents' preference for EVs vs petrol cars

Figure 11 shows the percentage of agreement with the statement "I am currently considering buying an EV". Most of the participants in all locations are not considering buying an EV. It can be observed that the cross-region comparison results are consistent with preference between petrol cars and EVs. That is, Greece expresses the highest consideration of buying an EV (12%). On the other hand, only 1% of respondents from Mississippi indicated that they are considering buying an EV. Interestingly, for Singapore, although there is the least percentage of participants that prefer EVs over petrol cars (14%), up to 8% of participants indicated that they are considering buying an EV.

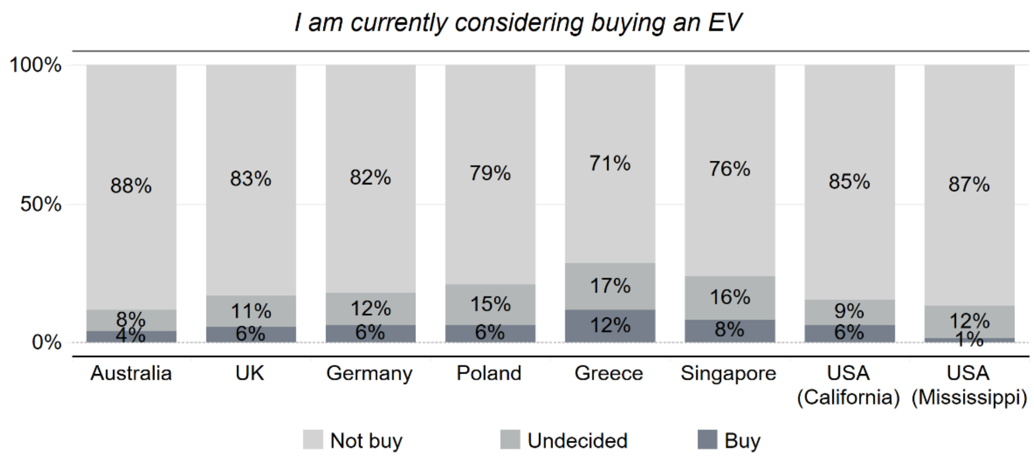
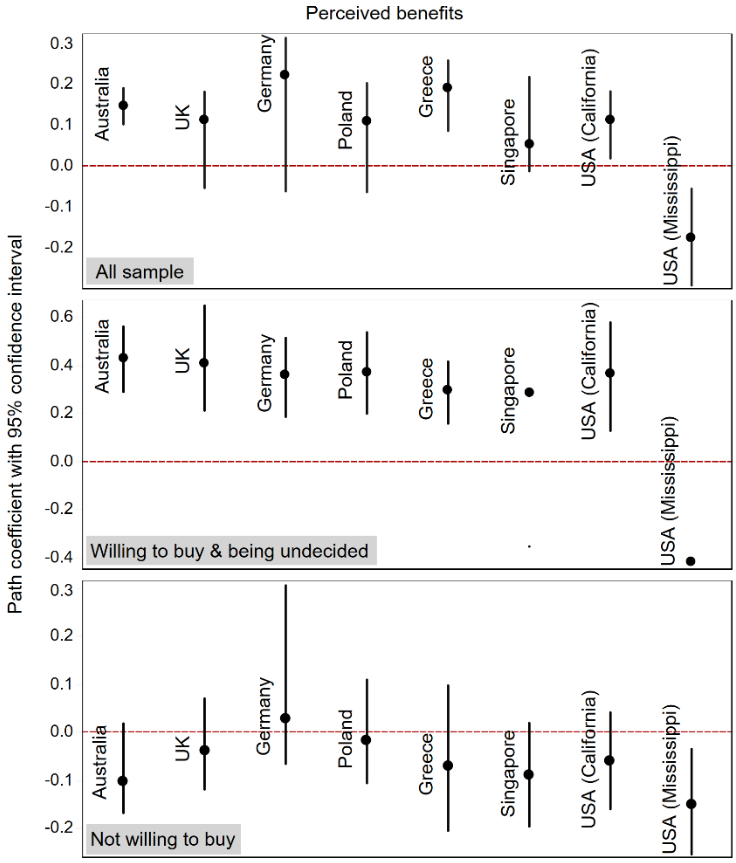


Figure 11 Percentage of respondents who are currently considering buying an EV

The influences of perceived benefits, purchase cost, and safety concern on EVs purchase intention

In the examination of the influences of perceived benefits, purchase cost, and safety concern on EVs purchase intention, we first ran the analyses for all samples (separately for all locations). Then the samples were divided into two groups based on respondents' willingness to buy an EV, which is measured by the question *"I am currently considering buying an EV"* (Figure 11). Due to the low number of respondents who indicated that they are considering buying an EV, we have divided the respondents in each region in two groups, namely (1) those who are willing to buy an EV and those who are being undecided, and (2) those who are not currently considering buying an EV. Note that the confidence intervals of the path coefficients for the 'Willing to buy and being undecided' group of Singapore and Mississippi were not available due to too small sample sizes.



(The corresponding coefficients are significant if an interval does not contain zero)

Figure 12 Effects of perceived benefits on EVs purchase intention

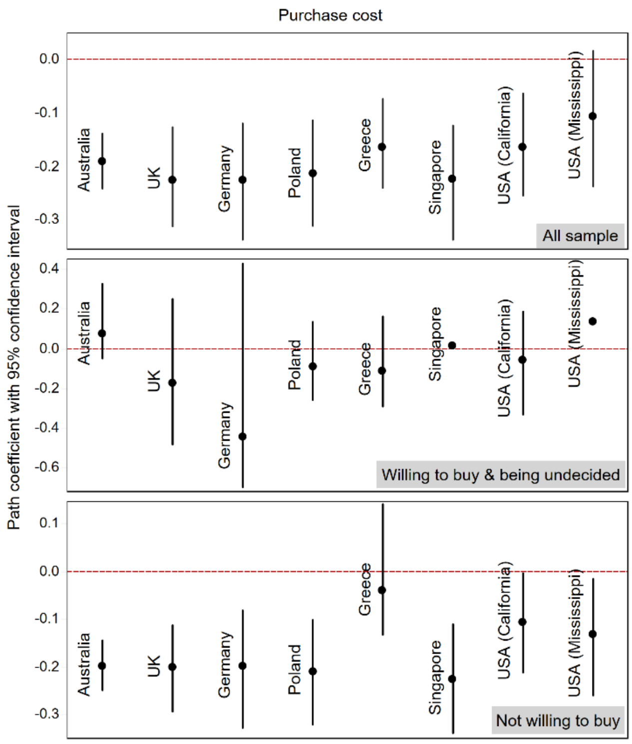
Figure 12 presents the influences of perceived benefits on EVs purchase intention. When looking at the results of the all sample, we see that while benefits of EVs, which cover both financial and environmental benefits, significantly facilitate the purchase intention in Australia, Greece, and California, it is not a significant factor for UK, Germany, Poland, and Singapore. At the same time, it is a significant impediment factor of EVs purchase intention for Mississippi.

However, when comparing respondents who are willing to buy and those who are not, the results show that in all locations, except for Mississippi, respondents who are willing to buy EVs or being undecided are perceptive to the benefit of EVs. Among these locations, the influence of perceived benefits on EVs purchase intention are strongest in Australia (0.43) and UK (0.43), followed closely by Poland (0.37), California (0.36), and Germany (0.36). The strength is slightly weaker in Greece (0.30) and Singapore (0.29).

For the respondents who are not willing to buy an EV, in contrast, perceived benefit does not appear to be an appealing factor for EVs purchase intention in all locations, except for Germany. The influence is the largest and statistically significant only for Mississippi. In the case of Germany, despite the respondents in this group are not currently considering buying an EV, the results showed that they still see benefits of EVs.

Figure 13 show the influences of purchase cost on EVs purchase intention. When looking at the results of all the samples, purchase cost appears to be a significant impediment factor for EVs purchase intention in all locations, except for Mississippi.

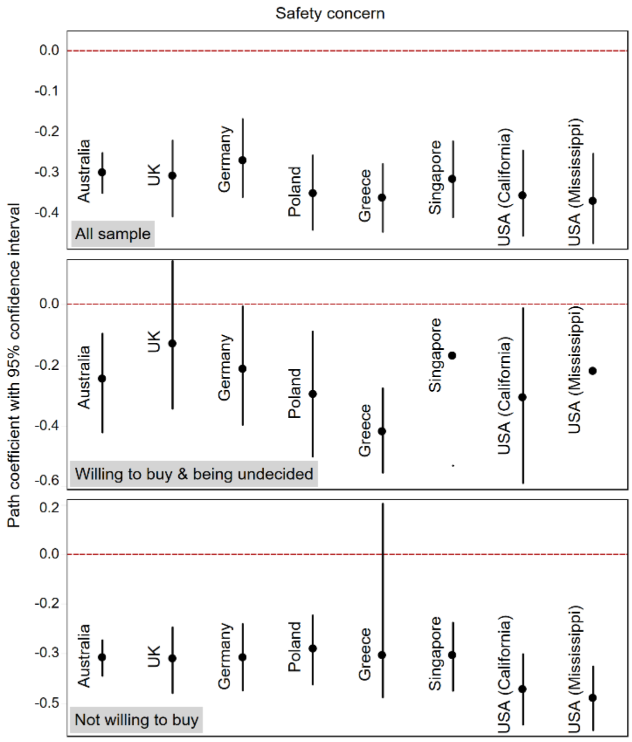
When comparing respondents who are likely to buy and those who are not, the results revealed that purchase cost is not a significant factor among those who indicated that they are considering buying an EV or being undecided in all locations. This could be attributed to confirmation bias, the tendency to seek, interpret, and use evidence to confirm existing belief (Charness & Dave, 2017). Once the decision to buy an EV is already made, the cost becomes less of an issue. However, purchase cost is a significant impediment factor for EVs purchase intention among the respondents who are not willing to buy an EV in all locations, except for Greece. The purchase cost has the strongest influence in Singapore (0.22), followed closely by Poland (0.21), Australia (0.20), UK (0.20), and Germany (0.20). The influence is smaller in Mississippi (0.13), and the smallest in California (0.11).



(The corresponding coefficients are significant if an interval does not contain zero)

Figure 13 Effects of purchase cost on EVs purchase intention

The influence of safety concerns on EVs purchase intention are shown in Figure 14. In this regard, the safety concern encompass concern about both the increased risk of road accidents (stemming from the quiet nature of EVs), and the potential for EVs to explode. It is important to note that these concerns apply broadly to EVs, rather than being specific to BEV or FCEV. The results are consistently showing that safety concerns have a negative influence on EVs purchase intention in all locations. Among the willing to buy and undecided group, the influence of safety concerns is largest in Greece, whereas it is smallest and not statistically significant in UK. Meanwhile, among the not willing to buy group, the influence of safety concerns is strongest in Mississippi, followed closely by California. The influence of safety concerns is comparable in the rest of the locations, but it is not statistically significant in Greece.

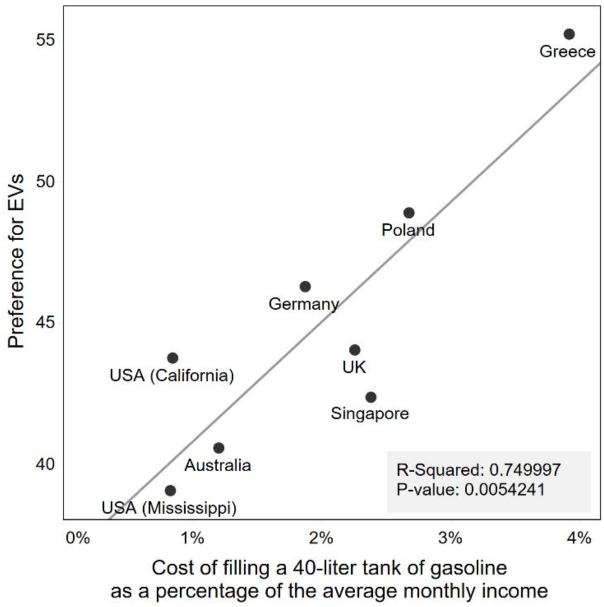


(The corresponding coefficients are significant if an interval does not contain zero)

Figure 14 Effects of safety concerns on EVs purchase intention

Impact of contextual factors

We have further tested the relevant contextual factors and our survey results. The results showed that preference for EVs and gasoline affordability are linearly related (Figure 15). Gasoline affordability explained a considerable proportion of variance in preference for EVs ($R^2 = 0.82$, $p < 0.01$). The higher the percentage of gasoline cost in the monthly income, the higher the preference for EVs. In addition, we found a relationship between environmental values and perceived benefits ($R^2 = 0.73$, $p < 0.01$). Figure 16 shows that the more people value the environment over economic growth, the more are they perceptive to the benefits of EVs. Furthermore, we also found a relationship between road traffic death rate and safety concerns ($R^2 = 0.64$, $p < 0.05$). Figure 17 shows that the higher the road traffic death rate, the larger the impact of safety concerns on EVs purchase intention.



(Preference for EVs is a reverse scoring of a statement "Overall, I prefer petrol cars over EVs")

Figure 15 Relationship between preference for EVs and gasoline affordability

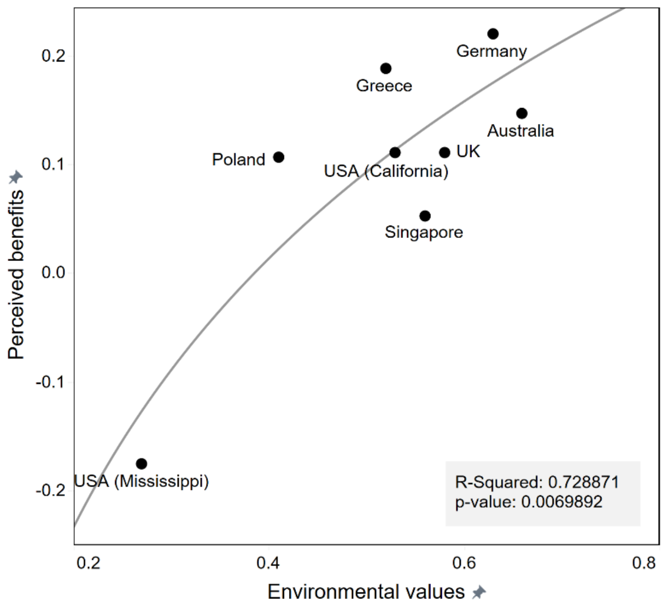


Figure 16 Relationship between perceived benefits and environmental values

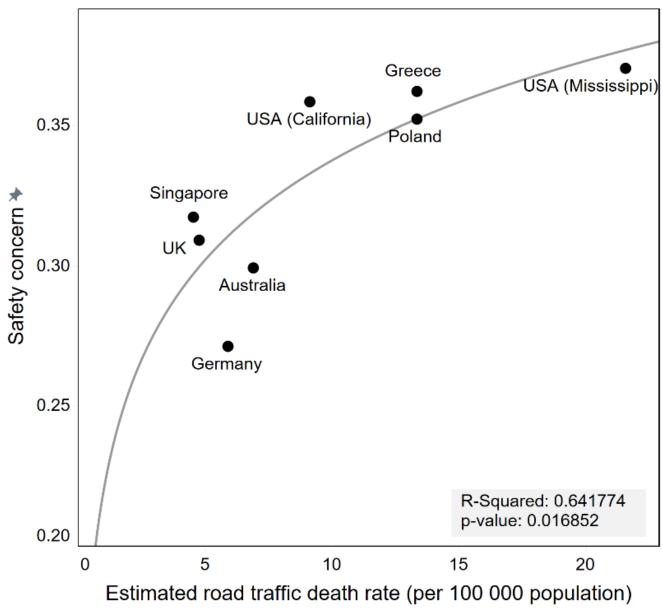


Figure 17 Relationship between safety concerns and road traffic death rate

3.5.2 EVs choices

BEVs vs. FCEVs

Percentage of respondents' EVs choice by region is presented in Figure 18. Overall, BEVs are more preferred than FCEVs across all locations, except for

Germany. For Germany, 31% of the respondents stated that they prefer FCEVs while 29% prefer BEVs. Mississippi has a very similar percentage as Germany. Among all the places, Singapore has the lowest preference for FCEVs (17%) and most prefer BEVs (46%). The rest of the locations, namely Australia, UK, Poland, Greece, and California, show similar percentage with approximately 20% of the respondents preferring FCEVs and 40% - BEVs.

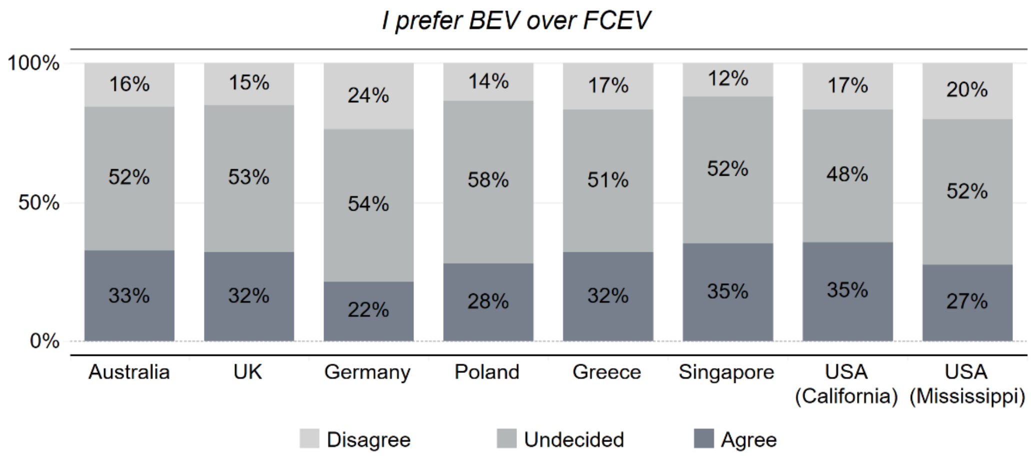


Figure 18 Percentage of respondents' EVs choice by region

Factors affecting EVs choice

Results of multiple regression analysis are shown in Table 4. The numbers represent the regression coefficients. A positive coefficient means that the respective independent variable positively related to the preference for BEVs over FCEVs, while a negative coefficient means the opposite and shows that there is a preference for FCEVs.

We see that in all regions, except for Mississippi, BEVs range sufficiency, the tolerance of the longer charging time, and the concern about hydrogen tank safety are consistently the three factors that positively related to the preference for BEVs over FCEVs. These three factors are highly significant ($p < 0.000$), and the regression coefficients (B) are comparable across all locations ($B = 0.2$ to 0.3). For Mississippi, the tolerance of the longer charging time ($B = 0.24$; $p < 0.000$), and the concern about hydrogen tank safety ($B = 0.16$; $p < 0.05$) are also significant factors that positively related to the preference for BEVs over FCEVs, but BEVs range sufficiency is not significant.

Another factor that positively related to the preference for BEVs over FCEVs is the concern over hydrogen explosion. This factor is highly significant for Australia ($B = 0.20$; $p < 0.000$), and Poland ($B = 0.19$; $p < 0.000$), followed by Germany ($B = 0.17$; $p < 0.01$). It is also significant for Greece, California, and Mississippi ($B = 0.14$ to 0.16; $p < 0.05$) but not significant for UK and Singapore.

Longer driving range, the major advantage of FCEVs, negatively related to the preference for BEVs over FCEVs in five locations. In other words, a longer driving range positively related to the preference for FCEVs over BEVs. This advantage is highly significant for Poland ($B = -0.28$; $p < 0.000$), Australia ($B = -0.08$; $p < 0.000$), followed by Greece ($B = -0.14$; $p < 0.01$). It is also significant for the UK ($B = -0.11$; $p < 0.05$), and Singapore ($B = -0.09$; $p < 0.05$). However, this advantage does not appear to be a significant factor for Germany, California, and Mississippi.

The concern about battery explosion is another factor that positively related to the preference for FCEVs over BEVs, which is significant in Australia ($B = -0.08$; $p < 0.01$), Germany ($B = -0.18$; $p < 0.000$), Greece ($B = -0.20$; $p < 0.000$), and California ($B = -0.12$; $p < 0.05$). However, this influence is not statistically significant for UK, Singapore, and Mississippi.

In the case of using hydrogen as vehicle fuel, an availability of hydrogen infrastructure related to the preference for FCEVs over BEVs only in Germany ($B = -0.14$; $p < 0.01$). Meanwhile, hydrogen affordability plays a significant role in influencing the preference for FCEVs over BEVs only in Australia ($B = -0.08$; $p < 0.000$).

Regarding the demographic variables, education level, income, daily travelling distances, and type of accommodation are significant factors for Australia. That is, the bachelor's degree holders tend to prefer BEVs over FCEVs more than those who have lower education levels. Similarly, high-income people are more likely to prefer BEVs over FCEVs than low-income people. This might be because people with high income, which is often correlated with high education level, are more likely to afford an EV in short term than lower income people. Since at present, BEVs are technically and commercially more mature than FCEVs, perhaps this makes them more attractive for high income people who may be considering a purchase soon. In addition, people who travel more than 20 km a day are less likely to prefer BEVs over FCEVs than those who travel less. As expected, apartment residents tend to prefer BEVs over FCEVs less, compared to those who live in a house with solar panels and have electricity to charge the batteries.

When considering only the respondents who are willing to buy an EV and who are being undecided, the results changed (Table 5). Here tolerance of the longer charging time still is an important factor that positively influences the preference for BEVs over FCEVs in almost all places, except UK and Singapore. Meanwhile, BEVs range sufficiency remains significant only for Greece, Singapore, and California. Hydrogen tank safety concern remain significant for Australia, while the fear about hydrogen explosion remains significant for Germany, and both factors are significant for Singapore.

It was also found that in Greece and Mississippi, EVs choice awareness is a significant factor that positively related to the preference for BEVs over FCEVs. This means that people who know about the differences between BEVs and FCEVs tend to choose BEVs. This could be explained by the diffusion of innovation theory (Rogers et al., 2014) according to which knowledge about the product is the first factor in consumers' purchase decision process. Bearing in mind that these respondents are those who are willing to buy an EV and those who are undecided. Therefore, these people possibly already have some information about EVs before participating in this study and presently BEVs are much more readily available on the market for them to purchase than FCEVs. In contrast, the results revealed that the fear of battery explosion has a negative influence on the preference for BEVs over FCEVs for Greece and Singapore, while high battery cost have negative correlation on the preference for BEVs over FCEVs for Mississippi.

In terms of factors that potentially correlate to the support of FCEVs, the results showed that the longer driving range of FCEVs is significant only for UK, Poland, and California. Furthermore, affordable hydrogen is significant for Australia and California, while hydrogen infrastructure availability is significant for Singapore.

It is worth noticing the results for Mississippi that show that the fear of battery explosion, the positive attitude toward hydrogen-based cars, and the longer driving range of FCEVs do not negatively related to the preference for BEVs over FCEVs. At the same time, the fear of hydrogen explosion negatively related to the preference for BEVs over FCEVs.

Table 4 Factors affecting EVs choices – All sample
(Positive regression coefficients show that the respective factor has a positive correlation on the preference on BEVs, negative ones indicate that there is a preference for FCEVs)

	AUS	GBR	DEU	POL	GRC	SGP	USA (CA)	USA (MS)
(Constant)	21.68***	21.39***	8.27	12.27**	20.75***	10.83*	8.54	11.67
EVs choice awareness	0.03	0.04	0.03	0.06*	0.07	0.01	0.03	0.09*
Batteries cost	0.05*	-0.01	0.05	0.08*	0.01	0.09*	-0.09*	0.00
BEVs range sufficiency	0.22***	0.21***	0.27***	0.21***	0.28***	0.22***	0.20***	0.10
BEVs charging time	0.31***	0.24***	0.28***	0.34***	0.24***	0.32***	0.32***	0.24***
Battery explosion	-0.08**	-0.02	-0.18***	-0.08	-0.20***	-0.06	-0.12*	0.01
Attitude toward hydrogen-based cars	-0.05	-0.05	0.03	0.08	0.01	0.09	0.05	0.12
FCEVs longer driving range	-0.08***	-0.11*	-0.03	-0.28***	-0.14**	-0.09*	-0.07	0.00
Hydrogen explosion	0.20***	0.09	0.17**	0.19***	0.15*	0.09	0.14*	0.16*
Hydrogen affordability	-0.08***	0.00	0.04	0.03	-0.03	-0.04	-0.04	-0.06
Hydrogen infrastructure	-0.03	0.03	-0.14**	-0.05	-0.06	-0.03	0.11	-0.02
Hydrogen tank safety	0.20***	0.28***	0.28***	0.26***	0.24***	0.30***	0.31***	0.16*
Age 36-55	-0.72	1.24	-1.80	0.04	0.50	-0.54	0.83	3.36
Age more than 55	-1.24	-1.41	-1.44	-5.04	-2.00	1.27	4.28	3.24
Female	-0.37	3.40	0.77	-3.71*	0.49	-1.61	1.95	0.01
Bachelor's degree	2.73*	-0.25	4.43	0.86	3.51	1.06	1.43	-4.21
Higher than bachelor's degree	0.31	0.89	4.33	-0.06	3.67	-0.24	2.63	-1.89
Working part-time	2.72	-5.82*	2.61	4.20	0.37	1.39	5.70	-4.43
Employment-others	-0.35	1.43	2.05	0.81	1.33	-0.57	0.53	-1.16
Income-high	2.74*	1.35	1.63	2.09	-0.49	1.82	1.77	4.27
Travelling distances-high	-2.48*	5.04	1.20	1.08	3.18	-1.08	1.84	1.00
Transportation_others	-1.02	0.87	-3.30	-0.42	2.80	-2.74	-1.40	-6.62*
A house without solar panel	-1.13	-0.92	-3.22	2.83	0.97	4.68	-1.93	-0.02
An apartment or others	-3.03*	-4.56	-0.22	2.03	-0.15	-0.83	-2.11	2.12
R^2	0.33	0.266	0.414	0.484	0.305	0.448	0.376	0.288
F Statistic	36.03***	6.827***	13.501***	19.071***	8.826***	15.985***	12.095***	4.580***
df	23	23	23	23	23	23	23	23
df residual	1661	433	439	468	462	453	462	260

Significance levels: $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$

Table 5 Factors affecting EVs choices – Respondents who indicated currently considering buying an EV, and who are being undecided
(Positive regression coefficients show that the respective factor has a positive correlation on the preference on BEVs, negative ones indicate that there is a preference for FCEVs)

	AUS	GBR	DEU	POL	GRC	SGP	USA (CA)	USA (MS)
(Constant)	29.780**	33.719	21.856	17.672	28.622*	31.685**	27.806	21.173
EVs choice awareness	0.056	0.171	-0.084	-0.003	0.159**	-0.033	0.024	0.268*
Batteries cost	-0.092	0.046	-0.081	0.050	0.012	0.039	0.073	-0.337**
BEVs range sufficiency	0.127	0.283	0.069	0.120	0.356***	0.186*	0.277*	-0.087
BEVs charging time	0.329***	0.112	0.251*	0.307**	0.214**	0.430	0.328*	0.429*
Battery explosion	-0.044	-0.096	-0.129	0.041	-0.330**	-0.305**	-0.131	0.475**
Attitude toward hydrogen-based cars	-0.102	-0.106	0.201	0.161	-0.060	0.009	0.213	0.395*
FCEVs longer driving range	-0.096	-0.463**	-0.152	-0.446***	-0.161	-0.056	-0.294**	0.360*
Hydrogen explosion	0.163	0.184	0.485**	0.239	0.118	0.360**	0.120	-0.437*
Hydrogen affordability	-0.149*	0.249	0.066	0.036	0.044	-0.019	-0.278*	0.009
Hydrogen infrastructure	0.066	-0.119	-0.223	-0.081	-0.115	-0.218*	0.078	-0.352
Hydrogen tank safety	0.265**	0.073	0.201	0.096	0.190	0.221*	0.046	-0.054
Age 36-55	-1.951	-0.159	3.365	5.025	1.384	-5.985	7.570	-11.064
Age more than 55	-4.948	-4.755	2.607	-1.097	-6.704	-8.545	-5.039	27.106
Female	-3.501	3.039	4.291	-3.170	-0.153	-4.185	-1.828	2.633
Bachelor's degree	-2.230	1.837	-0.574	1.362	1.192	3.768	1.023	-9.844
Higher than bachelor's degree	-6.917	9.327	-4.711	0.845	4.126	-3.751	-8.485	-28.055***
Working part-time	3.996	2.848	-2.153	-0.825	4.496	-9.067	18.987*	8.706
Employment-others	1.197	0.210	-0.831	7.244	5.343	-4.492	2.100	1.752
Income-high	9.129*	-7.700	13.930*	6.027	-2.451	-2.271	9.093	12.190
Travelling distances-high	-1.278	-1.872	-1.030	2.306	-3.545	-1.827	4.281	-10.603*
Transportation_others	5.563	6.163	2.361	5.252	3.698	-0.282	-2.034	-17.536*
A house without solar panel	-4.282	3.068	-4.991	3.932	-1.210	4.625	-9.115	4.360
An apartment or others	-5.261	0.658	-6.054	2.403	-2.265	-1.823	-9.637	4.200
R^2	0.381	0.383	0.502	0.516	0.436	0.524	0.568	0.923
F Statistic	4.654***	1.513	2.585**	3.666***	3.930***	4.355***	2.919***	7.847***
df	23	23	23	23	23	23	23	23
df residual	174	56	59	79	117	91	51	15

Significance levels: *p < .05; **p < .01; ***p < .001

3.6 Discussion

This study has investigated the effect of consumers' perceived benefits, purchase cost, and safety concerns, on EVs purchase intention, in eight locations: Australia, UK, Germany, Poland, Greece, Singapore, California, and Mississippi. We have also explored how various features of the cars impact the choice between BEVs and FCEVs.

Among all the participants in this survey, the preference for EVs over petrol cars is not very high. Greece has the highest preference for EVs, whereas Mississippi has the lowest. Although the level of preference for EVs differs across locations, factors that influence EVs purchase intention are consistent in most places: safety concerns significantly impede EVs purchase intention. Similarly, in all locations, except for Mississippi, purchase cost also impedes EVs purchase intention. Regarding perceived benefits, the findings reveal that this factor positively influences EVs purchase intention in Greece and Australia, but it is not significant in other places.

When considering the effect of consumers' perceived benefits, purchase cost, and safety concerns on EVs purchase intention among participants who are willing to buy an EV or are undecided, the results reveal that in all places, except for Mississippi, participants are perceptive to the benefits of EVs and safety concerns, but not sensitive to purchase cost. On the other hand, among the participants who are not willing to buy an EV, they are sensitive to purchase cost and safety concerns, but not perceptive to the benefits of EVs. These findings are consistent with previous literature which showed that perceived benefits are a driver for the adoption of EVs (Yang et al., 2020) and high purchase cost is a barrier to the adoption of EVs (Chhikara et al., 2021; Coffman et al., 2017; Egbue & Long, 2012; Ghadikolaei et al., 2021; Hardman et al., 2016; Hardman et al., 2017; Hidrue et al., 2011; Krishna, 2021; W. Li et al., 2020; Park et al., 2018; Rezvani et al., 2015; Rosales-Tristancho et al., 2022; Tarigan, 2019; Wang et al., 2018).

It can be seen that safety concerns are a barrier for EVs purchase intention for both groups of participants. These findings imply that safety concern is a common factor behind the decision to purchase EVs, regardless of culture and contextual factor. This is consistent with the findings from other studies (Browne et al., 2012; Hardman et al., 2017; Tarigan, 2019) and supports the findings of Daziano (2012) that when purchasing any new car, safety is an important feature considered by consumers.

Furthermore, our results showed that preference for EVs and gasoline affordability are inversely correlated. This finding is consistent with the results of Vergis and Chen (2015) and Bushnell et al. (2022) who also found that gasoline prices influence demand for EVs. In our study, further to gasoline price in each region, we also considered disposable income per capita. We defined gasoline affordability as the cost of filling 40-liter of gasoline as percentage of monthly income. Based on our results, the higher the percentage of gasoline cost in monthly income, the higher the preference for EVs. Furthermore, there is also a correlation between the strength of the influence of perceived benefits on EVs purchase intention, and environmental values. The more emphasis the respondents place on protecting the environment over economic growth, the more sensitive they are to the benefits of EVs. This could be an explanation of why perceived benefits do not positively influence EVs purchase intention even among those who are willing to buy an EV in Mississippi. In Mississippi, economic growth is more valued than protecting the environment (Figure 6) and gasoline is affordable (Figure 5). As a result, EVs there do not have appealing attributes. Environmental concern has also been identified as a predictor of EVs purchase intention in the literature (Habich-Sobiegalla et al., 2018). Besides, there is a correlation between the strength of the influence of safety concern on EVs purchase intention, and road traffic death rate. The higher road traffic death rate, the stronger the negative influence of safety concern on EVs purchase intention. This finding is somewhat in contrast with Gleitman (1995) which stated that frequent exposure to the risk decreases perception of risk. However, it may be because the vehicles involved in reported road accidents are usually conventional vehicles. So far, EVs accidents are rare because there are less EVs on the road. As a result, risk perception toward EVs accidents might be overestimated (Lichtenstein et al., 1978).

With regards to the choice between BEVs and FCEVs, our findings demonstrate a consistent cross-national pattern that people who tolerate long charging time, and people who are not confident with hydrogen tank safety are more likely to prefer BEVs. These findings are in line with the findings of Khan et al. (2022a) which found that hydrogen tank safety is one of the major factors for the discontinuance trend of FCEV in Japan. Regarding the tolerance of long charging time, while previous studies, such as Liao et al. (2017), have pointed out that the long charging times negatively influence BEVs purchase decisions, the convenience of home charging could potentially offset this concern (Hardman et al., 2017; Iogansen et al., 2023). Interestingly, even there are some locations in this study that majority of respondents live in apartments, the tolerance of long charging time still consistently emerges as a significant factor influencing the preference for BEV over FCEV. This maybe because individuals who do not live in houses can rely on public fast charging facilities.

Another factor that consistently correlated with the preference for BEVs over FCEVs is BEV range sufficiency. This factor is significant in all locations, except for Mississippi. Short driving range is another shortcoming of BEVs that has been frequently pointed out in previous studies (Hu et al., 2023; Moon et al., 2021). In our study, limited driving range may not negatively affect the preference for BEV because the majority of respondents travelled less than 20 km a day. In addition, the daily travelling distance might be an explanation on why BEV range sufficiency was not significant for Mississippi, where respondents have more daily travelling distance than other locations.

However, different results were obtained when considering only the respondents who are willing to buy an EV and who are undecided. The tolerance for BEVs long charging time become not significant in UK and Singapore. Meanwhile, BEVs range sufficiency remain significant only in Greece, Singapore, and California. Regarding the concern about hydrogen tank safety, this factor remains significant only in Australia, and Singapore. These differences are probably because the prospective buyers might have gained more knowledge about the products than non-prospective buyers (Yu & Lee, 2019).

When comparing results across all eight locations, Mississippi shows major differences with other places. These can be explained by the contextual differences. As can be seen in Figure 8, while most of the locations in this study have similarities in their environment concern and road safety level, Mississippi is different from the others.

3.7 Theoretical Contributions

This study has the following theoretical contributions. Our study examines the effect of perceived benefits, purchase cost, and safety concern on EVs purchase intention separately for participants who intend to purchase EVs and those who do not. Our findings indicate that the two groups may have different preferences and different influential factors for their intention to purchase EVs. For example, we see that participants who intend to purchase EVs are more perceptive to the benefits of EVs, while those who do not intend to purchase are sensitive to the high purchase cost. This is an expected rational behavior (Chen et al., 2019; Fan et al., 2022). We also confirmed that safety concerns play a significant role in EVs purchase intention, regardless of whether respondents are intending or not to purchase EVs. In addition, contextual factors were found to have correlation with the preference for EVs over petrol cars, as well as with the extent of the effect of influencing factors. For example, in Greece, where gasoline is least affordable compared to other places in this study, the preference for EVs over petrol cars is the highest. Meanwhile, in Mississippi, where economic growth is more valuable than protecting the environment, the perceived benefits of EVs are significantly lower than in other places. Thus, it is recommended that future studies account for contextual factors when developing an EVs purchase intention model. Besides, despite many studies investigating factors affecting EVs purchase intention, there are limited cross-national comparisons available (Habich-Sobiegalla et al., 2018). In this study, we compared eight (developed) regions, but wider studies are needed.

3.8 Limitations

This study is subject to some limitations. Firstly, given the survey was conducted online, and was beyond control of the researchers over the process of participant selection, selection biases might exist in this study. Our participants were those who happen to have access to the internet and were willing to fill in the survey. Secondly, the constructs in this study include a small number of items, resulting in the lack of construct reliability. To enhance construct reliability, future research should consider the constructs with enough items. Thirdly, participants' experience with EVs was not considered in this research. Future research should consider including the experience of the participants with EVs, which could influence their attitudes. Fourthly, this study measures the purchase intention of EVs which may not translate into actual behavior. Fifth, given that our survey provided a clear educational component (Figure 9), we do not know how this information influenced the responses to the survey. Sixth, respondent segmentation in this study was based on a single item due to limitations of data that was not suited for clustering technique. Future research may include more questions that capture respondents' preferences and employ clustering analysis for respondent segmentation. However, increasing the number of questions may impact the completion rate of survey.

3.9 Conclusion and Policy Implications

This study examined consumer intention to purchase EVs, and their preference between BEVs and FCEVs in Australia, UK, Germany, Poland, Greece, Singapore, California, and Mississippi. Based on our results, the preference for EVs over petrol cars is not very high. Our results consistently show across countries that participants who are currently considering buying an EV are perceptive to benefits of EVs, while those who currently considering buying an EV are sensitive to the high purchase cost. It was also found that in the place where consumers spend a significant amount of their income on gasoline, preference for EV is high. Besides, in the place where protecting the environment is prioritized, consumers perceived the benefits of EVs as strong in influencing EVs purchase intention. Furthermore, our results revealed that safety concerns are a significant impediment factor for EVs purchase intention, regardless of whether participants are considering purchasing EVs or not. Besides, our findings revealed that the negative impact of safety concerns on EVs purchase intention is high, along with high road traffic death rate. At the current stage, there are more preferences for BEVs than for FCEVs. The concern about hydrogen tank safety is a key barrier for the preference for FCEVs.

The findings of this study offer a few policy implications. First, given the importance of safety concerns on EVs purchase intention across different locations, and for both participants who intend and do not intend to purchase EVs, there is the need to inform consumers about the safety of EVs. This could be done by establishing regulations or standards that are in line with national standards that consumers are familiar with, such as crash testing (Hardman et al., 2017), to address the concerns and build trust. Second, the negative impact of purchase cost on EVs purchase intention among participants who do not intend to purchase EVs across locations, implies the potential positive impact of introducing subsidy schemes to make EVs costs more competitive. This is applicable to all eight regions that were studied. Prior studies have also confirmed the importance of financial incentives for EVs adoption (Ghasri et al., 2019; Hackbarth & Madlener, 2013; Jenn et al., 2018; Kim et al., 2019; W. Li et al., 2020; Wee et al., 2018).

Our findings also imply that there is no one-size-fits-all approach to increase the preference for BEVs and FCEVs. Contextual factors play an important role in consumers' perception toward BEVs and FCEVs, and they should be carefully tuned to the particular preferences and biases at different locations.

3.10 Acknowledgement

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4 ATTITUDES OF AUSTRALIAN HOUSEHOLDS TO COMMUNITY RENEWABLE ENERGY: THE IMPACT OF LOCATION AND AWARENESS

"I'd put my money on the sun and solar energy. What a source of power!

I hope we don't have to wait till oil and coal run out before we tackle that."

Thomas Alva Edison (1847–1931)

4.1 Preamble

Status

Paper Status

Under review, *Renewable and Sustainable Energy Transition*

Abstract

Consumers' positive attitude to community renewable energy (CRE) plays a crucial role in the success of CRE projects and in the transition to a low-carbon society. However, little is known about this factor in the context of Australia, where the situation is contradictory. On the one hand, the country is one of the world's

top coal and gas producers and exporters, and has the third biggest coal reserve in the world (Geoscience Australia, 2023). On the other hand, it has the world's highest installed solar power capacity per capita (IEA PVPS, 2021), much of which is rooftop based. There is considerable political resistance to phasing out fossil fuels and fossil fuel exports, and public opinion is polarized about the merits of such plans. In this study we analyzed the data collected from 860 respondents in Australia in a survey conducted in July - August 2022. Structural equation modeling was used to analyze the relationships between concern about climate change, sense of community, attitudes to renewable energy (RE), perceived community benefits of CRE, and attitudes to CRE. We found that positive attitudes towards RE, and perceived community benefits, influenced the attitude to CRE directly and positively. Climate change concerns indirectly influenced attitude to CRE through promoting a positive attitude to RE. Meanwhile, the sense of community, indirectly influenced attitude to CRE through the perceived community benefits. We also found that positive attitudes to RE, influenced perceived community benefits of CRE. The influence of perceived community benefits and climate change concerns are stronger among those respondents who already have RE. The influence of a sense of community is weaker among non-urban residents. Furthermore, for residents living in the greater capital cities, positive attitudes to RE and CRE are correlated with the number of solar installations in the area. For those living outside the greater capital cities, the attitude towards RE and CRE are correlated with the duration of power outages. The empirical results have policy implications, such as recommendations to increase positive attitudes to CRE by raising RE awareness, increasing people’s experience with RE, and the need for different strategies for urban and non-urban households.

Findings

In the previous chapter,

The factors that influence consumers' intention to purchase EV, and the factors that influence preference for battery-powered EV and hydrogen fuel cell EV were examined in eight different locations were examined. It also examined differences in factors affecting EV purchase intention between participants who intend to buy EVs and those who do not. Besides, the findings revealed the impact of contextual factors: affordability of gasoline, environmental values, and road traffic death rates, on people's willingness to purchase EV. In this chapter we continued looking at factors that can impact individual behavior.

In this chapter,

The focus is on collective energy-related behavior in a household context, which involves broader aspects and can result in structural or system changes that can benefit society as a whole. This chapter examines factors influencing Australian consumers' attitudes to community renewable energy. More specifically, the chapter investigates the impact of climate change concerns, attitude to renewable energy, sense of community, and perceived community benefits in influencing attitude to community renewable energy. The chapter also examines the location and renewable energy awareness's role in influencing positive attitudes toward community renewable energy.

The main findings of this chapter are

1. Positive attitudes towards renewable energy, and perceived community benefits, influence the attitude to community renewable energy directly and positively.
2. Climate change concerns indirectly influence attitudes toward community renewable energy through promoting a positive attitude toward renewable energy.
3. Sense of community indirectly influence attitude towards community renewable energy through the perceived community benefits.
4. Positive attitudes to renewable energy also influence perceived community benefits of community renewable energy.
5. The influence of perceived community benefits and climate change concerns is stronger among those respondents who already have renewable energy.
6. The influence of a sense of community is weaker among non-urban residents.
7. For residents living in the greater capital cities, positive attitudes to renewable energy and community renewable energy correlate with the number of solar installations in the area.
8. For residents living outside the greater capital cities, the attitude towards renewable energy and community renewable energy correlates with the duration of power outages.

In the next chapter,

The focus is on behavioral intervention strategies that can decrease energy consumption without compromising user satisfaction in the office context. A centrally controlled building on UTS campus is used as a case study. The chapter analyzes the role of occupant control over their working environment and its impact on their satisfaction, perceived productivity, and building energy demand.

Author Contributions

Wipa Loengbudnark: Conceptualization, Methodology, Formal analysis, Investigation, Writing –original draft, Visualization. **Jonathan Marshall:** Writing – review & editing, Funding acquisition. **Kaveh Khalilpour:** Conceptualization, Writing –review & editing, Supervision. **Gnana Bharathy:** Data Curation, Methodology, Writing –review & editing, Supervision. **Alexey Voinov:** Writing – review & editing, Supervision.

4.2 Introduction

Community renewable energy (CRE) is an emergent opportunity for consumers to engage in the local energy system (Kalkbrenner & Roosen, 2016). Besides playing a crucial role in reducing reliance on the centralized fossil fuel energy system, it also contributes to the development of knowledge and skills that help regional economies (Wang et al., 2022). The number of CREs has been rapidly increasing with robust support from governments in various countries. The countries leading in CRE are Germany, Denmark, and the Netherlands (Di Silvestre et al., 2021). In 2019, there were approximately 1750 CRE projects in Germany, 700 in Denmark, and 500 in the Netherlands (Caramizaru & Uihlein, 2020).

Although Australia possesses abundant renewable energy (RE) resources, 71% of electricity is still generated from fossil fuels (Department of Climate Change, 2022a). The country ranks 14th among greenhouse gas emitters in the world (CSIRO, 2021). But it ranks 11th in the world and the first amongst members of the Organization for Economic Co-operation and Development (OECD) in terms of CO_2 emissions per capita (Chang & Macleod, 2021). The transition to low carbon electricity generation has been challenged by political and corporate resistance, and polarized public opinion (largely generated by the Murdoch owned media) about the merits of phasing out fossil fuels and even about the truth of climate change (Marshall, 2022; Proudlove et al., 2020). The Australian case can be viewed as an example of the difficulties in developing CRE in developed nations that face substantial political obstacles to implementing renewable energy solutions (Mey et al., 2016).

In recent years, there has been a surge in academic publications about CRE. However, they mostly involve European case studies (e.g., Germany (Kalkbrenner & Roosen, 2016; Süsser & Kannen, 2017), the Netherlands (Fleur Goedkoop et al., 2022), Belgium (Bauwens, 2016; Bauwens & Devine-Wright, 2018; Conradie et al., 2021), Italy (Di Silvestre et al., 2021), and UK (Seyfang et al., 2013)). Case studies in the Australian context are limited (Byrnes et al., 2016; Mey et al., 2016; Proudlove et al., 2020). Insight into motivations and concerns associated with investing in CRE within the Australian context could hold significance in fostering the ongoing growth of CRE in Australia and promoting the formulation of more supportive policies (Proudlove et al., 2020).

In this study, we focus on a set of factors as predictors of positive attitude to CRE in Australian consumers, namely climate change concern, attitudes to RE, sense of community, and perceived community benefits. These particular factors came out of our initial research into CRE in the NSW country town of Narrabri, where the survey was first tested. We developed a conceptual model and used survey data to analyze the influence of the mentioned determinants on attitude to CRE. A large-scale Australia-wide dataset (gathered for us by the Community Power Agency), enabled us to examine the differences in the factors influencing attitude to CRE between individuals who live in different settings, as well as between individuals with and without RE.

The following sections of this article present: the specifics of the Australian situation (Section 2); the definition and theoretical foundation (Section 3); the methodology (Section 4); the results (Section 5); the discussion of the results

(Section 6); the policy implications (Section 7); the limitations (Section 8), and finally; some concluding remarks (Section 9).

4.3 Background and conceptual model

4.3.1 Australian context

Electricity generation and transmission

Australia possesses abundant fossil fuel and renewable energy resources. Currently, electricity generation in Australis is dominated by fossil fuels, namely coal and natural gas. In the eastern states[2], electricity is transported from generators to consumers through the interconnected National Electricity Market (NEM) network. Meanwhile, the electricity transmission networks of Western Australia (WA) and the Northern Territory (NT) operate independently (ElectraNet, 2022).

The NEM incorporates approximately 40,000 km of transmission lines and cables (AEMO, 2022a) with an installed capacity of 59.7 GW, as of November 2022. This capacity is dominated by fossil fuel power plants, 38% of which are coal plants and 20% gas. The remaining electrical generation capacity includes 13% hydro, and 27% alternative energy resources (solar, wind, and biomass) (AEMO, 2022b). In Queensland (QLD), New South Wales (NSW), and Victoria (VIC), the transmission grid is linked to 13 distribution networks which provide services to customers. Each of these networks has ownership and operational control over its specific geographic area. Meanwhile, in South Australia (SA), Tasmania

[2] Including Queensland, New South Wales, Australian Capital Territory, Victoria, Tasmania, and South Australia

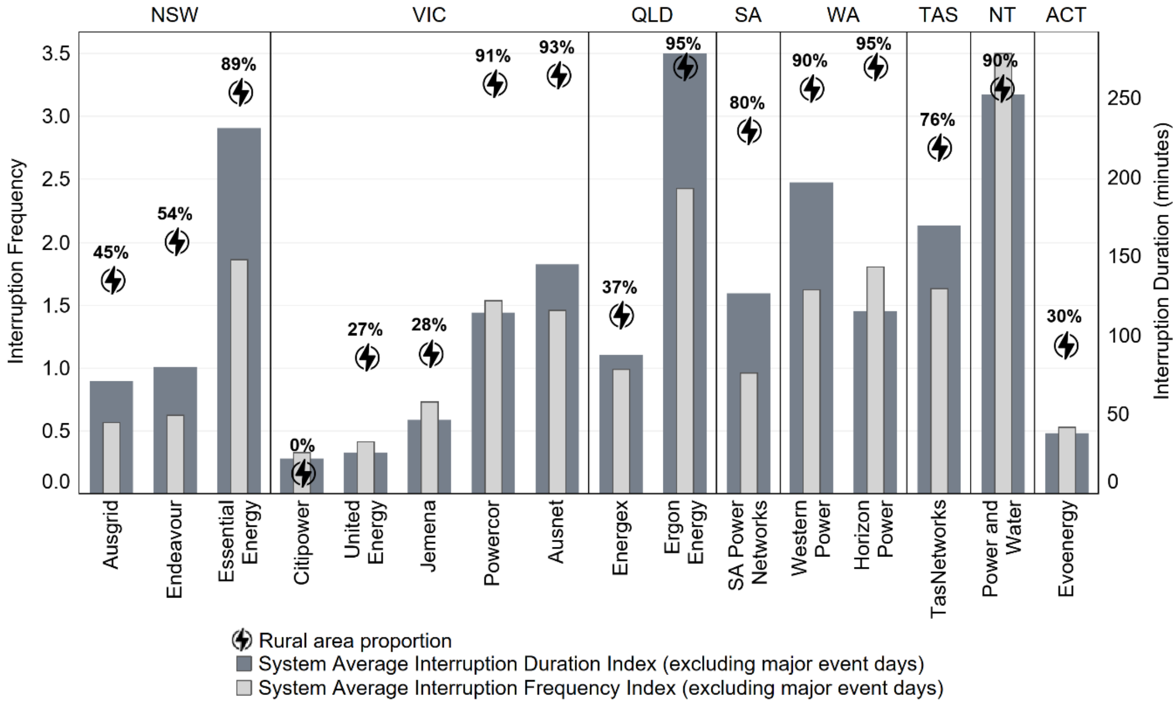
(TAS), and the Australian Capital Territory (ACT), a single distribution network provides service within each respective jurisdiction (AER, 2022b).

In WA, the government owns the major electricity networks, as well as the largest generators. As of 2021, 57% of electricity in WA is generated from gas, 22% from coal, and 6% from diesel (Department of Climate Change, Energy, the Environment and Water2022b). A small amount of electricity is generated from wind, solar, and landfill gas (Energy Policy WA, 2022).

In the NT, electricity generation and transmission are operated by government-owned corporations. As of 2021, most of the electricity in the NT is generated from gas (84%), while 10% is from oil, and the remaining 6% is from renewable sources (Department of Climate Change, Energy, the Environment and Water2022b).

Electricity distributors – the location dependency

The residential location of electricity consumers determines their electricity providers, which in turn impacts both electricity prices and reliability. Figure 19 summarizes the electricity distribution networks in each Australian state and territory. According to the Australian Energy Regulator's (AER) annual report: *State of the energy market 2022* (AER, 2022b), consumers' energy bills differ across locations. Except for WA and NT where electricity price is regulated, the amounts that consumers pay for energy depends on the level of competition among available retailers in their area, their ability to find a suitable and understandable energy plan, and whether they qualify for any concessions or rebates to assist in managing their energy expenses. As a result, different consumers are impacted by affordability challenges differently. The report points out that consumers living in regional and remote areas, where network costs are higher and spread over fewer consumers, tend to face higher energy bills compared to urban consumers.



Data source: AER performance reports (AER, 2022a), and ERA Annual data report - Energy distributors (ERA, 2022)

Figure 19 Electricity distribution networks in Australia and their performance in 2020-2021

In addition to the price, the frequency[3] and length[4] of electricity supply disruptions differ across distribution networks. AER (2022b) suggests that customer density and environmental conditions, which can vary between different networks, can

[3] System Average Interruption Frequency Index (SAIFI) means the average number of sustained interruptions per consumer during the year. It is the total number of sustained interruptions divided by number of customers.

[4] System Average Interruption Duration Index (SAIDI) means the average duration of interruptions per consumers during the year. It is the sum of the durations of all the sustained interruptions (in minutes) divided by the number of customers.

impact the number of affected customers and response time during outages of each network. Additionally, the amount of investment made in the network's infrastructure over time can also affect reliability outcomes. Areas such as the Central Business District (CBD) of cities, and urban network areas tend to have a higher density of load and customer connections. The distribution lines that supply urban areas are typically shorter than those that supply rural areas. Urban areas and the CBD also tend to have a larger proportion of underground cables, which are more secure from damage caused by pollution, storms, trees, wildlife, vandalism, equipment failure, and vehicle collisions. Additionally, these areas have more interconnections with other urban lines. As a result, distribution networks in urban areas generally have faster restoration times following interruptions to supply compared to those operating in rural areas.

On the other hand, AER (2022b) suggests that rural areas usually have lower load and customer densities, and often serve customers who live in smaller population centers that are farther away from the supply points. The distribution lines cover larger geographic areas, which increases their vulnerability to external factors such as storm damage, trees, and lightning strikes. Country Australia can have large distances between different towns and between houses, which make repairs difficult. Moreover, rural distribution lines are usually arranged in a radial pattern, limiting their ability to connect with neighboring lines (AER, 2022b). These attributes generally result in more frequent and longer power outages in rural areas, as shown in Figure 19.

Renewable energy potential

Australia not only possesses substantial fossil fuel resources but also has an advantageous geographical position for RE. It has higher than average solar radiation per square meter than many other countries (Geoscience Australia, 2022a; Geoscience Australia & ABARE, 2010; H. X. Li et al., 2020). There are approximately 58 million petajoules (PJ) of solar radiation falling on Australia per year (Geoscience Australia, 2022a; Geoscience Australia & ABARE, 2010) which is approximately 100 times the global annual energy consumption (BP, 2022). Although the areas with the greatest solar energy resources, in the northwest and center of the country, do not have access to transmission lines, there are still substantial solar energy resources within 25 km of existing grids (Geoscience Australia & ABARE, 2010). Even so there are potential struggles over land use and local aesthetics, as RE requires land.

Opportunities for wind energy in Australia are also abundant. There are substantial areas with wind speed suitable for electricity generation (Geoscience Australia & ABARE, 2010). Wind resources are mostly found in western, southwestern, southern, and south-eastern coastal areas with wind speeds above 7.5 meter per second (Geoscience Australia, 2022b). As of 2018, Australia has 94 wind power plants, with a generation capacity of 16 GW (ARENA, 2022).

Australia also has great opportunities for bioenergy - biomass and biofuel, - as one of the top sugar cane producers. Bagasse (sugarcane pulp) is the most common bioenergy fuel along with agricultural, forestry, and municipal residue and waste (H. X. Li et al., 2020). As of 2020, bioenergy accounted for 5% of electricity generation from supposedly renewable sources, and 1.5% of total electricity generation in Australia (Clean Energy Council, 2021).

CRE in Australia

CRE in Australia has evolved significantly from being a relatively abstract idea in 2006 (C4CE, 2015) to some early-stages developments by now (Proudlove et al., 2020). Currently, approximately 127 CRE groups are engaged in projects, with six of them actively generating energy (CPA, 2023).

There exist several challenges when it comes to establishing and expanding CRE in Australia (CPA, 2021), although there is clear government support for CRE in some jurisdictions (Sustainability Victoria, 2023). All policy support for renewable energy projects in Australia has predominantly been directed toward either household or small-commercial scale (via feed-in tariffs, small-scale renewable energy scheme and rebates) or large-scale renewables (via renewable energy target and reverse auctions). There is no policy support for renewable energy projects between 1-30 MW (CPA, 2021).

4.3.2 Definition and theoretical foundation

Despite an increasing attention to Community Energy (CE) in literature in recent years, there is no consensus about the definition and understanding of the term so far (Brummer, 2018; Seyfang et al., 2013). Slightly, different terms have been used to refer to these kinds of projects. For example, community energy (Bauwens & Devine-Wright, 2018; Kalkbrenner & Roosen, 2016), community energy initiatives (CEIs) (Fleur Goedkoop et al., 2022; Karytsas & Theodoropoulou, 2022; Mishra et al., 2022; Teladia & der Windt, 2022), community renewable energy (CRE) (Bauwens, 2016), renewable energy communities (RECs) (Conradie et al., 2021), Community Owned Renewable Energy (CORE) (Proudlove et al., 2020), Local energy autonomy (Bamberg et al., 2015), etc.

According to Seyfang et al. (2013) CE refers to: "*projects where communities (either based on location or shared interests) have a strong sense of ownership and control over the projects. These projects benefit the community as a whole, and include both supply- and demand-side sustainable energy initiatives*". Therefore, CE is a broader term which encompasses both locally-led demand-side management programs, and supply-side energy generation programs. Meanwhile, CRE is a subcategory of CE, referring to community projects that generate electricity and/or heat from RE technologies (Hicks & Ison, 2018). These projects are managed by local communities and are partially or fully funded by members, with occasional government assistance (Proudlove et al., 2020).

Acceptance and support from citizens are crucial for a successful energy transition. People can participate in CRE programs in various ways ranging from in person participation, such as volunteering planning, organizing, and managing the projects, to indirect financial investment (Kalkbrenner & Roosen, 2016; Romero-Castro et al., 2021). The theory of planned behavior (TPB) (Ajzen, 1991) has been applied to explain people's intentions and behavior in various fields including CRE (Proudlove et al., 2020). According to TPB, behavior is determined by intention. The behavioral intention is influenced by attitude (a personal belief toward behavior), subjective norms (a social pressure to perform a behavior), and perceived behavioral control (an ability to perform a behavior). A positive attitude towards CRE can be assumed to be an important determinant for people's participation in CRE (Conradie et al., 2021). Social pressure has the potential to influence people responses to the project (Huijts et al., 2012; Karakislak & Schneider, 2023). The degree to which people feel capable to engage with CRE will impact their intention to participate (Conradie et al., 2021; Huijts et al., 2012).

4.3.3 Conceptual model

In this study, we focus on a set of factors that influence attitudes to CRE, namely climate change concern, attitudes to RE, sense of community, and perceived community benefits. Below we will discuss our rationale for the hypothesized relationships between predictors and the attitude to CRE.

Attitude to RE: Positive attitudes to RE seem important for the widespread energy transition. When members of a community have a positive attitude to RE, they are more likely to perceive the benefits of transition (Ari & Yilmaz, 2021). These benefits may include a reduction in greenhouse gas emissions, improved air quality, increased energy independence and community involvement in its future. Furthermore, previous studies have found an association between general attitude to RE and attitude towards specific energy projects. On the one hand, participation in CRE can enhance positive attitudes to RE. For example, Bauwens and Devine-Wright (2018) found that members of energy cooperatives, even those new members characterized by lower levels of environmental concern and more financially oriented motives, have more positive attitude to RE and are more supportive of implementing local energy projects than non-members. On the other hand, attitude to RE has been found to be a strong predictor of attitudes towards a specific RE project (Jones & Eiser, 2009). The findings of Sposato and

Hampl (2018) indicated that individuals who hold a more favorable view of renewable energy are more inclined to approve the installation of renewable energy power stations within their locality. In contrast, individuals who have doubts regarding the viability of renewable energy are less likely to declare their acceptance of renewable energy technology. Furthermore, Conradie et al. (2021) found that attitudes to RE, along with financial gain and pro-environmental behavior, are significant determinants of attitude to CRE.

Climate change concern: Using renewable energy sources, instead of fossil fuels, is crucial for mitigating climate change. The way individuals perceive climate change has been identified as a significant factor in determining whether they are likely to take action to reduce its effects or not (Akter et al., 2012). Several studies have found that environmental concerns, including climate change, make one of the motivations for people to take energy-related action, such as purchase an electric vehicle (Degirmenci & Breitner, 2017), focus on energy-saving in a household (Hidalgo-Crespo et al., 2022), or a hotel (Wang et al., 2023), or start using residential energy management information systems (Yew et al., 2022). In addition to influencing energy-related action, Lin and Syrgabayeva (2016) suggested that environmental concern has a positive effect on attitude to renewable energy. In the context of CRE, Dóci and Vasileiadou (2015) found that protecting the environment played a role in the decision to invest in RE at community level in Germany and the Netherlands. Similarly, Kalkbrenner and Roosen (2016) found that environmental concern is a significant factor in willingness to participate in CRE projects in Germany. Moreover, Bauwens (2016) found that concern about climate change is a motivation for involvement in CRE.

Perceived community benefits: CRE is generally assumed to deliver a wide range of local benefits. Süsser and Kannen (2017) summarized some common categories of benefits to the community, including: community ownership, funding, enhancing local infrastructure, local employment, environmental impact mitigation, and participation in the process of project development. Berka and Creamer (2018) reviewed and conceptualized the local impacts commonly cited in the literature. These impacts include: socio-economic regeneration, knowledge and skill development, social capital, increased support for renewable energy, energy literacy and environmentally benign lifestyles, affordable energy access, and empowerment. Similarly, Brummer (2018) mention economic benefits, education and acceptance, participation, climate protection and sustainability, community building and self-realization, RE generation, and innovation. In addition to the reviewed literature, Soeiro and Ferreira Dias (2020) conducted a survey among CRE members in Portugal, Spain, and Belgium. They found that the positive impact of CRE on their communities is an important driver for the support of CRE project development. Proudlove et al. (2020) found that beliefs regarding the possibility of the project generating benefits for the community had the greatest influence on the intention to invest in CRE. The researchers emphasized that to encourage investment in CRE, the initiators should explore particular advantages for the community that prospective investors anticipate will be derived from the CRE. People who have control over an installation are also more likely to support the installation, and it is less likely to alienate neighbors who are participating, or to ignore local objections. People will generally have more positive attitudes to CRE, than to commercial farms.

Sense of community: The sense of community refers to people's emotional bonding to their community (Giuliani & Feldman, 1993). Kim and Cho (2019) suggest that motivating residents to engage with their local issues would be much easier with a sense of community. However, there are contradictory findings about the impact of sense of community on people's engagement with local activity in the literature. Omoto and Packard (2016) indicated that a sense of community is associated with involvement in environmental volunteering and activities. Similarly, Chavis and Wandersman (1990) found that a sense of community mediated local action through the perception of environment, social relation, and perceived control and empowerment. However, Suchyta (2020) investigated the relationship between place attachment and environmental concern regarding a proposed hydropower project in a rural community in Norway. Their findings indicated that individuals who were deeply connected to the natural areas that could be impacted by the project held more unfavorable attitude to it, whereas those who were attached to the municipality had more favorable views. This supports the point made earlier that projects outside people's control, and capacity, are more likely to have objectors. Furthermore, Li et al. (2022) found that a sense of community negatively influenced willingness to install solar photovoltaic (PV) in rural China. These findings were explained by the fact that China has thousands of years of agricultural tradition, thus, new technology (PV in this case) might affect local farmers' sense of belonging. Rural villagers who were deeply attached to the natural areas may worry about the visual impact of PV (Chen et al., 2021). They may have concerns that the use of solar PV panels could bring unforeseen hazards such as lightning strikes, environmental radiation (Li et al., 2022).

Based on the above literature and discussion, we have developed a conceptual model (Figure 20) to explain some factors influencing attitudes to CRE. We suggest that the attitude to CRE is influenced by the attitude to RE, and by perceived community benefits. The attitude to RE has been assumed to be influenced by concerns about climate change. Meanwhile, the perceived community benefits are assumed to be influenced by both the attitude to RE and the sense of community. All five variables may be influenced by age and gender. Furthermore, place of living and having RE are assumed to influence all the proposed relationships.

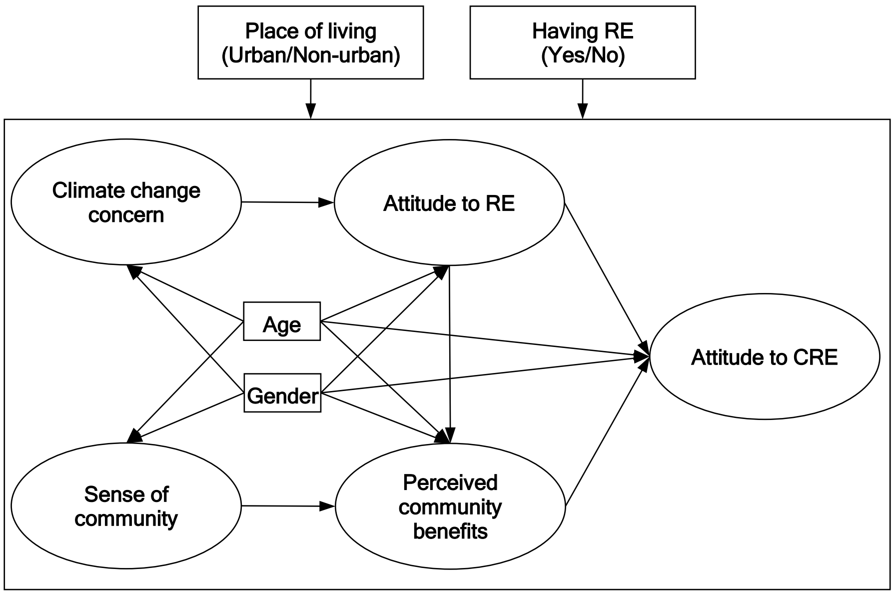


Figure 20 Conceptual model of factors influencing attitude to CRE

4.4 Methodology

4.4.1 Data

We used a subset of data from the Community Power Agency survey (CPA, 2022). The survey was conducted online among Australian people during July - August 2022. It has 941 responses, but we rejected the responses with more than 20% of missing data. As a result, 860 people's responses were used for our analysis. The incomplete responses with less than 20% missing values were imputed with the median response. The missing values of categorical variables (i.e., age, gender, and place of living) were coded as 'Prefer not to answer.'

Of the participants, 50% are male, 45% are female, and 5% are non-binary or those who prefer not to answer; the mean age is 35.3 (SD = 8.81). 48% of the participants live in urban areas, 48% live in regional or rural areas, and 4% preferred not to answer. It should be noted that the information about where participants live is indicated by the participants themselves. As a result, it may not completely follow the Australian Standard Geographical Classification (ABS, 2021a).

4.4.2 Measures

Sense of community: The scale to measure 'Sense of community' consists of 2 items: (1) "I feel strongly connected to the community I live in", and (2) "I think of my community as being a great place to live". The rating format is on a scale of 1 to 3, ranging from disagree (1) to agree (3). The composite reliability was 0.753.

Perceived community benefits: The scale to measure 'Perceived community benefits' consists of 2 items: (1) "Renewables will help regional development", and (2) "Joining CRE helps community building/social connection". The rating format is on a scale of 1 to 5, ranging from strongly disagree (1) to strongly agree (5). The composite reliability was 0.745.

Climate change concern: The scale to measure 'Climate change concern' consists of 2 items: (1) "I feel responsible for climate change", and (2) "Joining CRE helps acting on climate change/carbon emissions reductions". The rating format is on a scale of 1 to 5, ranging from strongly disagree (1) to strongly agree (5). The composite reliability was 0.669.

Attitude to RE: The scale to measure 'Attitude to RE' consists of 2 items: (1) "I think using renewable energy is a sensible idea", and (2) "renewable energy gives me a good feeling". The rating format is on a scale of 1 to 5, ranging from strongly disagree (1) to strongly agree (5). The composite reliability was 0.803.

Attitude to CRE: The scale to measure 'Attitude to CRE' consists of 2 items: (1) "I like the idea of a community owning and being in control of its energy supply", and (2) "CRE has greater independence from commercial energy providers". The rating format is on a scale of 1 to 5, ranging from strongly disagree (1) to strongly agree (5). The composite reliability was 0.667.

4.4.3 Analyses

We employed partial least squares structural equation modeling (PLS-SEM) to examine factors influencing the attitude to CRE based on the conceptual model, using SmartPLS 3.3.3 (Ringle et al., 2015). Then, we compared the strength of the influencing factors across 4 categories of participants, namely (1) urban residents who have RE installed (N = 192), (2) urban residents who do not have

RE installed (N = 217), (3) non-urban residents who have RE installed (N = 200), and (4) non-urban residents who do not have RE installed (N = 216). It should be noted that because there is a small number of participants who live in rural areas, we were unable to run the analyses separately. As a result, the non-urban residents are the combination of participants who indicated that they live in regional (N = 271) and rural area (N = 145). Moreover, those participants who preferred not to answer the question on where they live (N = 35) were not included in the multigroup comparison.

Common method bias: To check for common method bias, we performed Harman's one-factor test. The test results show that 15.92% of the variance is explained by the measurement items, well below the benchmark value of 50.0%. Thus, common method bias should not be a problem in this study (Harman, 1976).

Measurement model assessment: Measurement model assessment consists of three criteria, namely internal consistency reliability, convergent validity, and discriminant validity. Internal consistency reliability was identified by composite reliability with the threshold value of 0.6 (Hair et al., 2017). As shown in Table 6, all composite reliability values of the constructs were satisfactory. Therefore, internal consistency reliability is valid.

Table 6 Measurement model evaluation

Constructs	Items	Factor loadings	P-Value*	Composite Reliability	AVE	VIF
Sense of community	SC1	0.839	0.000	0.753	0.605	1.049
	SC2	0.712	0.000			1.049
Perceived community benefits	CB1	0.735	0.000	0.745	0.594	1.037
	CB2	0.805	0.000			1.037
Climate change concern	CC1	0.795	0.000	0.669	0.506	1.000

	CC2	0.617	0.000			1.000
Attitude to RE	ATT_RE1	0.847	0.000	0.803	0.671	1.134
	ATT_RE2	0.791	0.000			1.134
Attitude to CRE	ATT_CRE1	0.417	0.000	0.667	0.535	1.011
	ATT_CRE2	0.947	0.000			1.011

* Bootstrapping results (n = 5000)

Convergent validity is the degree to which an item correlates positively with alternative items of the same construct (Hair et al., 2017). It was assessed by evaluating factor loading and average variance extracted (AVE). As shown in Table 6, factor loading values of all items were significant. However, there were two items (CC2 and ATT_CRE1) with factor loading values below the threshold value of 0.7 (0.617 and 0.417). According to Hair et al. (2017), the weak factor loading items (< 0.7) can be retained to maintain content validity, but the items with very low factor loading (< 0.4) should be eliminated. Therefore, these two items were retained. On the other hand, the AVE value of all constructs met the recommended value of 0.5. Therefore, the convergent validity of the measurement model can be confirmed.

Lastly, discriminant validity was assessed by evaluating cross-loadings and the Fornell-Larcker criterion. Items should load more on their respective constructs than on any other constructs. On the other hand, according to the Fornell-Larcker criterion, the square root of the AVE should be higher than the correlation with any other construct. As shown in Table 7 and Table 8Table 8 , the measurement model met the cross-loading and the Fornell-Larcker criterion requirements. Therefore, the discriminant validity is established.

Table 7 Measurement model cross-loadings

Items	Sense of community	Perceived community benefits	Climate change concern	Attitude to RE	Attitude to CRE
SC1	0.839	0.171	0.208	0.088	0.072
SC2	0.712	0.111	0.134	0.127	0.053
CB1	0.155	0.735	0.215	0.148	0.244
CB2	0.131	0.805	0.190	0.255	0.204
CC1	0.247	0.212	0.795	0.194	0.176
CC2	0.049	0.156	0.617	0.240	0.261
ATT_RE1	0.118	0.239	0.255	0.847	0.394
ATT_RE2	0.100	0.194	0.233	0.791	0.341
ATT_CRE1	0.168	0.201	0.194	0.081	0.417
ATT_CRE2	0.029	0.245	0.256	0.464	0.947

Table 8 Fornell-Larcker criterion of the measurement model

Constructs	Sense of community	Perceived community benefits	Climate change concern	Attitude to RE	Attitude to CRE
Sense of community	**0.778**				
Perceived community benefits	0.184	**0.771**			
Climate change concern	0.224	0.261	**0.712**		
Attitude to RE	0.134	0.266	0.298	**0.819**	
Attitude to CRE	0.081	0.289	0.296	0.450	**0.732**

The number on the diagonal cells are the square root of the AVEs.

Structural model assessment: The structural model was assessed by evaluating indicator collinearity (Variance inflation factor (VIF)), the coefficient of determination (R^2), the f^2 effect size, and the predictive relevance Q^2 (Hair et al., 2017). As shown in Table 6, all VIF values are smaller than the threshold value of 5.0 (Hair et al., 2017), indicating no collinearity issue. The model had a moderate level of predictive accuracy (R^2 of attitude to CRE was 0.240), all relationships in the model had small effects (f^2 range from 0.017 to 0.177), and there was predictive relevance among endogenous variables in the structural model ($Q^2 > 0$), see Table C1 in the Appendix C.

4.5 Results

4.5.1 Factors influencing attitude to CRE

Direct relationships

The results of the structural equation model are presented in Figure 21. The results showed that attitude to RE, and perceived community benefits are the significant determinants and explain 24.0% of the variance for attitude to CRE. By comparing the path coefficients, attitude to RE (path coefficient = 0.388; $p < 0.001$) has a greater impact on attitude to CRE than the perceived benefits (path coefficient = 0.166; $p < 0.001$). Besides, the attitude to RE also has a positive impact on a perceived community benefits (path coefficient = 0.215; $p < 0.001$). The results also confirmed that climate change concern has an impact on attitude to RE (path coefficient = 0.258; $p < 0.001$). Furthermore, sense of community has an influence on perceived community benefits (path coefficient = 0.125; $p < 0.001$).

Regarding age and gender, the positive coefficient means that the respective attitudinal constructs (i.e., climate change concern, sense of community, attitude to RE, perceived community benefits, and attitude to CRE) are higher for the dummy variable than for the reference group. The magnitude of the coefficients is not interpretable, and therefore is not presented in the figure. Based on our results, age plays significant roles on all five attitudinal constructs. The older age groups tend to have higher climate change concern, sense of community, positive attitude to RE, perceived community benefits, and positive attitude to CRE than the reference group of age 18 to 24. On the other hand, gender plays a role only on the perception of sense of community. Our results showed that males are more likely to feel higher sense of community than females.

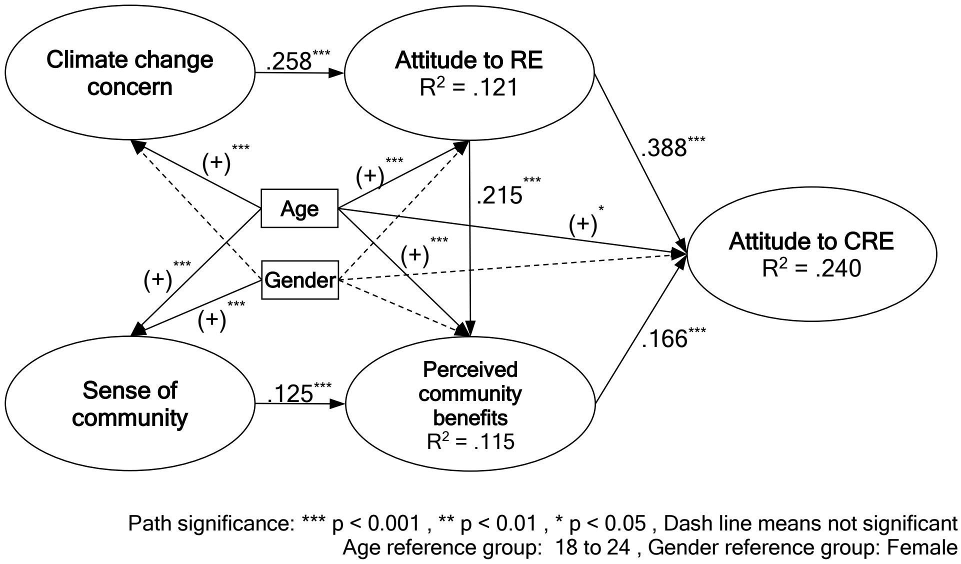


Figure 21 Results of PLS-SEM showing factors influencing consumers' attitude to CRE

Indirect relationships

We further tested whether there are mediation relationships between climate change concern and sense of community, and the attitude to CRE. As shown in Table 9, climate change concern influences the attitude to CRE indirectly through attitude to RE (path coefficient = 0.055; $p < 0.001$). It also influences the attitude towards CRE through the relationship between the attitude to RE and perceived community benefits (path coefficient = 0.009; $p < 0.01$). On the other hand, a sense of community influences attitude towards CRE indirectly through perceived community benefits (path coefficient = 0.021; $p < 0.01$). In other words, attitude to RE plays a mediating role in the relationship between climate change concern and attitude to CRE. Meanwhile, perceived community benefits play a mediating role in the causal link between sense of community and attitude to CRE.

Table 9 Indirect effects of climate change concern and sense of community on attitude to CRE

Path	Path coefficient
Climate change concern → Attitude to RE → Attitude to CRE	0.055***
Climate change concern → Attitude to RE → Perceived community benefits → Attitude to CRE	0.009**
Sense of community → Perceived community benefits → Attitude to CRE	0.021**

*** $p < 0.001$, ** $p < 0.01$

4.5.2 The moderating roles of location and renewable energy awareness

Figure 22 present a comparison of the results across the four categories of participants: (1) urban residents who have RE installed, (2) urban residents who do not have RE installed, (3) non-urban residents who have RE installed, and (4) non-urban residents who do not have RE installed (the full results are reported in Table C2 in the Appendix C). The results showed that while all the four proposed relationships are significant among the urban residents who already RE installed, only some of them are significant among the other categories of the respondents.

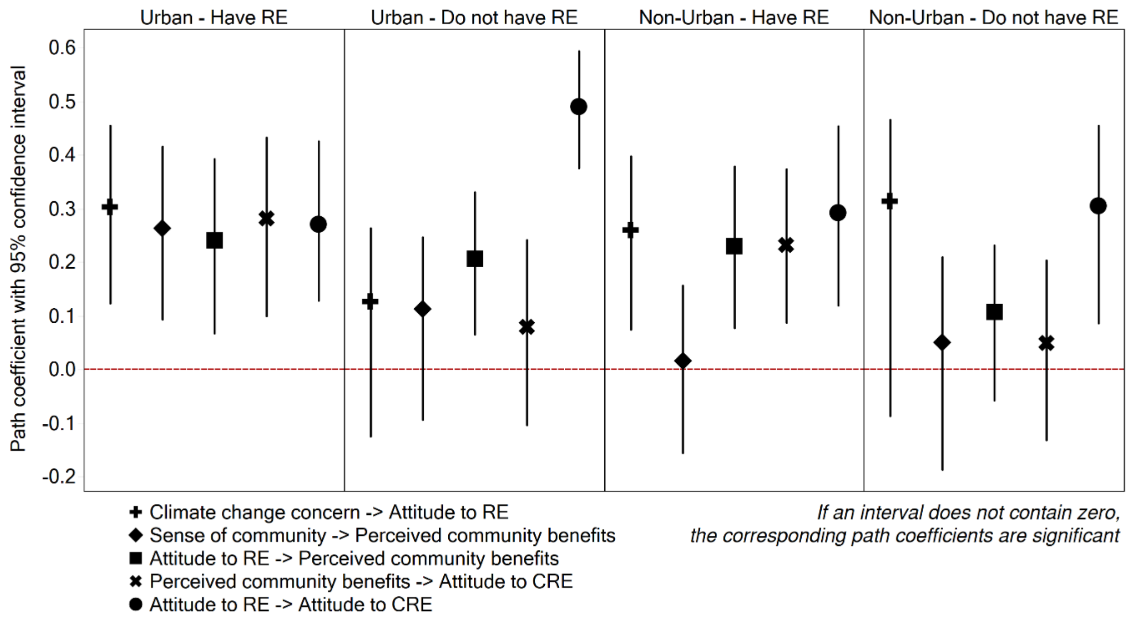


Figure 22 Comparison of path coefficients between 4 categories of participants

Positive attitudes to RE (the ● symbol) are a significant determinant of the positive attitude to CRE for all categories of participants. While its impact is comparable among the other categories (path coefficient range from 0.271 to 0.306), it has a strongest influence among urban residents who do not have RE installed (path coefficient = 0.490). On the other hand, the perceived community benefits (the ✖ symbol) are only significant among those who already have RE installed, both urban and non-urban residents. The influence of perceived community benefits on positive attitude to CRE is slightly stronger among the urban residents (path coefficient = 0.282) than the non-urban residents (path coefficient = 0.231). Besides, the attitude to RE has a positive impact on a perceived community benefits (the ■ symbol) in all categories of participants, except for the non-urban residents who do not have RE. The path coefficient is comparable across the three categories, range from 0.207 to 0.241.

The impact of climate change concern on the positive attitude to RE (the ✚ symbol) is only significant among those who already have RE installed, and the influence is stronger among the urban residents (path coefficient = 0.303) than the non-urban residents (path coefficient = 0.260). It also indirectly influences positive attitude to CRE through attitude to RE (path coefficient = 0.082 for urban, and 0.076 for non-urban residents), as shown in Table 10.

The influence of a sense of community on perceived community benefits (the ◆ symbol) is only significant among the urban residents who already have RE installed (path coefficient = 0.263). It also indirectly influences attitude to CRE through perceived community (path coefficient = 0.074) (Table 10). By comparing the magnitude of the coefficients across four categories (Figure 22), the influence of sense of community is clearly stronger among urban residents than non-urban residents.

Table 10 Comparison of indirect effects of climate change concern and sense of community on attitude to CRE

Path	Path coefficient	
	Urban - Have RE	Non-urban - Have RE
Climate change concern → Attitude to RE → Attitude to CRE	0.082*	0.076*
Climate change concern → Attitude to RE → Perceived community benefits → Attitude to CRE	0.021 n.s.	0.014 n.s.
Sense of community → Perceived community benefits → Attitude to CRE	0.074*	0.004 n.s.

* $p < 0.05$, n.s. = not significant

4.5.3 Impact of power outage duration and number of solar installations

Since there are impacts of location (urban/non-urban) and RE awareness (have/do not have RE), we further tested the impact of power outage frequency and duration (which differ between urban and rural area, as discussed in Section 2.2), and number of solar installations (which differ across locations) on the attitude to RE, and CRE from our surveyed data.

Following the Australian Bureau of Statistics (ABS, 2021b), we used postcodes to identify both the states or territories participants live in, and whether they live in the greater capital cities or in the remainder of the states. It was found that our participants are from six states: NSW, VIC, QLD, SA, WA, and TAS, while there are no participants from the territories of NT and ACT.

The results showed that among participants who live outside the greater capital cities, electricity interruption duration is linearly related with both the positive attitude to RE, and CRE (Figure 23). The average interruption duration explained a considerable proportion of variance in both attitude to RE ($R^2 = 0.84$, $p < 0.01$), and attitude to CRE ($R^2 = 0.85$, $p < 0.01$). The higher the average interruption duration, the more positive attitude to RE and CRE among participants who live outside the greater capital cities. However, no relation was found between the average interruption frequency and the attitude to RE, and CRE.

On the other hand, among participants who live in the greater capital cities, the number of solar installations (both PV and solar water heater) is linearly related to the positive attitude to RE and CRE. As shown in Figure 24, the number of solar installations explains 75% of the variance of attitude to RE, and 89% of the variance of attitude to CRE among greater capital cities residents.

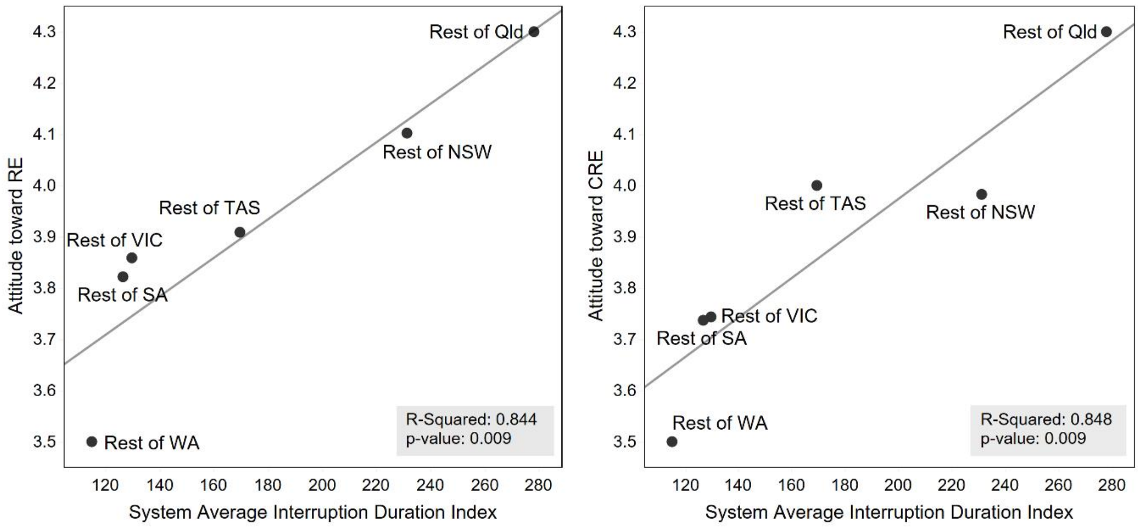
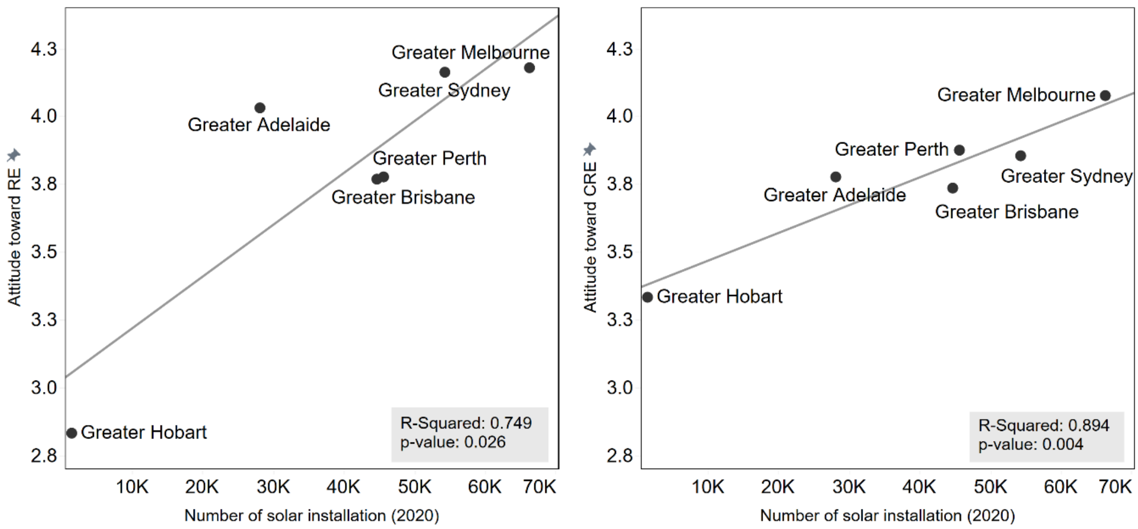


Figure 23 Relationship between electricity interruption duration and attitude to RE and CRE among participants who live outside greater capital cities



Data source: Number of solar installations from ABS (2023)

Figure 24 Relationship between number of solar installation and attitude to RE and CRE among participant who live in greater capital cities

4.6 Discussion

This empirical study has aimed to acquire a better understanding of Australian consumers' attitudes to CRE. We proposed a conceptual model and tested how attitude to RE, perceived community benefits, climate change concern, and sense of community, impact attitude to CRE. Furthermore, we tested whether there are any differences in the factors of attitude to CRE between urban and non-urban participants and between those who have or do not have RE. As well, we examined the impact of power outage frequency and duration, and the number of solar installations in the area on attitude to RE, and CRE.

Although Australia faces certain policies (CPA, 2021) and political challenges that make the situation different from situation in some European countries where CRE sector are more mature (Mey et al., 2016), the findings of this study align with the findings of case studies conducted in European countries. This indicates a shared enthusiasm among citizens for CRE.

The results of PLS-SEM revealed that both the attitude to RE and the perceived community benefits are significant predictors of the attitude to CRE, but the impact of attitude towards RE is a much stronger influence than the impact of perceived community benefits. With regards to the impact of the attitude to RE on the attitude to CRE, our findings are consistent with the findings of case studies in Germany (Dóci & Vasileiadou, 2015; Kalkbrenner & Roosen, 2016), and Belgium (Bauwens, 2016; Conradie et al., 2021). With regards to the impact of the perceived community benefits on attitude to CRE, our findings agree with Proudlove et al. (2020) which is also an Australian case study. We also found that climate change concern indirectly influences attitude to CRE through people's attitude to RE. This supports Conradie et al. (2021)' s argument that an interest in CRE should not only be seen as driven by the desire for financial gain but also through the lens of environmental responsibility.

Our findings revealed that positive attitudes to RE play a crucial role in influencing a positive attitude to CRE, regardless of where the individuals live or whether they already have RE installed. This supports the findings of Bauwens and Devine-Wright (2018) in Belgium, and Radtke et al. (2022) in Germany. The results also showed that the impact of attitude to RE is much stronger among the urban residents who do not currently have RE installed. It should be kept in mind that individuals who do not have RE installed do not necessarily unsupport RE. They may want to own RE but have some barriers (Poshnath et al., 2023). For example, although Australia has high solar energy potential, residents of apartments may not have their own roofs to install PV, renters may not be allowed to install RE in rental properties, or they might have limited space or inadequate sunlight due to overshadowing neighbors, people may not be able to raise the capital, and strata title regulations may affect owner's pricing of electricity use. These factors might explain why attitudes to RE are stronger for the urban residents who do not have RE. As they cannot have RE directly by themselves, CRE might be a good channel for them to become less reliant on fossil fuels.

With regards to the perceived community benefits, the results revealed that it is a significant predictor of attitude to CRE only among individuals who already have RE, regardless of where they live. This implies that individuals who are aware of RE, have obtained familiarity and have clear understanding of the benefits of RE. The level of familiarity with an object has the potential to impact preference formation (Dällenbach & Wüstenhagen, 2022). When there is a lack of familiarity, people tend to evaluate benefits and risks through emotion or trust rather than through logical reasoning based on factual evidence (Guo & Ren, 2017). The roles of familiarity in our findings are in line with those of Wang et al. (2020) who studied rebuilding a nuclear power plant, and those of Fischer et al. (2021) in the case of participation in RE cooperatives. Our findings point to a potential positive effect of RE awareness in enhancing a positive attitude to CRE. When people become more aware of RE and their benefits, they are more likely to support CRE.

With regards to a sense of community, it appears to indirectly influence the positive attitude to CRE through the perceived community benefits. This is in line with findings of the case studies in the US (Chavis & Wandersman, 1990; Omoto & Packard, 2016). However, the influence is stronger among individuals who live in urban areas than among those who live in non-urban areas. In other words, a sense of community does not lead to a positive attitude to CRE among non-urban people. This supports the finding of Li et al. (2022) that a sense of community may not positively influence pro-environmental behavior. One possible explanation is that non-urban people tend to be more attached to their homes and local areas than urban people (Anton & Lawrence, 2014). Individuals with a strong connection to their local area are less inclined to view new developments favorably, as it may alter the place they have an emotional attachment to (Devine-Wright, 2009). As a result, they may be resistant to change, even if the change is positive or could benefit the community in the long run.

Regarding the age, the findings revealed that older age groups tend to have higher climate change concern, sense of community, positive attitude to RE, perceived community benefits, and positive attitude to CRE than the reference group of age 18 to 24. These findings are consistent with Wang et al. (2021) which found that older people are more likely to engage in environmental behavior.

These impacts of age possibly be explained by the ‘sense of legacy’ which refer to perception that an individual or group holds regarding the impact, contributions, or lasting influence they will leave behind for future generations (Frumkin et al., 2012). Furthermore, Frumkin et al. (2012) also suggested that older people often display a sense of generosity and altruism, driven by a desire to leave a positive impact on the world. This is evident through their notable engagement in volunteer activities and the willingness of elderly Japanese engineers to offer their assistance at the disabled Fukushima nuclear plant in 2011, despite the potential risks involved (Lah, 2011).

Furthermore, our results showed that among participants who live outside the greater capital cities, the longer the electricity interruption duration that participants experienced, the more positive is the attitude to RE, and CRE. As mentioned by AER (2022b), the distribution lines in rural areas are vulnerable because they cover large geographical areas. As a result, people living outside the greater capital cities might experience longer power outages, as it could take more time for the supply to restore once the outage occurs. Our findings imply that RE and CRE are a promising alternative electricity supply for people who live outside the greater capital cities. On the other hand, for people who live in the greater capital cities, where the outage duration might not be an issue, there is a positive correlation between the number of solar installations in their area and the positive attitude to RE. This correlation can be explained from two perspective. On one hand, it can be attribute to the visibility and awareness. When people see solar panels on neighboring homes, it increases their awareness of RE, which can lead to a positive attitude to RE. On the other hand, this correlation may exist due to the fact that people with a positive attitude to RE have installed solar panels on their rooftop. Therefore, the presence of solar installations in the area could be a result of proactive people who have a favorable attitude to RE. Furthermore, there is also a correlation between the number solar installation and the positive attitude to CRE. This supports our findings in the previous section that positive attitude to RE is a significant determinant of positive attitude to CRE. It is plausible that positive attitude to RE could influence solar panels installation, and indirectly influence positive attitude to CRE. Alternatively, the visibility of solar panels in the area might enhance positive attitude to RE, which subsequently extends to positive attitude to CRE.

This study has several limitations. Firstly, it is possible that there may be biases in the selection process in this study as it was largely distributed through Community Power Agency newsletters and social media. Community Power Agency subscribers and followers may be those who are already interested in and support CRE. As a result, their answers may be more positive than with people in general. Secondly, we only assessed the attitude to CRE. Positive attitude to CRE may not completely translate into real action, participation in the CRE in this case, which leads to an attitude-behavior gap. This needs to be considered when interpreting the results. Thirdly, the PLS-SEM results are based on the hypothesized relationship in the conceptual model. The R^2 value indicated that 24.0% of the variation in attitude to CRE can be explained by attitude to RE and perceived community benefits. This implies that there may be additional variables and relationships not considered in this study that could contribute to the explanation of attitude to CRE. Future studies should consider adding more variables such as perceived innovation adoption, return of investment, social recognition, interpersonal trust (Karytsas & Theodoropoulou, 2022). In addition, other demographics variable such as income level, education level, race, ethnicity, number of children in the home, as well as experience with CRE could influence attitude toward CRE. Future research should consider including these variables in the model. Furthermore, the model could be expanded to the intention to participate in CRE which is a strong determinant of actual behavior. Besides, given that the survey was administered to individuals in Australia, the differences in electricity generation and distribution, availability of local renewable energy resources, as well as government policies across countries, may result in varying results. Further research is needed to identify the local specifics and the local policies that may be recommended.

4.7 Policy implications

The findings of this study provide some policy implications. Firstly, given the significant impact of attitude to RE on attitude to CRE, information and awareness raising campaigns to increase positive attitude to RE might have significant potential in enhancing positive attitude to CRE, which may in turn have impacts upon the possible speed of, and support for, energy transition. Although the promotion of RE is not new, misconception and insufficient awareness persist (Lucas et al., 2021). Thus, information campaigns are needed in order to address misconception and raise awareness about RE which may result in increased positive attitude to RE. Once people have positive attitude to RE, they tend to have positive attitude toward CRE. According to Lucas et al. (2021), improving RE communication could be done by, for example, creating a consistent message that highlights the advantages of all renewable energy technologies, and of CRE itself. This could involve simplifying the language used and using visual aids. Additionally, tailored information should be created for different groups of people. Once people have positive attitudes about RE, it can be expected that it will influence attitudes to CRE positively, and lead to willingness to take part in CRE.

Secondly, considering the significant impact of perceived community benefits on attitude to CRE among participants who already have RE, having prior experience with RE may lead people to have better understanding of the benefits of RE. As a result, they could have more informed perspectives on how CRE can benefit their community. Additionally, considering the correlation between attitude to both RE and CRE, and number of solar installations in the area among individuals living in the greater capital cities, familiarity with RE may lead people to have positive perception about RE and CRE. According to Arkesteijn and Oerlemans (2005), visual exposure to RE infrastructure plays a role in shaping perceptions about technology, and in turn, affects their willingness to accept and use it.

Thirdly, considering differences between urban and non-urban residents in the indirect impact of a sense of community on the attitude to CRE, we may conclude that there is no one-size-fits-all approach to shape a positive attitude to CRE. Our results suggest that for urban people, the stronger their connection to the local community, the more likely they are to hold a favorable view of CRE. For non-urban people, in contrast, the more they feel attached to their local community, the less likely they are to have a positive perception of CRE. This may be addressed by social network. As suggested by F. Goedkoop et al. (2022), social ties between community members and CRE initiators play a role for participation in CRE. Thus, for the CRE initiatives in non-urban areas, a good relationship between CRE initiators and the local members may address the unfavorable attitude to CRE due to the feeling of being attached to local community.

Fourthly, considering the impact of power outage duration on attitude to RE and CRE among participants who live outside the greater capital cities, highlighting the advantages of CRE as an alternative electricity supply might increase people's support for its development, especially in the areas where electricity supply is unstable.

We might also expect that regulations which enhance community capacity to engage in CRE, would also help people to have a more positive attitude towards CRE. If CRE seems impossibly difficult because of regulation, people may not want to get involved.

4.8 Conclusions

This study provides insights into factors influencing positive attitude to CRE in the context of Australia. Positive attitude to RE was the strongest predictor for positive attitude to CRE. Despite having weaker impact, perceived community benefits also play a role in driving positive attitude to CRE. We also showed that positive attitude to CRE could be indirectly driven by climate change concern and sense of community. Furthermore, our findings revealed that there were differences in the influential factors of positive attitude to CRE between individuals who already have RE and those who do not, as well as between urban residents and non-urban residents. We also found that the attitude to RE, and attitude to CRE are influenced by two factors: 1) poor power quality (measured by the length of power outages) in regional area (i.e., outside the greater capital cities), and 2) the number of solar installations in the greater capital cities. Therefore, different policies and measures may be required for the successful implementation of CRE in different settings.

4.9 Acknowledgement

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5 IMPACT OF OCCUPANT AUTONOMY ON SATISFACTION AND BUILDING ENERGY EFFICIENCY

“Buildings don't use energy: people do”

(Janda, 2011)

5.1 Preamble

Status

Paper Status

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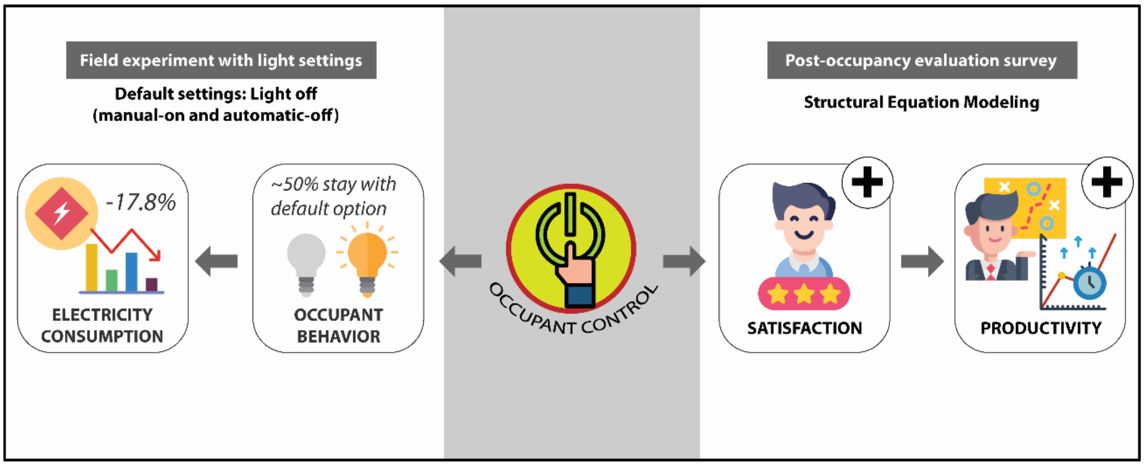
Abstract

The philosophy of building energy management is going through a paradigm change from traditional, often inefficient, user-controlled systems to one that is

centrally automated with the aid of IoT-enabled technologies. In this context, occupants' perceived control and building automation may seem to be in conflict. The inquiry of this study is rooted in a proposition that while building automation and centralized control systems are assumed to provide indoor comfort and conserve energy use, limiting occupants' control over their work environment may result in dissatisfaction, and in turn decrease productivity. For assessing this hypothesis, data from the post- occupancy evaluation survey of a smart building in a university in Australia was used to analyze the relationships between perceived control, satisfaction, and perceived productivity. Using structural equation modeling, we have found a positive direct effect of occupants' perceived control on overall satisfaction with their working area. Meanwhile, perceived control exerts an influence on perceived productivity through satisfaction. Furthermore, a field experiment conducted in the same building revealed the potential impact that occupant controllability can have on energy saving. We changed the default light settings from automatic on-and-off to manual-on and automatic-off, letting occupants choose themselves whether to switch the light on or not. Interestingly, about half of the participants usually kept the lights off, preferring daylight in their rooms. This also resulted in a reduction in lighting electricity use by 17.8% without any upfront investment and major technical modification. These findings emphasize the important role of perceived control on occupant satisfaction and productivity, as well as on the energy-saving potential of the user-in-the-loop automation of buildings.

Graphical abstract



Findings

In the previous chapter,

The focus was on collective energy-related behavior in household context. We examined factors influencing Australian consumers' attitudes to community renewable energy as an alternative electricity supply. We also highlighted the impact of location and renewable energy awareness on attitude to community renewable energy.

In this chapter,

Now we focus on behavioral intervention strategies that can decrease energy consumption without compromising user satisfaction at work. Office buildings are often occupied by organizations that consist of different people. The comfort preference of these people is subjective and can be different. However, centralized control systems, which aim to conserve energy use, usually limit occupants' control over their work environment. This chapter analyzes how occupants' controllability over their working environment can affect their satisfaction, perceived productivity, and building energy demand. It also shows that in some cases users can be more efficient in energy saving decisions, than the automatic control systems that are imposed on them, especially when those are poorly designed.

The main findings of this chapter are

1. Occupants' perceived control has a positive direct effect on overall satisfaction with their working area. It also has a positive indirect effect on occupants' perceived productivity.
2. With proper default settings, giving occupants control over their working environment can lead to changes in occupant behavior and, in turn, reduce energy consumption.

In the next chapter,

This thesis is wrapped up by summarizing the findings, clarifying its contributions, identifying implications, and pointing out the recommendations for future research.

Author Contributions

Wipa Loengbudnark: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Visualization. **Kaveh Khalilpour:** Conceptualization, Writing – review & editing. **Gnana Bharathy:** Methodology, Writing – review & editing. **Alexey Voinov:** Conceptualization, Writing – review & editing, Supervision. **Leena Thomas:** Investigation, Data curation.

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Impact of occupant autonomy on satisfaction and building energy efficiency

Wipa Loengbudnark [a,*], Kaveh Khalilpour [a], Gnana Bharathy [a], Alexey Voinov [a,c], Leena Thomas [b]

[a] *Center on Persuasive Systems for Wise Adaptive Living, Faculty of Engineering & IT, University of Technology Sydney, NSW 2007, Australia*
[b] *School of Architecture, Faculty of Design, Architecture and Building, University of Technology Sydney, NSW 2007, Australia*
[c] *Faculty of Engineering Technology, University of Twente, the Netherlands*

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ABSTRACT

The philosophy of building energy management is going through a paradigm change from traditional, often inefficient, user-controlled systems to one that is centrally automated with the aid of IoT-enabled technologies. In this context, occupants' perceived control and building automation may seem to be in conflict. The inquiry of this study is rooted in a proposition that while building automation and centralized control systems are assumed to provide indoor comfort and conserve energy use, limiting occupants' control over their work environment may result in dissatisfaction, and in turn decrease productivity. For assessing this hypothesis, data from the post-occupancy evaluation survey of a smart building in a university in Australia was used to analyze the relationships between perceived control, satisfaction, and perceived productivity. Using structural equation modeling, we have found a positive direct effect of occupants' perceived control on overall satisfaction with their working area. Meanwhile, perceived control exerts an influence on perceived productivity through satisfaction. Furthermore, a field experiment conducted in the same building revealed the potential impact that occupant controllability can have on energy saving. We changed the default light settings from automatic on-and-off to manual-on and automatic-off, letting occupants choose themselves whether to switch the light on or not. Interestingly, about half of the participants usually kept the lights off, preferring daylight in their rooms. This also resulted in a reduction in lighting electricity use by 17.8% without any upfront investment and major technical modification. These findings emphasize the important role of perceived control on occupant satisfaction and productivity, as well as on the energy-saving potential of the user-in-the-loop automation of buildings.

1. Introduction

Due to the high share of energy use in buildings, several attempts have been made to minimize building energy consumption. Occupants and their interaction with the building system have a significant impact on building energy performance [1]. As a result, more automated systems and less occupant control are often believed to reduce energy use for building operations [2]. One of the solutions is the use of automated building control systems, which aim to maintain the constant and predefined levels of comfort of occupants [3]. However, this solution may overlook occupants' preferences, and may not always be the most energy-efficient approach. Building automation and occupants' perceived control seem to be in conflict [2]. In fact, the relationship between occupant satisfaction and comfort is far beyond physical parameters [4]. Occupants are not only satisfied by comfort but also by other factors such as a sense of control over choosing the comfort level [5]. Several studies have confirmed the positive relationship between occupants' perceived control over their environment and satisfaction [3,6,7].

The key research question in this study is to understand the satisfyingly efficient ways of building energy management that satisfy multiple goals, particularly achieving reasonable energy efficiency as well as occupant satisfaction. The subsequent enquiry is whether a full automation strategy can enable these objectives or a compromise fuzzy approach, between 100% user-control and 100% automation, is more appropriate.

The impact of occupant control on their satisfaction needs more exploration [8], and studies on energy-saving potential of occupants' controllability are limited [6]. This paper aims to examine (1) the role of occupants' perceived control over building systems to determine whether and to what extent it influences satisfaction and perceived productivity, and (2) energy saving potential of giving occupants control over their environment. The innovation of this paper, from the research perspective, is that it relates occupants' satisfaction to their perceived control and shows that high levels of automation may weaken pro-environmental behaviors. We also show that the common expectation that automa-

* Corresponding author.
E-mail address: Wipa.Loengbudnark@student.uts.edu.au (W. Loengbudnark).

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tion can always improve efficiency may be flawed and that automation should be used with care, taking into account such factors as human psychology when choosing the default settings. From the methodological perspective, the paper employs structural equation modeling to analyze a post-occupancy evaluation survey and test the influence of occupants' perceived control on satisfaction and productivity.

The paper continues as follows Section 2. focuses on literature review. In Section 3, methodology is described, followed by the field experiment in Section 4 Section 5. focuses on data analysis and results with further discussions in Section 6. Finally, the paper overviews its findings and points out the limitations.

2. Literature review

2.1. Indoor environmental quality, satisfaction, and productivity

A building is designed to provide comfort conditions for its occupants [9], and occupants' satisfaction with the building is associated with indoor environmental quality (IEQ) [10]. The main IEQ parameters include: thermal comfort, indoor air quality, visual comfort, and acoustic comfort [11,12]. Several studies confirmed the influence of IEQ factors on occupants' satisfaction [13,14]. Whereas poor IEQ can negatively affect occupants by causing discomfort and sick building syndrome [10]. In the context of the workplace, several studies confirmed that IEQ also plays a significant role in occupants' performance at work [9,13,15].

Besides, IEQ is also associated with the amount of energy consumption in buildings [12]. Thermal comfort is influenced by several environmental parameters, namely air temperature, air velocity, mean radiant temperature, and relative humidity [12]. Heating, ventilation, and air-conditioning systems (HVAC) are used to control these parameters in order to provide thermal comfort. As a result, HVAC accounts for a great share of energy use in non-residential buildings [16].

On the other hand, visual comfort is associated with the use of artificial lighting, shading devices, as well as the accessibility to daylight. Lighting is one of the major energy end-use in buildings and accounts for a quarter of the total electricity consumption in office buildings in Australia [17]. Several attempts have been made to reduce energy consumption for lighting. For example, there has been a huge improvement of the light bulb from 60-watt incandescent to 14-watt compact fluorescent, and recently 7-watt light-emitting diode or LED.

2.2. Perceived control

Over the past few years, there has been a growing number of automated control systems used in buildings, which aim not only to provide more comfort to the occupants but also to minimize building energy consumption [18]. Nevertheless, in the context of office buildings, the relationship between office energy efficiency and occupants' well-being and working performance is still unclear [19].

The automated control systems in buildings can drastically limit occupants' ability to exert control over their environment [20]. While some research reveals that a centralized control system can improve occupants' satisfaction and perceived productivity [14,21], other research shows that occupants working in green-rated office buildings have a lower level of satisfaction and perceived productivity compared to those working in conventional buildings [22].

From a psychological perspective, people need autonomy. Having a sense of control increases the feeling of comfort and occupants' satisfaction [23]. Similarly, the concept of homeostasis states that: *"if a change occurs such as producing discomfort, people react in a way to restore their comfort condition*" [24];. In fact, having a sense of control and having choices is closely related. People exercise control by making a choice in order to achieve their desired results or avoid undesirable ones [25]. McCunn et al [26]. found that perceived productivity has a positive association with perceived control. Similarly, Göçer et al [7]. found that personal control is a strong predictor contributing to occupants' perceived productivity in both high- and low-performance offices.

2.3. Default lighting settings and occupant behavior

One of the notions that appear to align with the concept of controllability is nudging. Nudging is a promising tool that can be used to change human behavior towards desirable outcomes. The core concept of nudging is not to limit people's freedom to choose but to improve the choice architecture instead [27]. Thaler and Sunstein [28], who introduced the concept of nudging, defined nudging as: *"any aspect of the choice architecture that alters people's behavior in a predictable way, without forbidding any options or significantly changing their economic incentives"*. The advantage of nudging is that it does not require a great amount of money to administer and implement, and can begin with the simple question: "*What's keeping someone from already doing the good things?"* [29].

One of the cognitive biases that have been effectively applied for nudging is status quo bias or the bias that makes people tend to stick to the default option [30,31]. The default option has been successful in several fields. For example, organ donations [32], financial savings [33], charitable giving [34], and food choices [31]. In energy-related applications, the default option has been applied to promote the domestic uptake of green energy [35,36].

In the context of building energy, lighting offers one of the greatest energy-saving potentials [37]. It is especially attractive when one takes into account: (1) the (small) effort required to turn off an unnecessary light in an office room; and (2) the number of such light bulb opportunities. In this context, the interaction between occupants and lighting controls gains much interest. For instance, Yun et al [38]. conducted a monitoring study in shared offices in a university in Korea. The findings revealed that the lighting usage behavior has a strong relationship with the occupancy pattern, while there was no statistical significance with the external illuminance. In other words, there was a strong tendency that occupants switch the light on when they first arrived at the offices in the morning and the light stayed on during working hours regardless of external illuminance level. Heydarian et al [39]. emphasized the importance of default lighting settings. Through an application of an immersive virtual environment, they found that people are more likely to stick with the default condition if the rooms had maximum simulated daylight available, no matter if the artificial lights are on or off. However, people also stick with the default condition if all the artificial lights are on. Furthermore, Gilani and O'Brien [18] examined the impact of lighting control systems on the energy use of private offices in an academic building in Canada, using both experimental and simulation techniques. The results indicated a reduction in lighting energy use by a factor of seven with a manual control system compared to an automated control system.

2.4. Conceptual diagram

Based on the above literature review, a conceptual diagram is shown in Fig. 1. The indoor environment influences occupant satisfaction. When occupants perceive dissatisfaction with the indoor environment, they interact with the energy using systems in the building, such as lights and air-conditioners. On the one hand, the energy using systems will adjust the indoor environment to meet occupants' preference. On the other hand, the energy demand for the systems will increase or decrease following the interaction of occupants and the systems.

3. Methodology

In this study, structural equation modeling (SEM) was used to explore the influence of occupants' perceived control on satisfaction and productivity. Schweiker et al [40]., recommended SEM to study indoor environmental perception and behavior studies as it allows us to understand the interdependent relationships. In this study, one particular

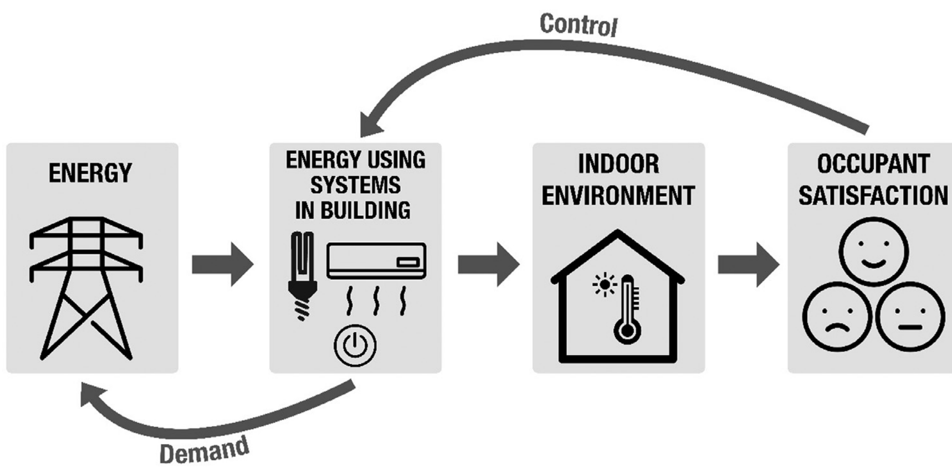

Fig. 1. Conceptual diagram of occupant interactions with energy using systems in building (For picture sources, see Appendix A in supplementary file).

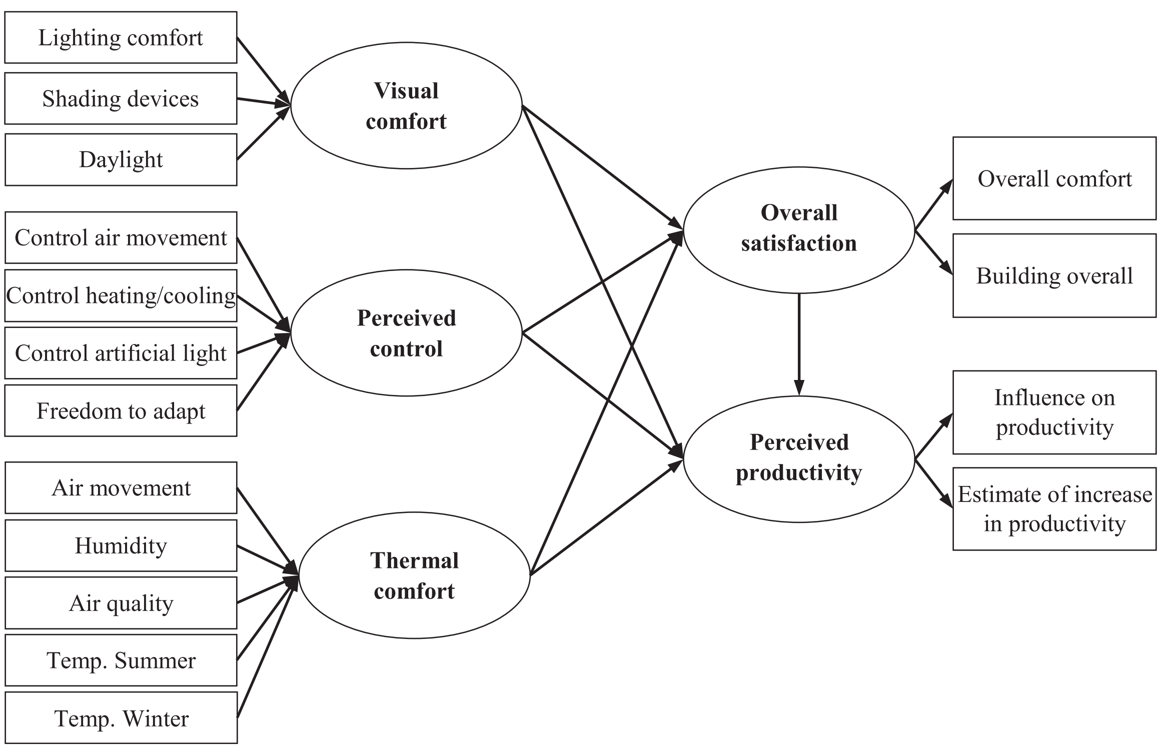

Fig. 2. The proposed model of occupants' satisfaction and perceived productivity.

variant of SEM, namely Partial Least Square (PLS) approach was used to estimate SEM parameters. The advantages of PLS are that the robust estimates are obtainable even with small sample sizes and it does not require multivariate normal distribution assumption [41,42]. The analysis was performed using the SmartPLS software version 3.3.3 [43].

3.1. Structural model

Based on the literature review, this study hypothesized that thermal comfort, visual comfort, and perceived control influence both occupants' overall satisfaction and occupants' perceived productivity. At the same time, satisfaction is hypothesized to influence perceived productivity. The proposed model is presented in Fig. 2.

Table 1 summarizes the model constructs and their underlying indicators. The means and standard deviations were calculated using RStudio [44]. It should be noted that the exogenous constructs, namely 'Thermal comfort', 'Visual comfort', and 'Perceived control' are evaluated by their underlying indicators formatively, as they influence the above latent variables. This is appropriate as these constructs are derived by the respective measures. Meanwhile, the endogenous constructs, namely 'Overall satisfaction', and 'Perceived productivity' are evaluated reflectively. This is appropriate as the constructs are influenced by the respective latent construct, correlated and are interchangeable.

3.2. Questionnaire

We used a subset of data from the post-occupancy evaluation survey called BOSSA [45], which originally aims to assess occupants' satisfaction with the IEQ performance of the building in a separate and independent research project. We therefore characterize this data as external and secondary to this study.

Participants are the occupants of a 13-story academic building located in Central Sydney, Australia. The building serves as both teaching spaces and staff offices. It is designed with sustainable features and has been awarded 5 Star Green Star Design & As-Built certified by the Green Building Council of Australia. The external wall of the building is made

Table 1
Model constructs and indicators.

Constructs	Indicators	Mean	SD
Thermal comfort	Air movement	4.342	1.960
	Overall humidity	4.973	1.617
	Overall air quality	4.824	1.805
	Temperature conditions in summer *(From uncomfortable to comfortable)*	4.947	1.679
	Temperature conditions in winter *(From uncomfortable to comfortable)*	4.813	1.762
Visual comfort	Lighting comfort	5.241	1.681
	Shading devices for controlling unwanted glare	4.668	1.852
	Access to daylight	4.877	2.132
Perceived control	Level of personal control over air movement *(From no control to full control)*	3.091	1.811
	Level of personal control over heating or cooling *(From no control to full control)*	3.086	1.880
	Level of personal control over artificial lighting *(From no control to full control)*	3.182	1.978
	Degree of freedom to adapt work area to meet preferences	3.406	1.903
Overall satisfaction	Overall comfort *(The overall ratings for work area comfort)*	4.492	1.710
	Building overall *(Satisfaction with the building)*	4.663	1.721
Perceived productivity	Influence on productivity *(From negatively to positively)*	4.321	1.780
	Estimate of increase in productivity *(From decrease by 30% to increase by 30%)*	3.963	1.801

of glass and covered with a semi-transparent façade. HVAC systems are centrally controlled from a facility plant and the local thermostats are set to be non-adjustable. Meanwhile, lighting systems are controlled by passive infrared (PIR) motion sensors to switch the light on and off.

Participants were asked to rate their satisfaction on a continuous seven-point scale where 1 is Unsatisfactory and 7 is Satisfactory unless specified otherwise. The survey was conducted between 23 July 2019 to 21 August 2019. It received 188 responses, for which one response was from a faculty staff working in another building. As a result, the final sample size for our analysis is 187.

The survey participants included professional staff (56%), administrative/technical/managerial staff (30%), and others (14%). Among these, 61% are males, 32% are female, and 7% prefer not to answer. The participants were distributed over 3 age groups: 30 years or under (14%), 31-50 years (53%), over 50 years (29%), and prefer not to answer. In addition, 45% work in private offices, 20% work in offices shared with other occupants, and the remaining 35% work in open-plan offices.

3.3. Model evaluation

3.3.1. Common method bias

Considering common method bias in survey research, Harman's one-factor test was performed. The test results indicate 41.58% of the variance is explained by the measurement items, less than the benchmark value of 50.0%. Thus, the common method bias should not be a concern in this study [44].

3.3.2. Measurement model assessment

This study consists of both formative and reflective constructs which require different assessment procedures [46]. The formative constructs in this study include 'Thermal comfort', 'Visual comfort', and 'Perceived control'. The measurement model results are reported in Appendix B. The formative items should be assessed for multicollinearity and their significance and weights. Variance inflation factor (VIF) is used to identify multicollinearity issues. VIF > 5 indicates a potential multicollinearity problem [46]. In this study, all items have satisfactory VIF, except the VIF of the item 'Control heating/cooling' was 5.0. This is probably because it is similar to the item 'Control air movement' because air movement and temperature can be controlled via thermostat. Thus, the item 'Control heating/cooling' was removed from the model. Regarding significance and weights of the items, item 'Temp. summer', 'Temp. winter', 'Control air movement' and 'Control artificial lighting' were not significant. However, their loadings are high (> 0.5), indicating the items are absolutely important and should be retained [46].

The reflective constructs in this study are 'Overall satisfaction', and 'Perceived productivity'. Three criteria should be examined, namely internal consistency reliability, convergent validity, and discriminant validity. Cronbach's alpha and composite reliability are used to identify internal consistency reliability. All Cronbach's alpha and composite reliability values of the constructs are larger than the threshold value of 0.6, indicating the reliability in the internal consistency among the constructs.

Next, convergent validity was tested based on factor loading and average variance extracted (AVE). The results of a bootstrapping procedure with 5,000 samples showed that factor loading of all items is significant and larger than the threshold value of 0.7 [46]. On the other hand, the AVE value of all constructs is greater than the recommended value of 0.5 [46]. Therefore, these examinations confirm the convergent validity of the measurement model.

Lastly, discriminant validity was examined based on cross-loadings and the Fornell-Larcker criterion. Discriminant validity is established when items load more on their intended constructs than on other constructs [47]. According to the Fornell-Larcker criterion, moreover, the square root of the AVE should be greater than the highest correlation with any other construct [46]. As shown in Appendix C, all the items load high on their own constructs. Also, the square root of the AVE of each construct is larger than the highest correlation with other constructs (Appendix D). Therefore, the discriminant validity of the measurement model meets the requirements.

3.3.3. Structural model assessment

The criteria to assess structural model are the coefficient of determination (R^2 value), the f^2 effect size, and the predictive relevance Q^2. The R^2 value represents a measure of in-sample predictive power. Meanwhile, the f^2 effect size indicates the relative impact of a predictor construct on a target construct. On the other hand, the Q^2 value is an indicator of the out-of-sample predictive power of the model. The structural model results are reported in Appendix E.

The R^2 values of the overall satisfaction and perceived productivity were 0.536, 0.624, respectively, indicating substantial level of predictive power of the model [46]. In terms of the f^2 effect size, the significant relationships had f^2 ranging from 0.062 to 0.8162. The f^2 value of 0.02, 0.15, and 0.35 represent small, medium, and large effect, respectively [46]. It should be noted that, as suggested by Chin et al [48]., the small f^2 does not necessarily mean an unimportant effect. On the other hand, the predictive relevance Q^2 of all constructs were above zero, confirming that items are well reconstructed, and the model has predictive relevance [46,49].

4. The field experiments

4.1. The offices

An experiment was carried out in the staff's private offices and meeting rooms. The lights in these offices are similar to other typical automatic lighting systems. As soon as someone enters an office the lights go on and stay on while any motion is detected inside. Then they are switched off after a fixed time delay, 20 minutes in our case, after the last motion detected. However, occupants are unable to switch the lights off as they always go back on whenever motion is detected. As mentioned earlier, the external wall of the building is made of glass and covered with a semi-transparent façade. There is plenty of diffuse daylight coming into the building while eliminating glare. In other words, the external walls of the offices along the edge of the building are all glass from floor to ceiling. The external side of the offices in this study is facing south, and there are two high-rise buildings across the street.

4.2. Sydney's daylight

The Sydney metropolitan is located on the eastern coast of Australia at 34°S, 151°E [50]. Daylight saving is observed which begins at 2 am on the first Sunday in October and ends at 3 am on the first Sunday in April [51].

The sunshine duration in Sydney varies depending on the season. During the experimental period, November and December 2019, approximate sunrise and sunset time are 5:40 am and 7:50 pm, respectively [52]. Although there is visible sunshine immediately after sunrise and just before sunset, the average number of hours of bright sunshine each day, as reported by the Bureau of Meteorology, is 7.8 hours in November and 7.6 hours in December 2019. However, this period has the highest bright sunshine hour of the year.

4.3. Experiment design

Based on the literature review above, our experiment stems from three assumptions: (1) we are not going to limit the participants' freedom of choice (2) if participants are satisfied by the conditions provided by the default option, they would stick to those conditions, and (3) if participants perceive discomfort, they would try to restore their comfort, by switching the light on in this case.

The experiment was done by reconfiguring lighting controls in the rooms facing outside in the case study building, which included 27 private offices and 2 meeting rooms. The reconfiguration was implemented through existing software, and no physical modification was involved. We reconfigured the default lighting setting from automatic on and off to manual-on and vacancy-off with a 10 minute time delay. It is worth noting that we are aware of the false-off events that can happen even when the participants were present in their offices but had an inadequate movement for a period of time. Thus, to avoid disturbing participants while minimizing energy use, if any motion is detected within 1 minute after the lights have turned off, the light will switch back on without requiring the participant to press the wall switch. The changes that have been made to the settings are summarized in Table 2. It should be noted that the changes to the lighting controls were implemented after the post-occupancy evaluation survey was done. Thus, the experiment does not influence the survey results.

Table 2
Summary of detailed settings used in the experiment.

	Previous setting	New setting
Light ON	Automatic ON when motion detected by the sensor	Manually ON by pressing wall switch
Light OFF	Automatic OFF when no motion detected by sensor for 20 minutes	Manually OFF by pressing wall switch
		Automatic OFF when no motion detected by sensor for 10 minutes - If the motion is detected within 1 minute after the lights have turned OFF, turn the light back ON - If no motion is detected within 1 minute after the lights have turned OFF, keep the lights OFF and allow them to be turned back ON manually

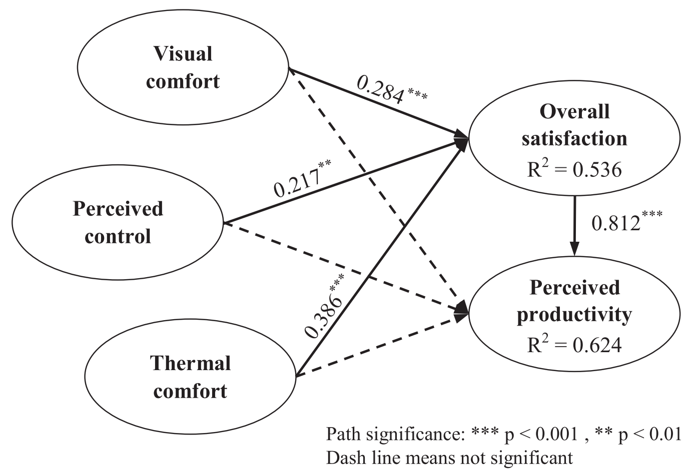

Fig. 3. Direct relationships between visual comfort, thermal comfort, perceived control with satisfaction and productivity.

4.4. Data collection

Data collection, including behavioral observation data and electricity consumption data, happened during weekdays in a four-week period, from 18 November to 13 December 2019. Inhabitant behavior was observed two times a day, at 10:30 am and 3:30 pm, by collecting the data on whether the rooms are occupied and whether the lights are on.

Electricity consumption data were obtained through the university's energy management system, which has sub-meters for measuring electricity consumption by lights in a particular area. However, the sub-meter is measuring electricity consumed by the lights in the whole school, which includes the inner-side rooms and research student workspaces that were not included in this experiment. A series of analysis of variance (ANOVA) is used to identify whether the reduction in electricity consumption is significant.

5. Results

5.1. The impact of perceived control on satisfaction and productivity

5.1.1. Direct relationships

Fig. 3 presents the direct relationships among the constructs. The results indicated that visual comfort, thermal comfort, and perceived control are the significant determinants of occupants' satisfaction, which 53.6% of the variance for occupants' satisfaction is explained by these constructs. Among the three constructs, the effect of thermal comfort is greatest (path coefficient = 0.386), followed by the effect of visual comfort (path coefficient = 0.284). Although perceived control has a smaller

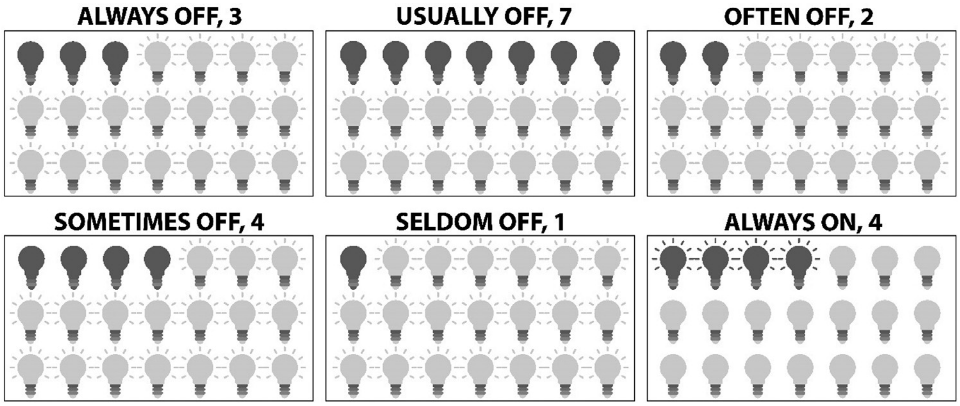

Fig. 4. Results of behavioral observation on the ratio of the lights were off to the number of times the offices were occupied (For picture sources, see Appendix A in supplementary file).

Table 3
Indirect relationships between each construct and perceived productivity.

Relationships	Path coefficient
Thermal comfort → Overall satisfaction → Perceived productivity	0.314***
Visual comfort → Overall satisfaction → Perceived productivity	0.230***
Perceived control → Overall satisfaction → Perceived productivity	0.176**

*** $p < 0.001$
** $p < 0.01$

effect than thermal comfort and visual comfort, it still emerges as a good predictor of occupants' overall satisfaction (path coefficient = 0.217).

However, the three constructs do not appear to influence occupants' perceived productivity significantly. According to the results, overall satisfaction is the only construct that significantly influences perceived productivity, which explained 62.4% of the variance. In addition, overall satisfaction also has a strong impact on perceived productivity (path coefficient = 0.812).

5.1.2. Indirect relationships

Since visual comfort, thermal comfort, and perceived control do not significantly influence perceived productivity, we further explore whether mediation relationships exist Table 3. presents the mediation relationships between the three constructs and perceived productivity. The results indicated that the three constructs significantly influence perceived productivity indirectly through overall satisfaction. In other words, it can be concluded that overall satisfaction plays a mediating role in the causal link between thermal comfort, visual comfort, perceived control, and perceived productivity. Similar to the direct relationships on overall satisfaction, the indirect effect of thermal comfort on perceived productivity is greater than the others (path coefficient = 0.314), followed by the effect of visual comfort (path coefficient = 0.230). On the other hand, perceived control also plays a significant role in indirectly influencing perceived productivity with the path coefficient of 0.176.

5.2. The impact of occupant control on energy consumption

5.2.1. Behavioral observation

From the observational data, the ratio of the number of times the lights were off to the number of times the offices were occupied was calculated. There were 21 offices frequently occupied during the observation period. Among these, the lights remained off in 10 offices for more than 80% of the time, with three of them the lights being always off. In contrast, there were four offices where the occupants always switched the lights on when they were in, while for the remaining seven offices, the lights were partially on, as shown in Fig. 4.

5.2.2. Electricity consumption reduction

Since it is not possible to isolate and measure the electricity consumption for the office rooms where the intervention was carried out, we report the electricity consumption for the whole area being monitored by the sub-meter. It should be emphasized that the corresponding sub-meter monitors electricity consumption for lighting only, electricity consumption for HVAC systems and plug loads are not included in this meter.

The electricity consumption during the period of the experiment is compared with the historical data of the same period in previous years since the commencement of the building in 2014 (Fig. 5). However, data for 2016 is missing, thus 2016 is excluded from our comparison. In addition, the average daily bright sunshine hours, which is the outdoor condition that potentially affects the need for indoor artificial lights, is also reported together with the electricity consumption.

Assuming similar academic activities for the same period in previous years, based on Fig. 5, the electricity consumption has shown a decrease in the year in which the experiment was carried out. Besides, it can be seen that the difference in bright sunshine hours does not reflect the difference in electricity consumption, which could be explained by the earlier automatic settings that switch the light on based on the presence of occupants.

To identify whether a reduction in electricity consumption is statistically significant, a series of analysis of variance (ANOVA) was conducted using IBM SPSS Statistics version 28.0. Before we ran ANOVA, the normality and homogeneity of variances assumption were tested. The results indicated the assumption held (Appendix F). The results of the ANOVA test show that there was a significant difference in electricity consumption between years (Appendix F). As a result, Tukey's HSD post-hoc tests were further performed to identify which year of comparisons the reduction was statistically significant.

Fig. 6 presents the results of Tukey's HSD post-hoc tests. The circles indicated the mean difference of average weekly electricity consumption of each pair of comparisons. The negative values mean the consumption between the pairs of comparison was decreased. However, if the interval contains zero, the corresponding means are not significantly different. Based on Fig. 6, the reduction in electricity consumption in 2019 is statistically significant when compared with the consumption in the previous years. Meanwhile, the reduction in electricity consumption from the commencement of the building to the year before the experiment was carried out is not statistically significant. The complete results of Tukey's HSD post-hoc tests are reported in Appendix G.

6. Discussion

This empirical study analyzed the role of occupants' perceived control over their thermal and visual comfort to determine whether and to what extent it influences satisfaction and perceived productivity, using data from post-occupancy evaluation survey for the case study build-

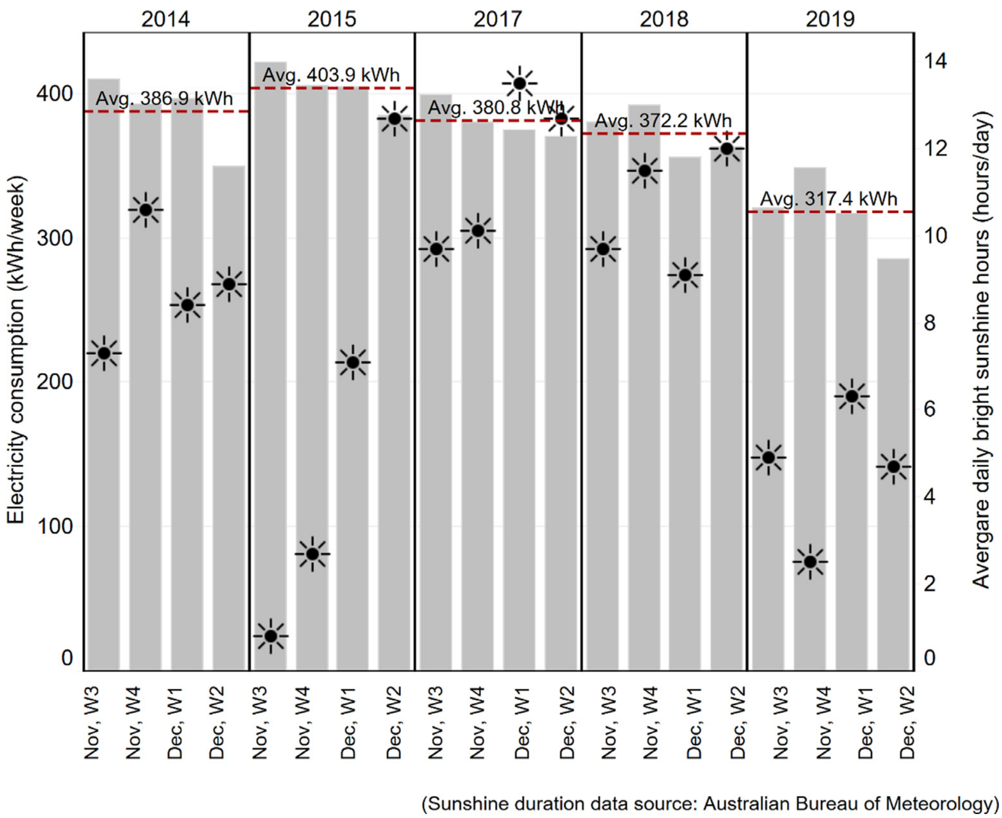

Fig. 5. Comparison of weekly electricity consumption and average daily bright sunshine hours (indicated by the sun symbol) during the period of study (Nov-Dec) in 2019 with the same periods in the preceding years.

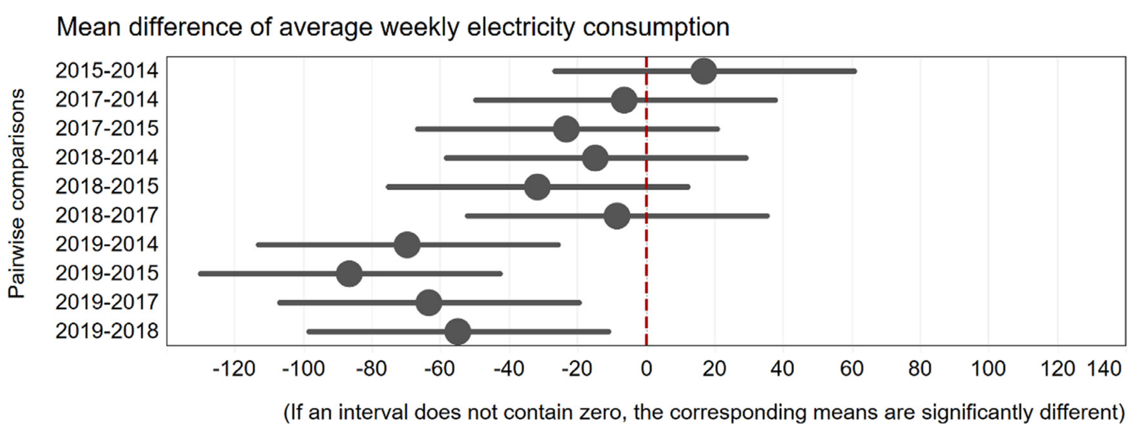

Fig. 6. Significant test results of electricity consumption reduction.

ing. The results of PLS-SEM revealed that perceived control has a positive influence on occupants' satisfaction. These findings are in line with the notion of controllability that having a sense of control increases the feeling of comfort and consequently makes occupants feel more satisfied [23,25]. At the same time, perceived control appears to indirectly influence occupants' perceived productivity through satisfaction. McCunn et al [26]. and Göçer et al [7]. also reported similar findings of the relationship between perceived productivity and perceived control.

Although the effect of perceived control on satisfaction and productivity is smaller than the effect of thermal and visual comfort themselves, it is still significant and should not be overlooked. In addition to the roles in improving satisfaction and productivity, our study also reveals energy-saving potential as a result of giving more control to the occupants.

In our experiment, we reconfigured the default setting of the lights from automatic to manual for switching the lights on but kept switching the lights off automatically when nobody was present. We also reduced the time delay before the lights go off when no motion is detected by sensors from 20 to 10 minutes. The experiment shows that about half of participants usually keep the lights off when they are in their offices, though they are free to switch them on. One-fourth of the participants do the same sometimes and only the remaining one-fourth always switch the lights on. It should also be noted that during the experiment period we also received some positive feedback; some occupants were telling us that they feel more comfortable without artificial lights in their offices and appreciated the new settings.

The modifications in the lighting system settings led to changes in occupant behavior and resulted in a 17.8% reduction in electricity consumption compared to the same period in previous years. These results are in line with Gilani and O'Brien [18] but contradict the simulation results of Zhang et al [53]., who found that automated lighting control strategy is more energy-efficient than manual control. However, the major difference between the present study and the previous one may be in the specifics of the buildings analyzed. As the external wall of the building in our study is made of glass, there is more potential to take advantage of natural light and less reliance on artificial lighting as compared to other buildings with the non-transparent wall materials.

Based on our findings, occupants' comfort and satisfaction are not only influenced by physical parameters, such as temperature, humidity, and illuminance, but also influenced by psychological parameters, like perceived control over their environment. It should also be emphasized that humans are heterogeneous and comfort preferences are subjective. Thus, the operation of building systems should take this into consideration. Besides, it can be seen from our experiment results that rather than following the fully automatic control strategy for switching lights on, the availability of control choices not only improves occupant satisfaction but also reduces energy use. Therefore, instead of restricting choice, redesigning default choices in order to accomplish desirable results is another way for servicing system control strategy in buildings that does not require huge upfront investments, as well as major technical modifications. A combination of occupants' control and nudging can help to both provide comfort and conserve energy.

7. Conclusions

This study used data from a post-occupancy evaluation survey to analyze the impact of occupants' control on satisfaction and perceived productivity. We also conducted an experiment to explore occupant behavior in response to the new default light switch setting and the effect on lighting energy demands. The results of the secondary survey analysis confirmed the positive effects of occupants' perceived control on satisfaction, and in turn perceived productivity. The results of our experiment also revealed that people's comfort preferences are subjective. Our experiment does not limit people's freedom to switch the lights on and off. In fact, we gave them more control over the lights but changed the default option. We thought that the rather traditional and technocratic idea that lights should always be on is outdated and today we should be giving people more opportunities to save energy and avoid artificial lighting when natural light is in abundance. Our findings emphasize the significance of choice architecture provided in order to influence people to make desirable decisions. More importantly, they stress the importance of the interconnection between technologies and behavior in relation to energy use in buildings. While human behavior plays a significant role in the building's energy uses, it is obvious that human behavior is driven by what technologies in the building allow or do not allow them to do.

This study is subject to some limitations. First, the findings of this study are specific to our case study and may not be generalizable to other buildings. The effect of several influential factors may lead to different results, such as location, building design, functions, and materials. In our case, the external wall is entirely glass, providing much daylight. The buildings with different external wall materials and design may have different daylight availability, and in turn different levels of energy-saving potential.

Second, the effects of such characteristics of occupants, as age, have not been included in the experiment analysis. People in different age groups may have different requirements for illuminance and visual comfort, which may lead to different behaviors. Thirdly, characteristics of the work area have not been included in the survey analysis. The experiment in this study was done in private offices, while perceived productivity for people working in private or open plan offices may be defined by different factors. Also, behavioral change and energy saving may not be generalizable to shared offices or rooms with other purposes as distributed responsibility phenomenon may affect the efficiency of the process.

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.

CRediT authorship contribution statement

Wipa Loengbudnark: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Visualization. **Kaveh Khalilpour:** Conceptualization, Writing – review & editing. **Gnana Bharathy:** Methodology, Writing – review & editing. **Alexey Voinov:** Conceptualization, Writing – review & editing, Supervision. **Leena Thomas:** Investigation, Data curation.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.enbenv.2022.02.007.

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6 CONCLUSIONS

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(Treety, 2014)

6.1 Summary of Findings

This thesis aims to explore factors that affect energy-related behavior in order to improve demand-side energy management, using three contexts as case studies: transportation, residential, and work environments.

Throughout the thesis, different behavioral theories were employed in different chapters. *Technology Acceptance Model* (Davis, 1989) was used to study EV purchase intention in Chapters 2 and 3 (road transport context). *Theory of Planned Behavior* (Ajzen, 1991) was used to study attitudes toward community renewable energy in Chapter 4 (household context). The notion of *Locus of Control* (Rotter, 1966) was employed in Chapter 5 to study the impact of occupant autonomy on satisfaction and perceived productivity (office building context). Additionally, *Nudge theory* (Thaler & Sunstein, 2008) was applied to the field experiment in Chapter 5 to study the impact of occupant autonomy and the default effect (Jachimowicz et al., 2019; Jaipuria, 2022) on energy saving potential.

The findings can be summarized as follows:

1. *Individual energy behavior in transportation context*

Chapters 2 and 3 explore which factors influence consumers' intention to purchase an EV as an alternative to conventional internal combustion engine vehicles. Besides, they also seek to understand which factors influence consumers' preferences for one of the two types of EV: the battery-based and the hydrogen-based. These chapters represent individual energy behavior as lifestyle choices that can contribute to climate change mitigation.

Chapter 2 focused on Australian consumers. It was found that safety concerns are a major factor that negatively impacts consumer willingness to purchase EV. Purchase costs influence consumer willingness to purchase EV negatively, but the impact is smaller than safety concerns. Meanwhile, the perceived benefits positively influence consumer willingness to purchase EV with a slightly smaller impact than the purchase cost. Furthermore, it was also found that age and consumers' current mode of transportation significantly impact consumer willingness to purchase EV. When choosing between the two types of EVs, consumers tend to prefer BEV if they think that the BEV range is sufficient, they do not mind about the battery charging time, and they fear hydrogen explosion. On the other hand, consumers tend to prefer FCEV because of its longer driving range, and their fear of electric battery exploding. Furthermore, it was also found that part-time employees tend to prefer BEV more than full-time workers. Besides, apartment residents tend to prefer FCEV more than people living in a house.

Chapter 3 expands the examination of influential factors of EV purchase intention and preferences to seven locations in addition to Australia, namely UK, Germany, Poland, Greece, Singapore, and two US states: California and Mississippi. This chapter's findings emphasize the importance of safety concerns, as it plays a significant role in EV purchase intention regardless of cultural background. It was also found that consumers who intend to purchase EV are sensitive to their benefits, while those who have no intention - care more about the cost. Once again this proves the confirmation bias that often impacts our decisions, when we try to find confirmation for what we intend to do. Consumers who do not mind the battery charging time are more likely to prefer battery-powered EVs, while those concerned with hydrogen tank safety are less likely to prefer fuel-cell EVs. The diversity of the participants from different locations enabled us to test the impact of contextual factors on EV purchase intention. The findings indicated that gasoline affordability (gasoline price/income) is inversely correlated with the preference for EVs over conventional vehicles. In contrast, environmental values are correlated with the perceived benefits of EV. Besides, the road traffic death rate is correlated with safety concerns.

2. *Collective energy behavior in household context*

In **Chapter 4** we switched from individual behavior to a collective one and took an interest in consumers' attitudes toward community renewable energy. The potential to produce electricity at the demand side can transform consumers into prosumers, meaning they both produce and consume energy (Khalilpour & Vassallo, 2015). The findings indicated positive direct effects of attitude toward renewable energy and perceived community benefits on attitude toward community renewable energy. Furthermore, climate change awareness and a sense of community influence attitude toward community renewable energy indirectly through attitude toward renewable energy and perceived community benefits, respectively. More importantly, this chapter highlights the important role of consumers' location and renewable energy awareness in influencing attitudes toward community renewable energy. The influence of perceived community benefits and climate change awareness is stronger among individuals who are more aware of renewable energy. The results also showed that the impact of attitude toward renewable energy on attitude toward community renewable energy is much stronger among the urban residents who do not currently have RE installed. On the other hand, the influence of a sense of community is weaker among individuals who live in non-urban areas. Besides, power outage duration was correlated with the positive attitude toward community energy among individuals who live outside the greater capital cities. Meanwhile, among individuals who live in the greater capital cities, the positive attitude toward community energy is correlated with the number of solar installations in the area.

This chapter discussed collective energy behaviors, which involve more social aspects than individual behaviors. As can be seen, perceived community benefits and a sense of community are important in influencing attitudes toward community renewable energy. More importantly, the findings also point out that collective behavior can be an alternative for people who wish to mitigate climate change but whose individual energy behavior and choices are restricted. This can be seen in the strong impact of attitude toward renewable energy on attitude toward community renewable energy among the urban residents who do not currently have renewable energy installed. In this case, having renewable energy at home is considered individual energy behavior. However, there could be some barriers that keep individuals from installing renewable energy, such as when residents of apartments may not have their own roofs to install PV, renters may not be allowed to install renewable energy in rental properties, or they might have limited space or inadequate sunlight due to overshadowing from neighbors. Thus, participating in community renewable energy projects (collective behavior) can be an alternative way to act environmentally friendly for those who cannot have renewable energy by themselves (individual behavior),

3. *Behavioral intervention strategies in action*

Chapter 5 focused on the office context, where energy users have different comfort preferences and are not responsible for paying energy bills. To conserve energy building automation and centralized control systems are used. As a result, users' control over their work environment is limited. The findings of this chapter reveal that users' perceived control has a positive direct effect on overall satisfaction with their working area, and in turn, on their perceived productivity. Meanwhile, giving users control over energy consuming system does not necessarily lead to wasting energy. On the contrary, this chapter shows that with proper default settings, energy can be saved while users still have the right to control their comfort preferences.

4. *Location matters*

Based on the findings of Chapters 3 and 4, the location where people live impacts several factors that influence their decisions and behavior. In the international scale (Chapter 3), living in different countries results in differences in gasoline affordability (determined by gasoline price and disposable income), environmental values, and road traffic death rate. These factors lead to differences in the degree to which individuals prefer EVs over conventional vehicles. Even in the same country, the differences in the mentioned factors between states (California and Mississippi in the US, in this case) also determine the degree to which individuals prefer EVs. The impact of location is again found in Chapter 4, regarding the attitude to community renewable energy. Living in or outside the greater capital cities, even in the same state, impacts power supply quality, influencing attitudes toward renewable and community renewable energy.

5. *Humans are heterogeneous*

Across this thesis, heterogeneity in energy users is evident. In addition to differences in energy-related behaviors and the related factors between countries, states, and in and outside greater capital cities discussed earlier, Chapter 5 has shown that there are also differences between individuals. The experiment results in Chapter 5 showed that individuals' comfort preferences are subjective. These subjective comfort preferences result in different energy-related behavior and, in turn, different energy consumption. These findings confirm the importance of considering heterogeneity in energy users when making strategies, policies, or behavioral interventions that aim at improving demand-side energy management. No one-size-fits-all approach exists in our complex world (Bryan et al., 2021). Strategies that fail to recognize the variability among energy users may not work effectively (Pellegrino & Musy, 2017).

6.2 Theoretical Contributions

The thesis confirms the importance of accounting for human behavior in energy demand-side management strategies, addressing calls for interdisciplinary energy research, specifically on human behavior that has energy implications (Pellegrino & Musy, 2017).

This thesis demonstrates how human decision-making is involved in everyday energy use through empirical studies in different energy-use contexts (on the road, at home, and in the office). It demonstrates the synergy of the engineering and social sciences, emphasizing the need to consider both the human dimension and technological solutions. Chapters 2, 3, and 4 demonstrate the application of rational behavioral theories to understand energy-related decision-making. Meanwhile, Chapter 5 demonstrates the application of bounded rationality to implement behavioral intervention toward energy saving.

Furthermore, this thesis address calls for understanding heterogeneity that exists among energy users (Bryan et al., 2021; Pellegrino & Musy, 2017), from the individual level (Chapter 5) to the national level (Chapter 4) and the international level (Chapter 3).

6.3 Practical Implications

This thesis has many practical implications. Firstly, considering the role of the human dimension in demand-side energy management, it is crucial to understand which factors influence individuals' energy-related decision-making to achieve the desired outcomes. Those factors include both enablers and barriers (Steg et al., 2015). Chapter 2, for example, shows that perceived benefits are an enabler for purchasing electric vehicles. At the same time, safety concerns and high purchase costs are the barriers. By knowing these, policymakers can establish the right strategies to use and support the enablers and address the barriers.

Secondly, considering the findings of Chapters 3 and 4, we should emphasize the role of situational factors, both at national and local levels, in influencing energy-related decisions. As demonstrated, humans are heterogeneous and there is no one-size-fits-all measure to produce the same expected outcome. It is crucial to consider the context in where the policies will be implemented. The enablers and barriers mentioned earlier can be varied from place to place. Chapter 4, for example, shows that the impact of power outage duration on attitudes toward renewable energy and community renewable energy differs between residents living in and outside the greater capital cities because residents in these two locations experience power outages differently.

Thirdly, considering the results of a field experiment in Chapter 5, improving demand-side energy management is not necessarily costly. By applying the notion of nudging into demand-side energy management, we can nudge people toward the desired behavior that saves energy. This kind of strategy can be implemented without a huge investment. It is also user friendly as it is not limiting users' freedom to choose. Instead, it changes how choices are presented, for example, by making the most desired choice the default, like in our case.

6.4 Limitations and Recommendations for Future Research

- All case studies in this thesis are from developed nations. However, the challenges faced by developing nations might be different. People in developing nations struggle more with basic needs than people in developed nations (Shahrasbi et al., 2021). As a result, they may be less concerned with sustainability issues (Udo & Jansson, 2009). Therefore, it would be worthwhile to understand their energy-related behavior and the influential factors. This understanding could help developing nations achieve Goal 7 of the Sustainable Development Goals: *Affordable and clean energy* (DSDG, 2023).
- Energy consumption behavior is subject to cultural influence (Ma et al., 2017). There is a significant contrast in energy-related practices across cultures (Wilhite et al., 1996). Thus, conducting a comparative study between various cultures would be worthwhile. Especially in the household context, as most of the household practices are tied to the cultural background: how we cook, how we live, how we perceive comfort. By gaining more insight into energy-related practices across cultures, we can have the best policy to suit different groups of people.
- The studies in this thesis are cross-sectional, which means that data are collected at a single point in time. However, behavior can change over time due to institutional, technical, economic, and societal changes (Mundaca et al., 2022). Further studies with the longitudinal research design may capture the long-term changes in energy attitude and behavior. Insight into

long-term changes in energy attitude and behavior could inform policies that improve demand-side energy management in the long run.

- The major methods used in this thesis is the stated preference approach which relies on attitudinal survey questions. The drawback of this approach is that stated preferences may not closely align with participants' actual preferences (Wardman, 1988) and behavior (Ajzen, 2005). In Chapters 2, 3, and 4, responses may be influenced by factors such as the desire to be socially accepted (Nock & Kurtz, 2005). Furthermore, the surveys might not be able to capture the full complexity of factors that impact choice preferences such as personal values, emotion, or the influence of subconscious mind. Future research may apply alternative methods such as experimental studies or observation of actual EV purchasing behavior (in the case of Chapters 2 and 3), and observation of actual participation in CRE (in the case of Chapter 4).

APPENDICES

Appendix A Supplementary information for Chapter 2

Table A1 Questionnaire items

Items		Mean	SD
Perceived benefits			
PU1	EVs have lower fuel cost	68.7	26.1
PU2	EVs have lower maintenance cost	56.6	24.2
PU3	EVs are more environmentally friendly	69.0	26.0
Purchase price			
PC1	EVs are more expensive	71.1	24.5
PC2	EVs are not economically feasible	48.0	27.1
Safety concern			
ST1	EVs increase the risk of road accidents	36.8	25.2
ST2	EVs explosion risk is a concern to me	52.2	26.8
EV adoption intention			
INT1	Overall, I prefer petrol cars over EVs	59.3	28.5
INT2	I am currently considering buying an EV	8.02	21.0
EV choices awareness			
Before reading the provided explanations, I knew the difference between Battery EV and Hydrogen Fuel Cell EV		38.7	31.4
Opinion about BEV			
The cost of batteries will always be too high		58.7	25.5
The range of a Battery EV is sufficient for my daily needs		63.3	26.7
I do not mind that it takes longer to charge the battery than to refuel petrol or hydrogen cars		48.2	28.9
I could still find time to charge batteries in my everyday life without any problems		55.2	28.1
Batteries can explode, this is a concern to me		51.4	27.7
Opinion about FCEV			
I have a positive view about hydrogen-based cars		61.5	27.0
I have no problems using hydrogen in my car if there is the infrastructure to provide it		63.5	27.2
I have no problems using hydrogen in my car if the hydrogen cost is low		55.2	28.1
I prefer Hydrogen Fuel Cell EV to Battery EV because of longer driving range		61.8	26.3
Hydrogen is dangerous for use, it can explode		53.0	25.9

Items	Mean	SD
I would never put a hydrogen tank in my car	46.0	27.6
Hydrogen tank is more dangerous than Compressed Natural Gas (CNG) tank, and I am not fine to use it in my car	48.8	25.9
EV choices		
Among EVs, I prefer Battery EV over Hydrogen Fuel Cell EV	56.09	24.59

Table A2 Picture sources used

"Money piles set" (https://www.freepik.com/free-vector/money-piles-set_1311446.htm#page=1&position=4#&position=4) by Iconicbestiary – Freepik (https://www.freepik.com/iconicbestiary).
"Money background design" (https://www.freepik.com/free-vector/money-background-design_1155249.htm#page=1&position=6) by aranjuezmedina – Freepik (https://www.freepik.com/aranjuezmedina)
"Clock icons" (https://www.freepik.com/premium-vector/clock-icons_795456.htm) by Freepik (https://www.freepik.com/freepik)
"Timer icons" (https://www.freepik.com/premium-vector/timer-icons_796723.htm) by Freepik (https://www.freepik.com/freepik)

Table A3 General characteristics of respondents (N=1735)

Variables	n	%
Age		
18-25	266	15%
26-35	345	20%
36-45	336	19%
46-55	255	15%
56-65	235	14%
More than 65	298	17%
Gender		
Male	707	41%
Female	1015	59%
Intersex	1	0%
Prefer not to answer	12	1%
Highest education level		
Up to high school	485	28%
Technical/vocational education above high school level (1-2 years study)	492	28%
Bachelor's degree (around 4 years study)	499	29%
Professional degree beyond Bachelor's degree (e.g., MD, DDS, DVM, LLB, JD)	85	5%
Post-graduate degree (e.g., masters, doctors or equivalent)	174	10%
Current working employment status		
Working full time	612	35%
Working part time	333	19%
Student	138	8%
Do not work (for pay)	465	27%
Other	163	9%
Prefer not to answer	24	1%
Approximate annual personal income		
Less than $18,000	345	20%
$18,000 - $25,000	234	13%
$25,001 - $40,000	296	17%
$40,001 - $60,000	293	17%
$60,001 - $90,000	292	17%
$90,001 - $180,000	226	13%
More than $180,000	49	3%
Daily traveling distances		
Less than 1 km	258	15%
1 - 5 km	382	22%
6 - 10 km	344	20%
11 - 20 km	326	19%
21 - 50 km	293	17%
51 - 99 km	95	5%
100 km or more	37	2%
Modes of transportation		

Variables	n	%
Personal car	1278	74%
Rental car	7	0%
Car share (Short term car rental, instead of owning a car)	15	1%
Carpool (Sharing of car journeys with someone else)	23	1%
Public transportation	194	11%
Motorcycle	4	0%
Bicycle	12	1%
Scooter	4	0%
Walk	143	8%
Other	19	1%
Not applicable	36	2%
Types of houses		
A house with solar panels	560	32%
A house without solar panels	859	50%
An apartment	280	16%
Other	36	2%

Table A4 Reorganized demographic variables for PLS-SEM (N=1722)

Variable	n	%
Age		
18-35	602	35%
36-55	587	34%
56 and more*	533	31%
Gender		
Male	707	41%
Female*	1015	59%
Highest education level		
Lower than bachelor's	972	56%
Bachelor's	493	29%
Higher than bachelor's*	257	15%
Current working employment status		
Working full time	609	35%
Working part time	329	19%
Others*	784	46%
Annual personal income		
Up to A$60,000	1159	67%
More than A$60,000*	563	33%
Daily traveling distances		
Up to 20 km	1299	75%
More than 20 km*	423	25%
Modes of transportation		
Personal car	1270	74%
Others*	452	26%
Types of houses		
House with solar panels	558	32%
House without solar panels	851	49%
Apartment and Others*	313	18%

* Reference category

Table A5 Measurement model cross-loadings

Items	Perceived benefits	Purchase cost	Safety concern	Intentions
PU1	0.721	0.221	-0.083	0.043
PU2	0.622	0.181	0.057	0.056
PU3	0.930	0.119	-0.113	0.142
PC1	0.379	0.537	0.051	-0.108
PC2	0.064	0.943	0.302	-0.274
ST1	-0.119	0.235	0.808	-0.250
ST2	-0.042	0.250	0.921	-0.379
INT1	0.146	-0.286	-0.412	0.909
INT2	0.047	-0.149	-0.168	0.754

Table A 6 Fornell-Larcker criterion of the measurement model

Constructs	Perceived benefits	Purchase cost	Safety concern	Intentions
Perceived benefits	0.768			
Purchase cost	0.185	0.767		
Safety concern	-0.083	0.279	0.867	
Intention	0.127	-0.274	-0.374	0.835

Table A7 Measurement model evaluation

Constructs	Items	Factor loadings	P-Values*	AVE	Cronbach's alpha	Composite reliability	VIF
Perceived benefits	PU1	0.721	0.000	0.590	0.698	0.808	1.549
	PU2	0.622	0.000				1.260
	PU3	0.930	0.000				1.421
Purchase cost	PC1	0.537	0.000	0.589	0.369	0.727	1.054
	PC2	0.943	0.000				1.054
Safety concern	ST1	0.808	0.000	0.751	0.680	0.857	1.362
	ST2	0.921	0.000				1.362
Intention	INT1	0.909	0.000	0.697	0.583	0.820	1.204
	INT2	0.754	0.000				1.204

* Bootstraping results (n = 5000)

Table A8 Results of structural equation modeling

Path	Path coef.	P-Values*	R^2	f^2	Q^2
Perceived benefits → Intention	0.147	0.000	0.237	0.026	0.152
Purchase cost → Intention	-0.190	0.000		0.041	
Safety concern → Intention	-0.299	0.000		0.104	
Control variables:					
Age	0.130	0.000		0.020	
Gender	0.045	0.053		0.002	
Education	-0.036	0.179		0.001	
Employment	0.014	0.699		0.000	
Income	0.040	0.084		0.002	
Traveling distances	0.014	0.546		0.000	
Mode of transportation	-0.140	0.000		0.023	
Type of accommodation	-0.018	0.433		0.000	

* Bootstraping results (n = 5000)

Appendix B Supplementary information for Chapter 3

Table B1 Measurement model assessment - Australia

Constructs	Items	Cronbach's Alpha	Composite reliability	Factor loadings	P-Values*	AVE	VIF
EV purchase intention	INT1	0.583	0.820	0.909	0.000	0.697	1.204
	INT2			0.754	0.000		1.204
Perceived benefits	PB1	0.698	0.808	0.721	0.000	0.590	1.549
	PB2			0.622	0.000		1.260
	PB3			0.930	0.000		1.421
Purchase cost	PC1	0.369	0.727	0.537	0.000	0.589	1.054
	PC2			0.943	0.000		1.054
Safety concern	ST1	0.680	0.857	0.808	0.000	0.751	1.362
	ST2			0.921	0.000		1.362

* Bootstrapping results (n = 5000)

Table B2 Measurement model cross-loadings – Australia

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
INT1	0.909	0.146	-0.286	-0.412
INT2	0.754	0.047	-0.149	-0.168
PB1	0.043	0.721	0.221	-0.083
PB2	0.056	0.622	0.181	0.057
PB3	0.142	0.930	0.119	-0.113
PC1	-0.108	0.379	0.537	0.051
PC2	-0.274	0.064	0.943	0.302
ST1	-0.250	-0.119	0.235	0.808
ST2	-0.379	-0.042	0.250	0.921

Table B3 Fornell-Larcker criterion of the measurement model – Australia

	EV purchase intention	Perceived benefit	Purchase cost	Safety concern
EV purchase intention	**0.835**			
Perceived benefit	0.127	**0.768**		
Purchase cost	-0.274	0.185	**0.767**	
Safety concern	-0.374	-0.083	0.279	**0.867**

Table B4 Structural model results – Australia

Path	Path coef.	P Values*	R^2	f^2	Q^2
Perceived benefits → Purchase intention	0.1470	0.000	0.237	0.026	0.152
Purchase cost → Purchase intention	-0.190	0.000		0.041	
Safety concern → Purchase intention	-0.299	0.000		0.104	
Control variables:					
Age	0.130	0.000		0.020	
Gender	0.045	0.050		0.002	
Education	-0.036	0.179		0.001	
Employment	0.014	0.695		0.000	
Income	0.040	0.086		0.002	
Daily traveling distances	0.014	0.547		0.000	
Mode of transportation	-0.140	0.000		0.023	
Type of accommodation	-0.018	0.432		0.000	

* Bootstrapping results (n = 5000)

Table B5 Measurement model assessment – UK

Constructs	Items	Cronbach's Alpha	Composite reliability	Factor loadings	P Values*	AVE	VIF
EV purchase intention	INT1	0.634	0.840	0.91	0.000	0.726	1.274
	INT2			0.790	0.000		1.274
Perceived benefits	PB1	0.642	0.839	0.765	0.007	0.724	1.288
	PB3			0.929	0.000		1.288
Purchase cost	PC1	0.316	0.702	0.475	0.000	0.567	1.037
	PC2			0.954	0.000		1.037
Safety concern	ST1	0.686	0.862	0.837	0.000	0.758	1.374
	ST2			0.903	0.000		1.374

* Bootstrapping results (n = 5000)

Table B6 Measurement model cross-loadings – UK

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
INT1	0.910	0.058	-0.345	-0.420
INT2	0.790	0.079	-0.170	-0.185
PB1	0.046	0.765	0.142	-0.054
PB3	0.080	0.929	0.135	-0.062
PC1	-0.109	0.437	0.475	0.045
PC2	-0.318	0.027	0.954	0.372
ST1	-0.286	-0.105	0.335	0.837
ST2	-0.365	-0.024	0.279	0.903

Table B7 Fornell-Larcker criterion of the measurement model – UK

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
EV purchase intention	**0.852**			
Perceived benefits	0.077	**0.851**		
Purchase cost	-0.318	0.159	**0.753**	
Safety concern	-0.378	-0.068	0.347	**0.871**

Table B8 Structural model results – UK

Path	Path coef.	P Values*	R^2	f^2	Q^2
Perceived benefits → Purchase intention	0.111	0.023	0.261	0.015	0.160
Purchase cost → Purchase intention	-0.225	0.000		0.057	
Safety concern → Purchase intention	-0.309	0.000		0.106	
Control variables:					
Age	-0.106	0.383		0.014	
Gender	0.047	0.274		0.003	
Education	-0.085	0.114		0.008	
Employment	0.003	0.959		0.000	
Income	-0.011	0.817		0.000	
Daily traveling distances	0.004	0.932		0.000	
Mode of transportation	-0.222	0.000		0.057	
Type of accommodation	0.052	0.451		0.003	

* Bootstrapping results (n = 5000)

Table B9 Measurement model assessment – Germany

Constructs	Items	Cronbach's Alpha	Composite reliability	Factor loadings	P Values*	AVE	VIF
EV purchase intention	INT1	0.654	0.847	0.917	0.000	0.736	1.310
	INT2			0.795	0.000		1.310
Perceived benefits	PB1	0.727	0.834	0.701	0.002	0.627	1.538
	PB2			0.831	0.000		1.478
	PB3			0.836	0.000		1.340
Purchase cost	PC1	0.517	0.768	0.588	0.000	0.637	1.138
	PC2			0.963	0.000		1.138
Safety concern	ST1	0.738	0.884	0.875	0.000	0.792	1.520
	ST2			0.905	0.000		1.520

* Bootstrapping results (n = 5000)

Table B10 Measurement model cross-loadings – Germany

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
INT1	0.917	0.126	-0.245	-0.403
INT2	0.795	0.063	-0.157	-0.169
PB1	0.037	0.701	0.304	-0.007
PB2	0.102	0.831	0.327	0.042
PB3	0.108	0.836	0.234	0.001
PC1	-0.084	0.346	0.588	0.086
PC2	-0.253	0.288	0.963	0.319
ST1	-0.297	0.005	0.301	0.875
ST2	-0.337	0.029	0.238	0.905

Table B11 Fornell-Larcker criterion of the measurement model – Germany

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
EV purchase intention	**0.858**			
Perceived benefits	0.116	**0.792**		
Purchase cost	-0.242	0.348	**0.798**	
Safety concern	-0.357	0.020	0.300	**0.890**

Table B12 Structural model results – Germany

Path	Path coef.	P Values*	R^2	f^2	Q^2
Perceived benefits → Purchase intention	0.220	0.003	0.227	0.053	0.121
Purchase cost → Purchase intention	-0.226	0.000		0.051	
Safety concern → Purchase intention	-0.271	0.000		0.081	
Control variables:					
Age	0.053	0.175		0.003	
Gender	0.001	0.975		0.000	
Education	-0.076	0.067		0.007	
Employment	-0.062	0.426		0.004	
Income	0.040	0.358		0.001	
Daily traveling distances	-0.077	0.089		0.006	
Mode of transportation	-0.187	0.000		0.038	
Type of accommodation	0.032	0.538		0.001	

* Bootstrapping results (n = 5000)

Table B13 Measurement model assessment – Poland

Constructs	Items	Cronbach's Alpha	Composite reliability	Factor loadings	P Values*	AVE	VIF
EV purchase intention	INT1	0.655	0.850	0.901	0.000	0.740	1.311
	INT2			0.818	0.000		1.311
Perceived benefits	PB1	0.720	0.840	0.899	0.000	0.639	1.666
	PB2			0.715	0.017		1.362
	PB3			0.772	0.002		1.409
Purchase cost	PC1	0.385	0.733	0.549	0.000	0.595	1.060
	PC2			0.942	0.000		1.060
Safety concern	ST1	0.778	0.900	0.906	0.000	0.818	1.679
	ST2			0.903	0.000		1.679

* Bootstrapping results (n = 5000)

Table B14 Measurement model cross-loadings – Poland

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
INT1	0.901	0.045	-0.338	-0.449
INT2	0.818	0.099	-0.231	-0.295
PB1	0.081	0.899	0.136	-0.070
PB2	0.046	0.715	0.265	0.111
PB3	0.056	0.772	0.076	-0.079
PC1	-0.135	0.375	0.549	0.156
PC2	-0.338	0.064	0.942	0.353
ST1	-0.402	-0.105	0.315	0.906
ST2	-0.398	0.046	0.332	0.903

Table B15 Fornell-Larcker criterion of the measurement model – Poland

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
EV purchase intention	**0.860**			
Perceived benefits	0.079	**0.799**		
Purchase cost	-0.337	0.184	**0.771**	
Safety concern	-0.443	-0.033	0.357	**0.904**

Table B16 Structural model results – Poland

Path	Path coef.	P Values*	R^2	f^2	Q^2
Perceived benefits → Purchase intention	0.107	0.082	0.270	0.015	0.169
Purchase cost → Purchase intention	-0.214	0.000		0.050	
Safety concern → Purchase intention	-0.352	0.000		0.140	
Control variables:					
Age	0.002	0.962		0.000	
Gender	-0.034	0.387		0.001	
Education	-0.015	0.769		0.000	
Employment	-0.055	0.332		0.003	
Income	0.010	0.791		0.000	
Daily traveling distances	-0.058	0.157		0.004	
Mode of transportation	-0.131	0.001		0.019	
Type of accommodation	-0.027	0.512		0.001	

* Bootstrapping results (n = 5000)

Table B17 Measurement model assessment - Greece

Constructs	Items	Cronbach's Alpha	Composite reliability	Factor loadings	P Values*	AVE	VIF
EV purchase intention	INT1	0.637	0.846	0.837	0.000	0.733	1.279
	INT2			0.875	0.000		1.279
Perceived benefits	PB1	0.638	0.806	0.792	0.000	0.582	1.381
	PB2			0.693	0.000		1.145
	PB3			0.798	0.000		1.364
Purchase cost	PC1	0.402	0.769	0.762	0.000	0.625	1.068
	PC2			0.819	0.000		1.068
Safety concern	ST1	0.676	0.859	0.899	0.000	0.753	1.353
	ST2			0.836	0.000		1.353

* Bootstrapping results (n = 5000)

Table B18 Measurement model cross-loadings - Greece

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
INT1	0.837	0.093	-0.180	-0.425
INT2	0.875	0.120	-0.167	-0.213
PB1	0.094	0.792	0.206	-0.107
PB2	0.091	0.693	0.132	0.109
PB3	0.100	0.798	0.251	-0.112
PC1	-0.150	0.310	0.762	0.043
PC2	-0.169	0.113	0.819	0.186
ST1	-0.349	-0.075	0.160	0.899
ST2	-0.278	-0.008	0.093	0.836

Table B19 Fornell-Larcker criterion of the measurement model - Greece

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
EV purchase intention	**0.856**			
Perceived benefits	0.125	**0.763**		
Purchase cost	-0.202	0.260	**0.791**	
Safety concern	-0.365	-0.052	0.15	**0.868**

Table B20 Structural model results - Greece

Path	Path coef.	P Values*	R^2	f^2	Q^2
Perceived benefits → Purchase intention	0.188	0.000	0.267	0.044	0.168
Purchase cost → Purchase intention	-0.163	0.000		0.032	
Safety concern → Purchase intention	-0.362	0.000		0.165	
Control variables:					
Age	-0.022	0.597		0.001	
Gender	-0.080	0.052		0.008	
Education	-0.049	0.316		0.003	
Employment	-0.033	0.440		0.001	
Income	0.044	0.291		0.002	
Daily traveling distances	-0.011	0.792		0.000	
Mode of transportation	-0.245	0.000		0.072	
Type of accommodation	0.096	0.368		0.012	

* Bootstrapping results (n = 5000)

Table B21 Measurement model assessment – Singapore

Constructs	Items	Cronbach's Alpha	Composite reliability	Factor loadings	P Values*	AVE	VIF
EV purchase intention	INT1	0.715	0.870	0.931	0.000	0.771	1.449
	INT2			0.821	0.000		1.449
Perceived benefits	PB1	0.630	0.762	0.636	0.019	0.527	1.386
	PB2			0.913	0.022		1.175
	PB3			0.586	0.045		1.278
Purchase cost	PC1	0.434	0.760	0.625	0.000	0.621	1.083
	PC2			0.923	0.000		1.083
Safety concern	ST1	0.703	0.870	0.898	0.000	0.770	1.416
	ST2			0.856	0.000		1.416

* Bootstrapping results (n = 5000)

Table B22 Measurement model cross-loadings – Singapore

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
INT1	0.931	-0.136	-0.355	-0.416
INT2	0.821	0.002	-0.174	-0.220
PB1	-0.029	0.636	0.255	0.062
PB2	-0.099	0.913	0.344	0.189
PB3	-0.038	0.586	0.235	-0.034
PC1	-0.156	0.312	0.625	0.158
PC2	-0.317	0.319	0.923	0.328
ST1	-0.361	0.107	0.304	0.898
ST2	-0.307	0.155	0.274	0.856

Table B23 Fornell-Larcker criterion of the measurement model - Singapore

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
EV purchase intention	**0.878**			
Perceived benefits	-0.092	**0.726**		
Purchase cost	-0.320	0.384	**0.788**	
Safety concern	-0.383	0.147	0.330	**0.877**

Table B24 Structural model results - Singapore

Path	Path coef.	P Values*	R^2	f^2	Q^2
Perceived benefits → Purchase intention	0.053	0.300	0.205	0.003	0.134
Purchase cost → Purchase intention	-0.223	0.000		0.047	
Safety concern → Purchase intention	-0.317	0.000		0.109	
Control variables:					
Age	-0.002	0.963		0.000	
Gender	0.041	0.353		0.002	
Education	-0.001	0.977		0.000	
Employment	-0.046	0.351		0.002	
Income	-0.008	0.851		0.000	
Daily traveling distances	-0.008	0.866		0.000	
Mode of transportation	-0.107	0.020		0.012	
Type of accommodation	0.021	0.670		0.001	

* Bootstrapping results (n = 5000)

Table B25 Measurement model assessment - USA (California)

Constructs	Items	Cronbach's Alpha	Composite reliability	Factor loadings	P Values*	AVE	VIF
EV purchase intention	INT1	0.594	0.822	0.921	0.000	0.700	1.218
	INT2			0.743	0.000		1.218
Perceived benefits	PB3	1.000	1.000	1.000		1.000	1.000
Purchase cost	PC1	0.433	0.753	0.592	0.000	0.615	1.083
	PC2			0.938	0.000		1.083
Safety concern	ST1	0.722	0.877	0.868	0.000	0.782	1.468
	ST2			0.900	0.000		1.468

* Bootstrapping results (n = 5000)

Table B26 Measurement model cross-loadings – USA (California)

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
INT1	0.921	0.018	-0.363	-0.511
INT2	0.743	0.110	-0.180	-0.201
PB3	0.061	1.000	0.177	-0.010
PC1	-0.149	0.391	0.592	0.191
PC2	-0.348	0.043	0.938	0.511
ST1	-0.382	-0.038	0.450	0.868
ST2	-0.436	0.016	0.431	0.900

Table B27 Fornell-Larcker criterion of the measurement model – USA (California)

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
EV purchase intention	**0.837**			
Perceived benefits	0.061	**1.000**		
Purchase cost	-0.345	0.177	**0.784**	
Safety concern	-0.464	-0.010	0.497	**0.884**

Table B28 Structural model results – USA (California)

Path	Path coef.	P Values*	R^2	f^2	Q^2
Perceived benefits → Purchase intention	0.111	0.007		0.015	
Purchase cost → Purchase intention	-0.163	0.001		0.026	
Safety concern → Purchase intention	-0.358	0.000		0.126	
Control variables:					
Age	0.064	0.298	0.279	0.005	0.160
Gender	-0.010	0.805		0.000	
Education	-0.065	0.239		0.004	
Employment	-0.015	0.748		0.000	
Income	0.025	0.571		0.001	
Daily traveling distances	0.015	0.720		0.000	
Mode of transportation	-0.172	0.000		0.037	
Type of accommodation	0.049	0.385		0.003	

* Bootstrapping results (n = 5000)

Table B29 Measurement model assessment – USA (Mississippi)

Constructs	Items	Cronbach's Alpha	Composite reliability	Factor loadings	P Values*	AVE	VIF
EV purchase intention	INT1	0.594	0.815	0.939	0.000	0.692	1.218
	INT2			0.708	0.000		1.218
Perceived benefits	PB1	0.647	0.808	0.801	0.000	0.586	1.297
	PB2			0.675	0.000		1.201
	PB3			0.812	0.000		1.340
Purchase cost	PC1	0.388	0.766	0.776	0.000	0.620	1.061
	PC2			0.799	0.000		1.061
Safety concern	ST1	0.635	0.830	0.732	0.000	0.713	1.276
	ST2			0.943	0.000		1.276

* Bootstrapping results (n = 5000)

Table B30 Measurement model cross-loadings – USA (Mississippi)

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
INT1	0.939	-0.322	-0.384	-0.503
INT2	0.708	-0.225	-0.142	-0.113
PB1	-0.281	0.801	0.337	0.178
PB2	-0.204	0.675	0.227	0.234
PB3	-0.278	0.812	0.355	0.103
PC1	-0.271	0.428	0.776	0.255
PC2	-0.284	0.218	0.799	0.414
ST1	-0.223	0.062	0.223	0.732
ST2	-0.457	0.249	0.447	0.943

Table B31 Fornell-Larcker criterion of the measurement model – USA (Mississippi)

	EV purchase intention	Perceived benefits	Purchase cost	Safety concern
EV purchase intention	**0.832**			
Perceived benefits	-0.336	**0.765**		
Purchase cost	-0.353	0.407	**0.788**	
Safety concern	-0.435	0.215	0.427	**0.844**

Table B32 Structural model results – USA (Mississippi)

Path	Path coef.	P Values*	R^2	f^2	Q^2
Perceived benefits → Purchase intention	-0.176	0.003	0.306	0.034	0.170
Purchase cost → Purchase intention	-0.106	0.102		0.011	
Safety concern → Purchase intention	-0.370	0.000		0.156	
Control variables:					
Age	0.091	0.055		0.010	
Gender	-0.082	0.087		0.009	
Education	0.075	0.302		0.007	
Employment	-0.025	0.725		0.001	
Income	0.038	0.534		0.001	
Daily traveling distances	-0.069	0.171		0.006	
Mode of transportation	-0.033	0.585		0.001	
Type of accommodation	-0.073	0.446		0.007	

* Bootstrapping results (n = 5000)

Appendix C Supplementary information for Chapter 4

Table C1 Results of structural equation modeling (All sample, N = 860)

Path	Path coef.	P-Value*	R^2	f^2	Q^2
Climate change concern → Attitude to RE	0.258	0.000	0.121	0.072	0.077
Sense of community → Perceived community benefits	0.125	0.000	0.115	0.017	0.062
Attitude to RE → Perceived community benefits	0.215	0.000		0.049	
Perceived community benefits → Attitude to CRE	0.166	0.000	0.240	0.033	0.122
Attitude to RE → Attitude to CRE	0.388	0.000		0.177	
Control variables:					
Age → Attitude to RE	0.180	0.000		0.035	
Age → Attitude to CRE	0.081	0.038		0.008	
Age → Climate change concern	0.223	0.000		0.052	
Age → Perceived community benefits	0.149	0.000		0.023	
Age → Sense of community	0.181	0.000		0.034	
Gender → Attitude to RE	-0.041	0.204		0.002	
Gender → Attitude to CRE	0.032	0.294		0.001	
Gender → Climate change concern	-0.001	0.986		0.000	
Gender → Perceived community benefits	0.032	0.332		0.001	
Gender → Sense of community	0.086	0.010		0.008	

*Bootstrapping results (n = 5000)

Table C2 Path coefficients of each category of participants

Path	Urban - Have RE (N=192)		Urban - Do not have RE (N=217)		Non-urban - Have RE (N=200)		Non-urban - Do not have RE (N=216)	
	Coef.	P-Values*	Coef.	P-Values*	Coef.	P-Values*	Coef.	P-Values*
Climate change concern → Attitude to RE	0.303	0.000	0.127	0.178	0.26	0.001	0.314	0.019
Sense of community → Perceived community benefits	0.263	0.001	0.112	0.165	0.017	0.830	0.050	0.600
Attitude to RE → Perceived community benefits	0.241	0.004	0.207	0.002	0.229	0.003	0.107	0.138
Perceived community benefits → Attitude to CRE	0.282	0.001	0.079	0.367	0.231	0.001	0.049	0.559
Attitude to RE → Attitude to CRE	0.271	0.000	0.49	0.000	0.292	0.001	0.306	0.001
Control variables:								
Age → Attitude to RE	0.257	0.000	0.035	0.718	0.378	0.000	0.247	0.007
Age → Attitude to CRE	0.085	0.327	0.15	0.369	0.247	0.001	0.145	0.082
Age → Climate change concern	0.284	0.000	0.194	0.339	0.469	0.000	-0.126	0.559
Age → Perceived community benefits	0.032	0.648	-0.098	0.500	0.276	0.000	0.191	0.008
Age → Sense of community	0.216	0.000	-0.153	0.333	0.304	0.000	0.223	0.002
Gender → Attitude to RE	-0.049	0.494	0.007	0.912	-0.061	0.306	-0.115	0.076
Gender → Attitude to CRE	0.059	0.390	-0.061	0.307	0.050	0.406	0.003	0.964
Gender → Climate change concern	0.011	0.873	-0.035	0.677	-0.026	0.681	0.018	0.839
Gender → Perceived community benefits	0.101	0.158	0.074	0.285	-0.046	0.484	0.016	0.823
Gender → Sense of community	0.105	0.151	0.126	0.073	0.014	0.843	0.106	0.229

*Bootstrapping results (n = 5000)

Appendix D Supplementary information for Chapter 5

Table D1 Picture sources used

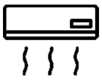
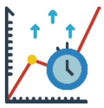
	https://www.flaticon.com/free-icon/electrical-tower_100567
	https://www.flaticon.com/free-icon/air-conditioner_1190242
	https://www.freepik.com/free-vector/bulb-icons-set_799033
	https://www.flaticon.com/free-icon/standby_1242962
	https://www.flaticon.com/free-icon/indoor-plants_653923
	https://www.flaticon.com/free-icon/thermometer_1229487
	https://www.flaticon.com/free-icon/satisfaction_263171
	https://www.flaticon.com/free-icon/light_1100328
	https://www.flaticon.com/free-icon/turn-off_902511
	https://www.flaticon.com/free-icon/person_1198343
	https://www.flaticon.com/free-icon/businessman_1253775
	https://www.flaticon.com/free-icon/productivity_951139
	https://www.flaticon.com/free-icon/energy_463158
	https://www.flaticon.com/free-icon/graph_1130408

Table D2 Model assessment criteria (Hair et al., 2017)

Criteria	Comments
Common method bias (Harman's one-factor test < 50%)	The test results indicate 41.58% of the variance is explained by the measurement items. Thus, the common method bias should not be a concern in this study (Harman, 1976).
Formative measurement model assessment (Thermal comfort, Visual comfort, and Perceived control)	
Indicator collinearity (Variance inflation factor (VIF) < 5)	VIF values of the item 'Control heating/cooling' was 5.0. This is probably because it is similar the item 'Control air movement' since air movement and temperature can be control via thermostat. Thus, the item 'Control heating/cooling' was removed from the model. (Table D3)
Significance and weights of the items	Item 'Temp. summer', 'Temp. winter', 'Control air movement' and 'Control artificial lighting' were not significant but their loadings were high (> 0.5). This indicates that the items are absolutely important and should be retained (Hair et al., 2017). (Table D3)
Reflective measurement model assessment (**Overall satisfaction, and Perceived productivity)**	
Internal consistency reliability • Cronbach's Alpha ≥ 0.6 • Composite reliability ≥ 0.6	Cronbach's Alpha and Composite reliability value of all constructs was larger than the threshold value of 0.6 (Table D3)
Convergent Validity • Factor loading ≥ 0.7 • Average variance extracted (AVE) ≥ 0.5	• Factor loading of all items is significant and larger than the threshold value of 0.7 (Table D3) • AVE value of all constructs was greater than the recommended value of 0.5 (Table D3)
Discriminant Validity • Cross-loading • Fornell-Larcker criterion	• All item's loadings on associated construct were greater than their cross-loading on other constructs (Table D4) • Square root of the AVE was greater than the highest correlation with any other construct (Table D5)
Structural model assessment (Table D6)	
Path coefficients significance test	All the significant path coefficients were significant at a significance level of 0.001, while the rest have P-value above 0.1, indicating non-significant path coefficients.
Coefficient of determination R^2	The R^2 values of the overall satisfaction and perceived productivity were 0.505, 0.626, respectively, indicating substantial level of predictive power of the model (Hair et al., 2017).
Effect size f^2	The significant relationships had f^2 ranging from 0.060 to 0.902. The f^2 value of 0.02, 0.15, and 0.35 represent small, medium, and large effect, respectively (Hair et al., 2017).
Predictive relevance $Q^2 > 0$	The Q^2 values of all constructs were above zero, indicating that items are well reconstructed, and the model has predictive relevance among endogenous variables in the model (Hair et al., 2017).

Table D3 Measurement model results

Constructs	Items	Weight		Loading		VIF	Cronbach's alpha	Composite reliability	AVE
		Weight	P Value	Loading	P Value				
Thermal comfort	Air movement	0.493	0.012	0.903	0.000	3.224			
	Overall humidity	-0.357	0.025	0.668	0.000	2.989			
	Overall air quality	0.732	0.000	0.932	0.000	4.007			
	Temp. summer	-0.036	0.796	0.571	0.000	1.961			
	Temp. winter	0.192	0.143	0.687	0.000	2.048			
Visual comfort	Lighting comfort	0.343	0.014	0.700	0.000	1.384			
	Shading devices	0.330	0.021	0.589	0.000	1.290			
	Access to daylight	0.682	0.000	0.830	0.000	1.095			
Perceived control	Control air movement	0.209	0.133	0.759	0.000	2.269			
	Control artificial lighting	-0.117	0.413	0.654	0.000	2.250			
	Freedom to adapt	0.927	0.000	0.990	0.000	2.195			
Overall satisfaction	Overall comfort	0.603	0.000	0.929	0.000	1.771	0.795	0.906	0.829
	Building overall	0.494	0.000	0.891	0.000	1.771			
Perceived productivity	Productivity	0.563	0.000	0.953	0.000	2.669	0.883	0.945	0.895
	Estimate productivity	0.493	0.000	0.939	0.000	2.669			

Table D4 Measurement model cross-loadings

Items	Thermal comfort	Visual comfort	Perceived control	Overall satisfaction	Perceived productivity
Air movement	0.903	0.461	0.598	0.586	0.458
Overall humidity	0.668	0.323	0.430	0.423	0.353
Overall air quality	0.932	0.467	0.518	0.604	0.473
Temp. summer	0.571	0.276	0.453	0.365	0.298
Temp. winter	0.687	0.203	0.537	0.458	0.333
Lighting comfort	0.388	0.700	0.317	0.409	0.282
Shading devices	0.271	0.589	0.300	0.353	0.225
Access to daylight	0.382	0.830	0.304	0.446	0.384
Control air movement	0.480	0.199	0.759	0.424	0.348
Control artificial lighting	0.366	0.277	0.654	0.363	0.304
Freedom to adapt	0.594	0.437	0.990	0.565	0.441
Overall comfort	0.632	0.533	0.533	**0.929**	0.811
Building overall	0.556	0.484	0.503	**0.891**	0.609
Productivity	0.485	0.458	0.459	0.793	**0.953**
Estimate productivity	0.460	0.355	0.379	0.696	**0.939**

Table D5 Fornell-Larcker criterion of the measurement model

Constructs	Thermal comfort	Visual comfort	Perceived control	Overall satisfaction	Perceived productivity
Thermal comfort	-				
Visual comfort	0.483	-			
Perceived control	0.608	0.415	-		
Overall satisfaction	0.655	0.560	0.570	**0.910**	
Perceived productivity	0.500	0.433	0.446	0.790	**0.946**

The number on the diagonal cells are the square root of the AVEs.

Table D6 Structural model results

Path	Path coefficient	P Values	R^2	f^2	Q^2
Thermal comfort → Overall satisfaction	0.386	0.000	0.536	0.182	0.421
Visual comfort → Overall satisfaction	0.284	0.000		0.129	
Perceived control → Overall satisfaction	0.217	0.001		0.062	
Thermal comfort → Perceived productivity	-0.032	0.675	0.624	0.001	0.540
Visual comfort → Perceived productivity	-0.009	0.885		0.000	
Perceived control → Perceived productivity	0.007	0.921		0.000	
Overall satisfaction → Perceived productivity	0.812	0.000		0.816	

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