Doctoral Dissertation

Essays on CO2 Emissions and Renewable Energy Development in Developing Countries

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ABSTRACT

This comprehensive abstract synthesizes the findings from three distinct studies examining the intersection of renewable energy sources and environmental sustainability within the framework of the Sustainable Development Goals (SDGs).

Study 1 delves into the differential impacts of traditional and modern renewable energy sources on CO_2 emissions in emerging economies, utilizing an autoregressive distributive lag (ARDL) model across 31 countries from 1990 to 2016. The findings underscore a negative long-run correlation between CO_2 emissions and both energy types, with a pronounced sensitivity to modern renewables. This suggests that modern renewable energy is a more efficacious target for environmental policies in these nations, highlighting the imperative for international support in green technology transfer.

Study 2 shifts the focus to Southeast Asia, where the burgeoning hydropower sector along the Mekong River is scrutinized for its environmental and public implications. Employing a vignette experiment to circumvent conventional survey biases, the study evaluates Cambodian residents' attitudes influenced by varied informational framings—environmental impact, funding origins, and international aid. The results reveal a predominant sway of negative environmental framing on public opinion and a discernible distrust towards Chinese international assistance, signaling a call for policymakers to enhance public engagement and trust through transparent and sustainable practices in hydropower development.

Lastly, Study 3 explores the global ascent of solar home systems as a sustainable electricity alternative, assessing household attitudes through vignette experiments that manipulate framing around cost, accessibility, and environmental benefits. The study finds that eco-friendly framing garners positive responses, whereas emphasis on high costs elicits adverse perceptions. It advocates for strategic communication that balances environmental merits with economic considerations, tailored specifically to influential demographics such as women heads of households, to foster informed and favorable engagement with solar energy solutions.

Collectively, these studies illuminate the nuanced relationships between renewable energy adoption and public perception, emphasizing the need for nuanced policy approaches that consider both technological efficacy and socio-environmental communication strategies to advance global environmental sustainability.

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Chapter 1: Introduction

Climate change and global warming represent urgent global dilemmas with extensive consequences across diverse sectors such as economics, energy management, and environmental management. The human-induced causality behind these environmental crises, principally via greenhouse gas emissions, is substantiated by a plethora of scientific studies. These emissions principally stem from industrial operations, deforestation, and fossil fuel consumption. Economically, the challenges posed by climate change exacerbate existing inequalities and have the potential to undermine long-term economic viability. Extreme meteorological events, increasingly prevalent due to climate alterations, inflict considerable damage on infrastructure and human assets, culminating in substantial financial costs. Within the realm of energy, the phasing out of fossil fuels in favor of renewable energy sources like hydropower, solar and wind is imperative for emissions reduction. Nevertheless, this energy transition presents its own set of intricacies, such as the intermittent of renewable energy and the capital-intensive nature of infrastructural development. Environmentally, climate change amplifies a host of issues including biodiversity loss, ocean acidification, and resource depletion. Addressing these challenges necessitates a comprehensive approach that includes technological advancements, policy modifications, and behavioral shifts at both micro and macro levels.

One salient approach to curbing CO2 emissions involves facilitating an energy transition from non-renewable to renewable sources. Recent advancements in renewable energy have gained global traction, evidenced by frameworks and initiatives such as the Kyoto Protocol and the Paris Agreement. However, more comprehensive measures are urgently needed to realize a globally sustainable environment. According to the International Energy Agency (IEA), the total global energy supply in 2018 stood at 14,282 million tons of oil equivalent, with a mere 13.5% derived from renewable sources (i.e., biofuel and waste constituted 9%, hydroelectric power 2.5%, and solar, wind, and other sources 2%).

Concerned about environmental issues, carbon dioxide (CO2) emissions are widely acknowledged as a significant contributor to the exacerbation of climate change and global warming, eliciting considerable public apprehension. In response, the Sustainable Development Goals (SDGs) strive to foster environmental and energy policies conducive to a more sustainable environment, particularly focusing on the regulation of CO2 emissions. Furthermore, as devloping economies experience rapid economic growth, there is an escalating demand for energy. Consequently, managing

CO_2 emissions from these nations becomes imperative for attaining global environmental sustainability. SDG 7 underscores the necessity for clean energy to preserve the planet.

The objective of this essay is to explore the role of modern renewable energy in mitigating CO_2 emissions and to evaluate public attitudes toward the development of modern renewable energy in developing countries. Structured in a series of interconnected sections, the essay aims to provide a comprehensive understanding of the subject matter. Chapter 2 investigates the nexus between CO_2 emissions and various facets of renewable energy sources in emerging economies. These countries frequently struggle with barriers in adapting modern renewable energy technologies. Consequently, Chapters 3 and 4 pivot to an in-depth case study of Cambodia, which is a lower-income country. Cambodia is one of the developing countries which has rapid economic growth in south-east Asia escalating for gradual demand for energy. Moreover, the need for modern renewable energy in Cambodia is important to help reducing CO_2 emission in the region. The priority of modern renewable energy development could be hydropower and solar power. Therefore, this case study examines public perceptions regarding the implementation of a hydropower development initiative and the adoption of solar home systems. Both hydropower and solar home systems are integral components of the contemporary renewable energy paradigm.

Chapters 2, 3, and 4 constitute the first, second, and third distinct analytical studies, respectively.

- Chapter 2 of the essay explores the relationship between both modern and traditional renewable energy sources and CO_2 emissions in emerging economies. Utilizing an Autoregressive Distributed Lag (ARDL) model, the study aims to capture the long-term relationship between CO_2 emissions and these two forms of renewable energy. The study focuses on 31 emerging countries that are actively formulating policies to promote renewable energy. By centering on these nations, the chapter underscores the urgent need for the adoption of renewable energy as a strategy to reduce CO_2 emissions. Additionally, the study identifies the key characteristics that set modern renewable energy sources apart from traditional ones. This section serves as a foundational framework for comprehending the inherent advantages and limitations of each type of renewable energy. The implications of the study emphasize the pivotal role that modern renewable energy plays in mitigating CO_2 emissions.
- Chapter 3 of the essay investigates public attitudes toward hydropower projects along the Mekong River. Hydropower has been a long-standing focus of development in both developed and developing countries, aimed at augmenting energy supply. The Mekong River originates in China and flows through Thailand, Myanmar, Laos, Cambodia, and Vietnam.

Numerous dams and hydropower facilities have been constructed along the river in these countries. This study gauges public attitudes toward hydropower projects in Cambodia by employing a vignette experiment involving 501 households in three districts of Kampong Cham province, which is situated in the lower part of the Mekong River. Existing research gaps enable the study to examine the impact of three key factors: (1) the positive and negative environmental framing of the hydropower project, (2) the financial burden borne by taxpayers and private investors for the project, and (3) the role of international assistance, such as from China and the World Bank, in contributing to the project. The implication of the study highlights the necessity for policymakers and project developers to proactively mitigate the adverse effects of hydropower on environmental issues to increase public support for future projects. Additionally, it is important for policy makers to promote trust from the public and emphasize positive aspects of China's involvement in Cambodia.

- Chapter 4 of the essay examines the market adoption of solar home systems in rural Cambodia. This section aims to assess the level of public perception regarding the adoption of solar power in rural communities. The study employs vignette experiments to present information related to the cost of solar power, accessibility of the electrical grid, and environmental benefits associated with solar energy. By providing this information to respondents, we can gauge their preferences for supporting solar home systems. The study conducted interviews with 351 rural households in Cambodia, where more than one-third lack access to grid electricity. While solar power serves as a supplementary energy source to grid electricity in developed countries, it assumes a more vital role in low-income countries like Cambodia. In such regions, many rural areas lack access to grid connections, necessitating alternative power supplies from private local companies, batteries, or solar power. These findings offer valuable insights for businesses and policymakers, enabling the development of more effective market penetration strategies and policy frameworks for promoting solar home systems in rural areas.

Overall, the essay aspires to provide a multifaceted exploration of the role of renewable energy in climate change mitigation, particularly focusing on the context of developing countries.

The remainder of this paper proceeds as follows: Chapter 2 explains study 1. Chapter 3 explains study 2. Chapter 4 explains study 3. In chapter 5, we provide summary conclusions of the three chapters along with each study’s policy implications and suggestions.

Chapter 2: Modern and traditional renewable energy sources and CO2 emissions in emerging countries

1. Introduction

Renewable energy is available from various types of sources, including biogas, geothermal, hydro, liquid biofuels, marine, renewable waste, solar, solid biofuels, and wind (IEA, 2020). These sources can be categorized into two main forms: traditional and modern renewable sources (IEA, 2020; UNCTAD, 2019), however, not all renewable energy sources are considered 'clean'. Some traditional renewable resources such as wood and charcoal, are considered less sustainable (UNCTAD, 2019). In many developing countries, solid biofuels and charcoal are widely used as traditional sources of renewable energy for heating and cooking, which contributes to the large share of renewable energy sources (IEA, 2020). Thus, it is essential to promote clean and sustainable renewable energy primarily generated from modern renewable energy sources rather than traditional renewable energy sources, particularly in less developed countries (Goldemberg and Teixeira Coelho, 2004; UNCTAD, 2019).

In the last decade, modern renewable energy has gained significant popularity in emerging countries. Meanwhile, many low-income countries continue to face challenges while adopting modern green technologies such as infrastructural development, which is necessary to integrate renewable energy sources into electrical systems (UNCTAD, 2019). Several studies on environmental issues, at the macroeconomic level, have called for increasing renewable energy to tackle environmental pollution problems (Bekun et al., 2019; Bhattacharya et al., 2020; Bilgili et al., 2016; Cetin and Bakirtas, 2020; Dong et al., 2017; Ike et al., 2020; Inglesi-Lotz and Dogan, 2018; Sebri and Ben-Salha, 2014). However, most previous studies assume that all sources of renewable energy are identical, without accounting for the differences between traditional and modern renewable energy sources. Differently from past studies, this study evaluates possible differences in the relationship with CO_2 emissions between the two renewable energy sources (traditional and modern ones). Such heterogeneity of the effects requires examination to obtain a complete picture of the role of renewable energy sources from a sustainability perspective. This study aims to address this by examining the way that CO_2 emissions relate to the two components of renewable energy (i.e., traditional and modern renewable energy sources), which provides significant novel contributions to the existing literature in the field of environmental studies. This analysis can help environmental and energy regulators in emerging economies plan and implement sound policies for promoting modern renewable energy development and green technology investment.

Following the work of other studies (Cristina Gonçalves et al., 2019; Goldemberg and Teixeira Coelho, 2004; Hartmann, 2017; IEA, 2020; UNCTAD, 2019; Yan and Shi, 2021), we categorize solid biofuel and charcoal as traditional renewable energy sources and hydro, wind, solar, liquid biofuels, biogas, geothermal, marine, and renewable waste as modern ones. Our study focuses on emerging countries, since these countries have played an important role in global environmental issues and have faced the challenges of energy security and environmental quality issues. Regulators have attempted to encourage the development of cleaner and more sustainable renewable energy sources in the place of non-renewable energy sources. Emerging economies have become large energy consumers globally associated with their rapid economic growth (Cetin and Bakirtas, 2020). Environmental issues and renewable energy development have attracted researchers and policy regulators in emerging countries (Cetin and Bakirtas, 2020; Dong et al., 2017; Mangla et al., 2020; Sebri and Ben-Salha, 2014). In addition, some emerging economies have recently increased the installation of modern renewable energy sources, partly because of the dissemination of advanced green technology (Chakraborty and Mazzanti, 2020).

To evaluate the relationship between renewable energy and CO_2 emissions, we employ a panel pooled mean group-autoregressive distributive lag (PMG-ARDL) approach. Using this technique, we can examine the short- and long-run linkages of CO_2 emissions with both modern and traditional renewable energy sources. The samples cover 31 emerging countries from 1990 to 2016. First, results confirm the negative long-run linkage of CO_2 emissions with total renewable energy, as well as traditional and modern renewable energy sources. Second, more importantly, CO_2 emissions are more responsive to modern renewable energy sources than traditional ones in the long run. These findings provide clear evidence supporting that promoting modern renewable energy sources in emerging economies can be more effective in mitigating CO_2 emissions than traditional ones. Our results coincide with the argument that modern and traditional renewable energy sources correspond to clean and less clean energy sources, respectively.

Our results, emphasizing the prevalence of modern sources of renewable energy, could have important policy implications for environmental and energy regulators in emerging countries to deal with various environmental problems and to develop sustainable sources of energy. Considering the conventional argument that some traditional renewable energy sources are considered harmful to forest sustainability and human health, regulators should encourage the development of modern sources of renewable energy, since most emerging countries generally rely heavily on non-renewable energy sources, such as fossil fuels. In addition, emerging countries often prioritize achieving high economic growth rather than environmental sustainability. Simultaneously, however, their demand for eco-friendly or green technology has intensified, partly because environmental degradation has become a global agenda under various frameworks of international communities. Crucial obstacles to adopting such advanced technology are the issues of intellectual property and lack of management skills related to advanced technology. To facilitate the transfer of green technology, particularly related to modern renewable energy sources, to developing countries, international communities should strengthen existing environmental frameworks, such as the clean development mechanism (CDM), to improve resilience to climate change and achieve environmental sustainability.

The remainder of this paper proceeds as follows: Section 2 reviews past studies to investigate the association between CO_2 emissions and renewable energy sources. Section 3 explains the empirical method and data used in this analysis. Section 4 presents several preliminary tests, such as cross-sectional dependence tests, panel unit root tests, and panel cointegration tests, and then explains the estimated results of the ARDL models and their related implications. In the final section, we provide conclusions, along with policy implications and suggestions.

2. Literature review

Many past studies have examined the associations between CO_2 emissions and renewable energy use in different countries or specific groups of countries, mainly in the context of environmental Kuznets curve (EKC) arguments (Grossman and Krueger, 1991).[1] (Bhattacharya et al., 2017) examine the role of renewable energy use in 85 developed and developing countries by applying generalized method of moments (GMM) estimations and show that renewable energy use has a negative influence on CO_2 emissions for developed and developing countries. Several studies have found that the use of renewable energy would reduce CO_2 emissions, because CO_2 emissions mainly stem from the increasing use of fossil fuels (Bekun et al., 2019; Bhattacharya et al., 2020; Cetin and Bakirtas, 2020; Ike et al., 2020; Inglesi-Lotz and Dogan, 2018). Several empirical studies have confirmed such a favorable relationship, focusing on advanced or developed countries. Bilgili et al. (Bilgili et al., 2016) evaluate the EKC hypothesis by using panel dynamic ordinary least squares (DOLS) estimations and panel fully modified ordinary least squares (FMOLS) estimations, for 17 Organisation for Economic

[1] There are many studies on the relationship between energy consumption and macroeconomic variables, such as economic growth and urbanization. For example, Ali et al. (2020) evaluate the nexus between electricity consumption, urbanization and economic growth in Nigeria and show that urbanization impedes economic growth. They also suggest that Nigeria should concentrate on renewable energies which are environmentally friendly. Nathaniel and Bekun (2021) examine the link between electricity consumption, urbanization, and economic growth in Nigeria and reveal that electricity consumption induces economic growth, while the impact of urbanization appears to hinder growth. Nathaniel et al. (2021) examine the link among natural resources, globalization, urbanization, and environmental degradation and show that economic growth, urbanization, and natural resource increase CO_2 emissions, which suggests that policymakers should motivate the urban population to use renewable energy instruments.

Co-operation and Development (OECD) countries and present a negative influence of renewable energy on CO_2 emissions. Ike et al. (Ike et al., 2020) also apply the FMOLS and DOLS estimations to the case of G7 countries and confirm that renewable energy would reduce CO_2 emissions. (Bekun et al., 2019) investigate the long-run relationship between renewable energy and CO_2 emissions using the PMG-ARDL models for 16 countries in the European Union and argue that renewable energy consumption helps reduce CO_2 emissions. Baloch et al. (2021) evaluate the link between energy innovation and environmental quality by using the ARDL model for 27 OECD countries and show that energy innovation leads to an improvement in environmental quality, suggesting a shift from fossil fuel energy to more renewable energy sources that are cleaner and ecosystem friendly.

Some empirical studies on the nexus between renewable energy use and CO_2 emissions have focused on emerging or less developed countries. Dong et al. (Dong et al., 2017) apply a vector error correction model (VECM) for emerging BRICS countries (i.e., Brazil, Russia, India, China, and South Africa) and find renewable energy consumption to have a negative effect on CO_2 emissions. Cetin and Bakirtas (Cetin and Bakirtas, 2020) study 15 emerging economies from 1980 to 2014 by employing the PMG-ARDL model, and confirm the role of fossil fuel energy consumption in increasing CO_2 emissions, lending further credence to the necessity of the use of renewable energy sources. Inglesi-Lotz and Dogan (2018) examine the determinants of CO_2 emissions in Sub-Saharan African countries by using the group-mean DOLS estimator and argue that renewable energy should be used to combat pollution issues. Moreover, many studies have also discussed the role of renewable energy in specific countries and have generally confirmed its favorable effects on environmental pollution. Gupta et al. (Gupta et al., 1995) study non-conventional sources of energy in India, including renewable energy sources, by applying an ordinary least square (OLS) regression, and find that CO_2 emissions increase when using energy from fossil fuels but reduce when using non-conventional energy sources. (Boontome et al., 2017) evaluate the case of Thailand, using cointegration and causality approaches to confirm the negative influence of renewable energy use on CO_2 emissions. Chen et al. (Chen et al., 2019) also find similar results for China, by applying the ARDL approach. Sharif et al. (2020) examine the roles of renewable and non-renewable energy consumption on Turkey's ecological footprint by applying the quantile autoregressive lagged (QARDL) approach, and show that renewable energy can decrease Turkey's ecological footprint in the long term.

One critical issue is that not all renewable energy sources are recognized as being 'cleaner', and some traditional renewable sources are considered less clean and less sustainable (UNCTAD, 2019). For example, traditional renewable energy sources, such as wood and charcoal, have been widely used to facilitate household heating by means of stoves, fireplaces, furnaces, and boilers. These traditional energy sources have recently raised concerns about in-house smoke, health issues related to smoke inhalation, and the felling future forests for firewood (Cristina Gonçalves et al., 2019). In addition, Das et al. (Das et al., 2020) discuss the possible advantages and disadvantages of biofuel energy sources, i.e., renewable sources of energy, as a replacement for petro-fuels. They mention that "traditional biomass is long established and is followed for centuries without any modification," and "modern biomass is biomass that has been innovated economic utilization such as biogas, liquid fuel, and different fertilizer production types." Their study supports the use of modern biomass, which is considered a sustainable biomass (e.g., biodiesel, bio-hydrogen, bio-methane, bio-gas, and bio-alcohols), to replace fossil fuels in the energy production sector. Many empirical studies have examined the link between CO_2 emissions and renewable energy, but most of them have discussed the roles of renewable energy just in total. (Goldemberg and Teixeira Coelho, 2004) emphasize that the concept of segregation between traditional and modern renewable energy sources is important for all stakeholders.

Although traditional and modern renewable energy sources have distinct features, empirical works on the association of different components of renewable energy sources with pollutant emissions at the macroeconomic level are still relatively limited. Some studies discuss specific components of renewable energy sources and evaluate their possible relevance to CO_2 emissions; for example, Ben Jebli and Ben Youssef (Ben Jebli and Ben Youssef, 2015) focus on the link of combustible renewables and waste with CO_2 emissions in North African countries. Their FMOLS and DOLS estimators show a negative link, and claim that combustible renewables and waste should substitute fossil fuel energy sources for mitigating environmental degradation. (Ben Jebli and Ben Youssef, 2019) also evaluate the role of combustible renewables and waste in Brazil by employing the ARDL method, and confirm that the use of combustible renewables and waste tends to decrease CO_2 emissions in the country.

Concerning traditional renewable energy sources, Wang (Wang, 2009) examines the use of traditional biomass in Tibet and shows that traditional biomass induces environmental degeneration, such as deforestation, grassland, and soil erosion. His study suggests that the efficiency of stoves should be improved, and that modern energy sources such as solar energy and hydroelectricity should be promoted as a substitute for traditional sources of energy from biomass. (Gurung and Oh, 2013) review various research articles and project reports about traditional biomass in Nepal and present that traditional biomass is low-efficient energy, giving rise to environmental degradation. In contrast, concerning modern renewable energy sources, a few studies discuss the benefits of specific components of renewable energy to reduce CO_2 emissions at the macroeconomic level. (Ren et al., 2020) employ data envelopment analysis to examine the role of solar photovoltaic cells in six regions of China, and conclude that solar photovoltaic cells could reduce CO_2 emissions. (Uddin and Kumar, 2014) analyze the life cycle of wind turbines in Thailand and find that wind turbines also help reduce

CO_2 emissions and thus improve the environment. Although several studies exist on the nexus between CO_2 emissions and some components of renewable energy sources, to the best of our knowledge, there is no extensive empirical research distinguishing between traditional and modern sources of renewable energy, while incorporate them into a single model with a focus on emerging countries that are currently recognized as the engine of global economic growth.

3. Empirical method

This section examines how CO_2 emissions relate to the two components of renewable energy sources (i.e., traditional and modern renewable energy sources) in emerging countries. Using the IEA's database, we construct the data on modern and traditional renewable energy sources, in line with several preexisting studies on sources of renewable energy (Cristina Gonçalves et al., 2019; Goldemberg and Teixeira Coelho, 2004; Hartmann, 2017; UNCTAD, 2019; Yan and Shi, 2021). Traditional renewable energy sources consist of solid biofuel and charcoal, and modern renewable energy sources consist of hydro, wind, solar, liquid biofuels, biogas, geothermal, marine, and renewable waste (see IEA, 2020, for the definition of each component).

To evaluate the short- and long-run associations of CO_2 emissions with renewable energy , modern and traditional renewable energy sources, we estimate the following empirical equation:

$$LCO2_{i,t} = \beta_0 + \beta_1 \text{SHRENEW}_{i,t} + \sum_k \gamma_k X_{k,i,t} + \epsilon_{i,t}, \quad (1)$$

$$LCO2_{i,t} = \beta_0 + \beta_1 SHTRAD_{i,t} + \beta_2 SHMOD_{i,t} + \sum_k \gamma_k X_{k,i,t} + \epsilon_{i,t}, \quad (2)$$

where $LCO2_{i,t}$ denotes the logarithm of CO_2 emissions in country i at year t, $SHRENEW_{i,t}$ denotes the share of overall renewable energy to the total energy supply, $SHTRAD_{i,t}$ denotes the share of traditional renewable energy sources to the total energy supply, $SHMOD_{i,t}$ denotes the share of modern renewable energy sources to the total energy supply, $X_{k,i,t}$ are other explanatory variables that may relate to the level of CO_2 emissions, and $\epsilon_{i,t}$ is the error term. This model includes the logs of the total energy supply (LENERGY) and real GDP per capita (LRGDPPC) as other control variables, much like in previous studies (Arouri et al., 2012; Bilgili et al., 2016; Child et al., 2018; Dong et al., 2017; Ike et al., 2020; Magazzino, 2016; Mensah et al., 2019; Mujtaba et al., 2020; Sahin et al., 2016). LRGDPPC captures a country's income level and LENERGY controls the size of a country's total energy supply.

This study applies a panel ARDL approach to estimate the short- and long-run linkages of CO_2 emissions with traditional and modern renewable sources (Pesaran et al., 1999), which is described by

$$LCO_{2_{i,t}} = \sum_{j=1}^{p} \alpha_{i,j} \Delta LCO_{2_{i,t-j}} + \sum_{j=0}^{q} Z_{i,t-j} \theta_{i,j} + \mu_i + \eta_{i,t}, \quad (3)$$

where $Z_{i,t-j}$ is a set of the independent variables ($SHTRAD_{i,t}$, $SHMOD_{i,t}$, and $X_{k,i,t}$) in equation (1), μ_i is the fixed effects, and $\eta_{i,t}$ is the error term. In equation (2), different coefficients are allowed across countries. Assuming the presence of a cointegration and a stationary process of the error term, equation (2) can be reparametrized in the following error-correction form:

$$\Delta LCO_{2_{i,t}} = \varphi_i ECT_{i,t} + \sum_{j=1}^{p-1} \alpha_{i,j}^{*} \Delta LCO_{2_{i,t-j}} + \sum_{j=0}^{q-1} \Delta Z_{i,t-j} \theta_{i,j}^{*} + \varepsilon_{i,t}, \quad (4)$$

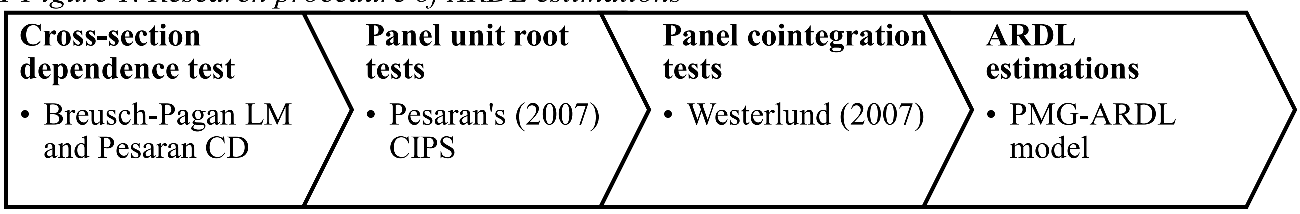
$$ECT_{it} = LCO_{2_{i,t-1}} - Z_{i,t}\delta_i, \quad (5)$$

where ECT_{it} is the error correction term and $\varepsilon_{i,t}$ is the error term. In equation (3), the first term, $\varphi_i ECT_{i,t}$, captures the speed of convergence to a long-run equilibrium, and the latter terms capture the dynamics in the short run. The coefficient φ_i captures the group-specific speed of adjustment or the short-run adjustment. The estimated coefficient of ECT needs to be significantly negative (i.e., $\varphi_i < 0$), so that the system converges to a long-run equilibrium. The coefficient $\delta_i = -(\sum_{j=0}^{q} \theta_{i,j}) / \varphi_i$ captures the long-run coefficients. The coefficients, $\alpha_{i,j}^{*} = -\sum_{d=j+1}^{\mathrm{p}} \alpha_{i,d}$ and $\theta_{i,j}^{*} = -\sum_{d=j+1}^{q} \theta_{i,d}$, correspond to the short-run coefficients of the dependent and explanatory variables, respectively.

Since the panel ARDL model generates long- and short-run estimates in a single framework, it has been widely used in the context of energy and environmental research (Adebayo et al., 2021; Assi et al., 2021; Ren et al., 2021; Tenaw and Beyene, 2021). The panel ARDL approach has advantages over other dynamic panel models, such as the generalized methods of moment (GMM) estimators and the fixed effects estimators ((Anderson and Hsiao, 1982, 1981; Arellano, 1989; Arellano and Bover, 1995), since these methods may suffer from inconsistent parameter estimates unless all countries share identical coefficients (da Silva et al., 2018). Additionally, this approach can estimate a long-run association regardless of whether the variables are stationary at the level, at the first difference, or a mix of both (Pesaran et al., 2001). A panel ARDL model can be estimated either by a Pooled Mean Group (PMG) estimator or a Mean Group (MG) estimator (Pesaran et al., 1999; Pesaran and Smith, 1995). The PMG estimator imposes a homogeneity restriction on the long-run coefficients but allows the model to take into account different short-run coefficients and error variances across countries, while the MG estimator allows the long- and short-run coefficients to differ across countries. In this study, the Hausman tests are conducted to check whether the PMG or MG estimator is appropriate for our panel ARDL model estimation. The PMG and MG models differ fundamentally in their assumptions about economic behavior across countries. The PMG model, as described by Pesaran et al. (1999), suggests that in the short term, countries may follow different economic models due to immediate, unique factors. However, it assumes that over the long term, these differences diminish, leading all countries to follow a similar, unified economic model. On the other hand, the MG model proposes a different perspective. It asserts that each country maintains its distinct economic model even in the long term, highlighting the persistence of economic diversity across nations.

This study uses panel data covering 31 emerging countries from 1990 to 2016.[2] The choice of emerging countries is based on the IMF's income classifications; Table 1 lists the sample countries used in this study. Energy-related data are taken from the International Energy Agency (IEA). Data on CO_2 emissions and real GDP per capita are obtained from the World Development Indicators (WDI) of the World Bank (see Table A1 in the appendix). Tables 2 and 3 report the summary statistics of the variables and the correlation matrix. As expected, CO_2 emissions are negatively correlated with the share of total renewable energy and the shares of traditional and modern renewable energy sources. In addition, CO_2 emissions are positively correlated with real GDP per capita and the total energy supply. Our empirical analysis takes several steps: we conduct cross-sectional dependence tests, panel unit root tests, and panel cointegration tests to ensure the validity of the ARDL approach, after which we estimate ARDL models (see Figure 1 for our complete research procedure).

1 Figure 1. Research procedure of ARDL estimations



1 Table ***1****. List of sample countries (31 emerging countries)*

Albania	China	India	Mexico	South Africa
Algeria	Colombia	Indonesia	Morocco	Thailand
Argentina	Costa Rica	Iran	Pakistan	Turkey
Bolivia	Dominican Republic	Iraq	Paraguay	
Brazil	Ecuador	Jordan	Peru	
Bulgaria	Egypt	Lebanon	Philippines	
Chile	Guatemala	Malaysia	Russia	

[2] The choice of 31 countries is based on the availability of the data.

2 Table 2. Summary statistics

Variable	Description	Obs	Mean	Std. Dev.	Min	Max
LCO_2	Log of CO_2 emissions	837	11.33	1.76	7.34	16.15
SHTRAD	Ratio of traditional renewable energy source to total energy supply	837	0.15	0.16	0.00	0.73
SHMOD	Ratio of modern renewable energy source to total energy supply	837	0.09	0.18	0.00	1.19
LRGDPPC	Real GDP per capita (log)	837	8.30	0.69	6.36	9.60
LRGDPPC2	Square of log of real GDP per capita	837	69.31	11.14	40.39	92.18
LENERGY	Total energy supply (log)	837	14.20	1.66	10.83	18.65

3 Table 3. Correlation matrix

Variable	LCO_2	SHRENEW	SHTRAD	SHMOD	LRGDPPC	LENERGY
LCO_2	1.000					
SHRENEW	-0.413	1.000				
SHTRAD	-0.272	0.835	1.000			
SHMOD	-0.427	0.884	0.481	1.000		
LRGDPPC	0.114	-0.204	-0.426	0.037	1.000	
LENERGY	0.986	-0.284	-0.143	-0.331	0.092	1.000

4. Results

4.1 Stationarity tests

For the panel ARDL model to be valid, all variables are required to be stationary at either the level or the first difference (Pesaran et al., 2001, 1999). Past empirical studies have checked the stationarity of variables by using traditional (or first-generation) panel unit root tests, such as (Breitung, 2000; Hadri, 2000; Im et al., 2003; Levin et al., 2002) (LL test), where the LL test assumes homogeneity of autoregressive coefficients, while the IPS test allows for heterogeneous coefficients. These traditional panel unit root tests assume that disturbances are not cross-sectionally dependent but are cross-sectionally independent in panel data. However, panel data often have cross-sectionally dependent disturbances, which may lead to inconsistent estimates and misleading interpretations (Banerjee et al., 2004). The presence of cross-sectional dependence can originate from various factors, including geographical characteristics, political and economic features, and other unobserved common factors (Breitung and Pesaran, 2008; Gaibulloev et al., 2014). Thus, as suggested by (Baltagi et al., 2014), evaluating the possibility of cross-sectional dependence is important before applying stationarity tests.

To test for the cross-sectional dependence for each variable, this study uses the Breusch–Pagan Lagrange multiplier (LM) tests (Breusch and Pagan, 1980) and the Pesaran cross-sectional dependence (CD) tests (Pesaran, 2004). Given the number of cross-sections (i.e., countries) N, and the number of periods T, the Breusch–Pagan LM statistic is described by:

$$LM = \sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T_{ij}\delta_{ij}^{2} - 1\right) \rightarrow \chi^{2}_{\frac{N(N-1)}{2}},$$

where δ_{ij} denotes the correlation coefficient obtained from the residuals of the panel data model. Pesaran (2004) mentions that the LM statistic tends to exhibit size distortion for small T_{ij}, particularly for a large N. To solve this size distortion, (Pesaran, 2004) proposes the alternative test statistic:

$$CD = \sqrt{\frac{2}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} T_{ij}\delta_{ij}^{2} \rightarrow N(0,1).$$

Table 4 presents the results of the two cross-sectional dependence tests (i.e., LM and CD tests). All statistics are statistically significant at the 1% significance level, so that the null hypothesis of cross-sectional independence can be rejected. This confirms that cross-sectional dependency is present for each variable across countries, so that we can proceed to applying the panel unit root tests and cointegration tests that are based on cross-sectional dependency.

After confirming the presence of cross-sectional dependence, this study employs panel unit root tests to check the stationary properties of each variable. (Pesaran, 2007) proposes a panel unit root test (CIPS) that allows for heterogeneity and cross-sectional dependence by incorporating the averages of lagged levels and differences for each cross-section (i.e., country). This test is known as the second-generation panel unit root test. The equation for the panel unit root test is as follows:

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{i,t-1} + \gamma_i \bar{Y}_{t-1} + \sum_{j=0}^{p}\theta_{ij}\Delta\bar{Y}_{t-1} + \sum_{j=0}^{p}\vartheta_{ij}\Delta Y_{i,t-1} + \mu_{it},$$

where Y_{it} represents an analyzed variable, $\bar{Y}_t$ and $\Delta\bar{Y}_{t-1}$ are the cross-section averages of the levels and differences, respectively, and μ_{it} is the error term. Pesaran's (2007) cross-sectionally augmented IPS (CIPS) test statistic is calculated using the cross-sectionally augmented Dickey-Fuller (CADF) statistic for each cross-section or country:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i,$$

where $CADF_i$ represents the augmented Dickey-Fuller (ADF) test statistic for the i-th cross-section (i.e., country), which can be calculated by the t-ratio of the OLS estimate of β_i. Table 5 reports the results of CIPS tests. The test statistics are confirmed to be statistically significant at the first difference for all variables in the analysis, so that all variables are stationary at the first difference. This result allows us to proceed with further panel cointegration tests and ARDL analyses.

4.2 Panel cointegration tests

Many empirical studies have conducted traditional (often called a first-generation) residual-based tests for cointegration, such as tests developed by (Kao, 1999) and (Pedroni, 2004), with a common factor restriction. Failure to meet such a restriction causes a significant loss of power to reject the null of no cointegration (Banerjee et al., 1998; Kremers et al., 1992). To mitigate the issue, (Westerlund, 2007) develops a panel cointegration test based on structural dynamics rather than residual dynamics, without a common factor restriction. This test is often categorized as a second-generation cointegration test. By employing an error-correction model approach, this technique overcomes the problems associated with cross-sectional dependence and heterogeneity in the short- and long-term dynamics (Persyn and Westerlund, 2008). Thus, we apply this panel cointegration test to evaluate the long-run association or cointegration among the variables. This method proposes four test statistics. The group mean statistics (G_τ and G_α) test for the entire cointegrated panel, and the panel statistics (P_τ and P_α) test for whether at least one country is cointegrated or not.

This approach is based on an error correction form:

$$\Delta z_{it} = \delta_i d_t + \alpha_i z_{i,t-1} + \lambda_i x_{i,t-1} + \sum_{j=1}^{p_i} \theta_{ij} \Delta z_{i,t-j} + \sum_{j=-q_i}^{p_i} \vartheta_{ij} \Delta x_{i,t-j} + e_{it}, \quad (6)$$

where z_{it} is the dependent variable; $x_{i,t}$ is a vector of independent variables; d_t is a vector of deterministic components; and e_{it} is the error term. The parameter $\alpha_i < 0$ represents the speed of convergence at which the system converges to the equilibrium relationship after a shock. Using the ordinary least squares (OLS) estimates of equation (4), we compute $\hat{u}_{i,t} = \sum_{j=-q_i}^{p_i} \hat{\vartheta}_{ij} \Delta x_{i,t-j} + \hat{e}_{it}$, which derives $\hat{\alpha}_i(1) = \frac{\hat{w}_{ui}}{\hat{w}_{zi}}$, where $\hat{w}_{ui}$ and $\hat{w}_{zi}$ are, respectively, the long-run variance estimators of Newey and West (1994) based on $\hat{u}_{it}$ and Δz_{it}. The group mean test statistics of the panel cointegration tests can be described by $G_\tau = \frac{1}{N}\sum_{i=1}^{N} \frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)}$ and $G_\alpha = \frac{1}{N}\sum_{i=1}^{N} \frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)}$, where $SE(\hat{\alpha}_i)$ represents the standard error of $\hat{\alpha}_i$. These test statistics are utilized to evaluate the null hypothesis of no cointegration. The rejection of the null hypothesis suggests the existence of cointegration or long-run association among the variables for at least one country.

For the panel statistics, regressing $\Delta z_{i,t}$ on d_t, the contemporaneous and lagged values of $\Delta x_{i,t}$, and the lagged values of $\Delta z_{i,t}$ yields the projection error of $\Delta z_{i,t}$:

$$\Delta \tilde{z}_{i,t} = \Delta z_{i,t} - \hat{\delta}_i d_t - \hat{\lambda}_i x_{i,t-1} - \sum_{j=1}^{p_i} \hat{\theta}_{ij} \Delta z_{i,t-j} - \sum_{j=-q_i}^{p_i} \hat{\vartheta}_{ij} \Delta x_{i,t-j},$$

and regressing $z_{i,t-1}$ on d_t, the contemporaneous and lagged values of $\Delta x_{i,t}$, and the lagged values of $\Delta z_{i,t}$ yields the projection error of $z_{i,t-1}$:

$$\tilde{z}_{i,t-1} = z_{i,t-1} - \tilde{\delta}_i d_t - \tilde{\lambda}_i x_{i,t-1} - \sum_{j=1}^{p_i} \tilde{\theta}_{ij} \Delta z_{i,t-j} - \sum_{j=-q_i}^{p_i} \tilde{\vartheta}_{ij} \Delta x_{i,t-j}. \quad (7)$$

Using $\Delta\tilde{z}_{i,t}$ and $\tilde{z}_{i,t-1}$, we can derive an estimate of the common error correction coefficient:

$$\hat{\alpha} = \left(\sum_{i=1}^{N}\sum_{t=2}^{T}\tilde{z}_{i,t-1}^{2}\right)^{-1}\sum_{i=}^{N}\sum_{t=2}^{T}\frac{1}{\hat{\alpha}_i(1)}\tilde{z}_{i,t-1}\Delta\tilde{z}_{i,t-1},$$

with its standard error SE($\hat{\alpha}$). Then, we compute the panel statistics by $P_\tau = \frac{\hat{\alpha}}{SE(\hat{\alpha})}$ and $P_\alpha = T\hat{\alpha}$. These panel statistics are also utilized to evaluate the null of no cointegration, such that the rejection of the null hypothesis suggests no cointegration for the whole panel.

Table 6 presents the results of the Westerlund panel cointegration tests. Model 1 uses the share of renewable energy sources to the total energy supply (SHRENEW) as the main independent variable, and model 2 uses the shares of traditional and modern renewable energy sources (SHTRAD and SHMOD) as the two main independent variables. All test statistics are statistically significant, except for the group mean statistic G_α in model 2. These test results support the rejection of the null of no cointegration at the 1% significance level for both models, so that there exists a long-run linkage or cointegration among the variables for emerging countries. Thus, we can proceed with the estimates of the ARDL models.

4 Table 4. Tests for cross-section dependence.

Variables	Breusch-Pagan LM	Pesaran CD
LCO_2	9,092.04***	77.21***
SHRENEW	4,224.37***	31.65***
SHTRAD	5,550.36***	50.30***
SHMOD	2,079.83***	6.61***
LRGDPPC	10,041.92***	99.60***
LENERGY	9,168.59***	79.96***

*** p<0.01, ** p<0.05, * p<0.10.

5 Table 5. CIPS panel unit root tests.

Variables	Level	First difference
LCO_2	-2.972***	-5.053***
SHRENEW	-2.133	-4.277***
SHTRAD	-1.800	-4.607***
SHMOD	-2.301**	-3.912***
LRGDPPC	-2.221**	-3.836***
LENERGY	-2.181**	-4.625***

*** p<0.01, ** p<0.05, * p<0.10.

6 Table 6. Westerlund panel cointegration tests.

	Statistic	z-value	p-value
Model 1			
Gt	-4.375***	-4.375	0.000
Ga	-14.003***	-14.003	0.008
Pt	-17.194***	-17.194	0.000
Pa	-13.71***	-13.710	0.000
Model 2			
Gt	-3.961***	-8.836	0.000
Ga	-8.942	2.917	0.998
Pt	-17.75***	-5.343	0.000
Pa	-14.347***	-3.702	0.000

*** p<0.01, ** p<0.05, * p<0.10.

4.3 Long-run estimates with short-run dynamics

This subsection estimates the panel ARDL model to evaluate the long- and short-run relationships between renewable energy (its two components) and CO_2 emissions. We perform the Hausman test to select either the MG or the PMG estimator (Pesaran et al., 1999; Pesaran and Smith, 1995). Table 7 presents the results of the Hausman tests, which shows that the test statistics are statistically insignificant. The tests fail to reject the null hypothesis, i.e., there are no systematic differences between the PMG and MG estimators. This supports the homogeneity restriction of long-run relationships across countries, so that the PMG estimator is more suitable for our model specifications than the MG.

Table 7 presents the estimated results of the PMG-ARDL models for emerging countries. The first column reports the estimated results of the model with the share of total renewable energy to total energy supply (SHRENEW) as the main independent variable (model 1). The second column reports the estimated results of the model with the shares of traditional and modern renewable energy sources (SHTRAD and SHMOD) as the two main independent variables (model 2). The estimated coefficients of the error correction term (ECT) are significantly negative, with the convergence speeds of 42.3% and 41.5% toward the long-run equilibrium level in models 1 and 2, respectively. Concerning the results of model 1, the PMG-ARDL estimate confirms a significantly negative long-run association of CO_2 emissions with total renewable energy use, which coincides with the conventional argument supporting that an increase in overall renewable energy could reduce CO_2 emissions (Bekun et al., 2019; Bhattacharya et al., 2020; Bilgili et al., 2016; Cetin and Bakirtas, 2020; Dong et al., 2017; Ike et al., 2020; Inglesi-Lotz and Dogan, 2018; Sebri and Ben-Salha, 2014). The estimated long-run coefficient of SHRENEW is -0.68, implying that a 1% rise in the share of renewable energy is associated with a 0.68% decline in CO_2 emissions in the long run. Our results are similar to the findings of Bekun et al. (2019), which show that renewable energy has a negative long-run association with CO_2 emissions and concludes that renewable energy helps reduce CO_2 emissions. Similarly, Dong et al. (2017) and Cetin and Bakirtas (2020) reveal the presence of a negative link of renewable energy with CO_2 emissions in some emerging countries, which calls for the promotion of renewable sources of energy to combat environmental pollution.

*7 Table 7**.** The PMG-ARDL estimates.*

	Model 1		Model 2	
	Coef.	p-value	Coef.	p-value
Long-run estimates				
SHRENEW	-0.677***	0.000	---	---
SHTRAD	---	---	-0.379**	0.014
SHMOD	---	---	-1.761***	0.000
LRGDPPC	0.056**	0.018	0.087***	0.001
LENERGY	0.903***	0.000	0.923***	0.000
Short-run estimates				
ECT (lag)	-0.423***	0.000	-0.415***	0.000
SHRENEW	0.663	0.747	---	---
SHTRAD	---	---	-32.429	0.313
SHMOD	---	---	1.303	0.538
LRGDPPC	0.214***	0.003	0.201***	0.007
LENERGY	0.275***	0.005	0.181	0.261
Constant	-0.749***	0.000	-0.947***	0.000
Hausman test (p-value)	0.929		0.822	
No. of obs.	806		806	
No. of countries	31		31	

*** p<0.01, ** p<0.05, * p<0.10.

For the results of model 2, the estimated long-run coefficients of traditional and modern renewable energy sources are significantly negative, implying that the prevalence of these renewable energy sources helps reduce CO_2 emissions in the long run. More importantly, the results clearly reveal different long-run associations of traditional and modern renewable energy sources with CO_2 emissions. The estimated long-run coefficients of SHMOD and SHTRAD are -1.76 and -0.38, respectively. This suggests that a 1% rise in the share of modern renewable energy sources would decrease CO_2 emissions by 1.76%, and a 1% rise in the share of traditional renewable energy sources would decrease CO_2 emissions by 0.38%. Modern renewable energy sources have a more favorable effect on CO_2 emissions than traditional sources. On the other hand, the PMG-ARDL estimation fails to show clear evidence of the short-run links between renewable energy sources and CO_2 emissions.

Our estimations show that among the two renewable energy sources, modern renewable energy sources are more environmentally friendly and more efficient in mitigating environmental degradation and achieving sustainable energy supply in emerging countries. (da Silva et al., 2018; Panwar et al., 2011) suggest that renewable energy technologies deliver a potential opportunity to mitigate environmental degradation, which calls for the technological progress of renewable energy sources, such as wind energy, solar energy, and hydropower. Meanwhile, traditional renewable energy sources, which are widely used in developing countries, also play a role in suppressing environmental pollutants to some extent, although their favorable effects on the environment are less substantial compared with the effects of modern renewable energy sources. In addition, several studies have emphasized the adverse side effects of traditional renewable sources on the environment and people's health. For example, (Wang, 2009) mentions that the use of traditional renewable energy sources causes damage to the environment and valuable ecosystems, which could lead to deforestation and soil erosion. (Goldemberg and Teixeira Coelho, 2004) argue that the use of traditional biomass leads to deforestation in developing countries. (UNCTAD, 2019) reports that traditional renewable energy, particularly solid biofuels such as wood and charcoal, is considered less clean and less sustainable. Although emerging countries tend to prioritize economic growth, which needs to meet the increasing demand for energy over environmental degradation, environmental and energy policies targeting the prevalence of modern renewable energy sources have become more important for sustainable development.

Concerning other control variables, the estimations of model 2 present the significantly positive long-run coefficients of real GDP per capita and total energy supply, so that CO_2 emissions are positively associated with the country's income level and total energy use. These results are consistent with the findings of previous studies (Apergis and Ozturk, 2015; Dong et al., 2017; Ozturk and Acaravci, 2013; Shahbaz et al., 2019). Our estimations show that in the long run, a 1% rise in real GDP per capita and total energy supply would increase CO_2 emissions by 0.09% and 0.92%, respectively. The analysis of model 2 also shows a significantly positive short-run coefficient of real GDP per capita but a less significant coefficient of total energy use, so that an increase in the income level raises CO_2 emissions in the short run.

We also conduct sensitivity analyses to check the empirical validity of our baseline findings. As the first robustness check, we estimate the ARDL model with two additional control variables: the square of the log of real GDP per capita (LRGDPPC2), and trade openness (the ratio of trade flows to GDP) (TRADE). The quadratic specification controls for the possible presence of the EKC pattern, that is, the nonlinear or inversed U-shaped linkage between the income level and CO_2 emissions (Grossman & Krueger, 1991). Recent studies have provided clear evidence that international trade or globalization, which is captured by the trade openness measure, is closely associated with CO_2 emissions (Arouri et al., 2012; Bilgili et al., 2016; Chen et al., 2019; Essandoh et al., 2020; Sebri and Ben-Salha, 2014). As the second check for robustness, we estimate the ARDL model using an alternative income group classification. In the baseline analysis, we use the income classification of the International Monetary Fund (IMF), and our sample consists of emerging market economies under the IMF classification. The World Bank and the IMF have different approaches towards income classification, and their groupings suffer from a lack of clarity concerning how to distinguish among income groups (Nielsen, 2013). To ensure the validity of the baseline findings, we construct an alternative sample based on the World Bank (WB) income classification, where our sample is composed of upper-middle income countries under the WB classification. The estimated results of the sensitivity analyses generally confirm our baseline findings (see Tables A2 and A3 in the appendix).

5. Conclusion

Considering ongoing global climate change, both environmental regulators and private enterprises have paid more attention to green technologies, which are now recognized as a key solution to climate change and global warming (Hoang et al., 2021; Nguyen et al., 2021). In addition, the concepts of Industry 4.0 and Society 5.0 seek to integrate information between different industries and call for green technologies associated with modern renewable energy and sustainable development, which could improve the living standards of people (Deguchi et al., 2020).

This study investigated the relevance of renewable energy sources, as well as modern and traditional renewable energy sources, with CO_2 emissions. The results of PMG-ARDL estimations have confirmed that the overall renewable energy source has a negative long-run association with CO_2 emissions, so that the prevalence of renewable energy helps mitigate environmental degradation. More importantly, the results revealed that CO_2 emissions have a negative long-run relationship with both modern and traditional renewable energy sources. A 1% increase in the share of modern renewable energy sources is associated with a 1.76% decrease in CO_2 emissions, and a 1% increase in the share of traditional renewable energy sources is associated with a 0.38% decrease in CO_2 emissions. This confirms that modern renewable energy sources are more effective in reducing CO_2 emissions because of their advanced green technology to produce clean energy. Similar to the argument of Bekun et al. (2019), these results call for green technology development to mitigate environmental degradation.

This study also provides important policy implications for emerging countries to tackle environmental degradation and develop sustainable energy sources. It is often argued that developing countries have struggled with a dilemma related to the trade-off between economic development and environmental degradation. Although these countries have strong incentives to pursue high growth rates with poverty reduction, they also have a large demand for eco-friendly or green innovations. In addition, emerging countries have experienced technological progress through technology spillover from advanced countries, which is typically associated with foreign direct investment and international trade with global supply chains. Such advanced technologies, including green technology, enable emerging countries to enjoy efficient usage of energy sources and to develop a roadmap of energy technology for the prevalence of modern renewable energy. The current advanced technology allows the generation of clean energy from renewable energy sources, including solar, wind, and modern bioenergy. Although traditional biomass is not 'clean,' it can be transformed into environmentally friendly bioenergy using advanced bioenergy technology.

Most developing countries, however, often face various obstacles to adopting such advanced technologies. One crucial obstacle is related to intellectual property, which is the most controversial issue between developed and developing countries. To solve this problem, several international agreements and domestic regulations have supported the transfer of green technologies to the developing world. The Kyoto Protocol has encouraged developed countries to reduce greenhouse gas (GHG) emissions through the Clean Development Mechanism (CDM), which intends to promote the transfer of advanced technologies, including green technology related to the promotion of modern renewable energy sources. Simultaneously, Cima (2016) emphasizes that green technology transfer may not be efficient and effective without sound domestic policies and adequate legal frameworks, since such domestic measures encourage trade, foreign direct investment, and the related transfer of physical technology and management skills. In this regard, our empirical results provide strong support for strengthening international schemes as well as domestic policies, to mitigate environmental degradation by promoting the use of modern renewable energy sources for rapidly growing, emerging economies.

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Appendix

8 Table A1. Data sources

Data	Sources
CO_2 emissions (kiloton)	World Development Indicators (WDI)
Real GDP per capita (US dollar, constant 2010)	World Development Indicators (WDI)
Renewable energy supply (terajoule)	International Energy Agency (IEA)
Traditional renewable energy sources (solid biofuel and charcoal: terajoule)	International Energy Agency (IEA)
Modern renewable energy sources (hydro, wind, solar, liquid biofuels, biogas, geothermal, marine, and renewable waste: terajoule)	International Energy Agency (IEA)
Total energy supply (terajoule)	International Energy Agency (IEA)

9 Table A2. Robustness check (additional controls).

	Model 1		Model 2	
	Coef.	p-value	Coef.	p-value
(A) Long-run estimates				
SHTRAD	-0.544***	0.001	-0.731***	0.000
SHMOD	-1.084***	0.000	-1.143***	0.001
LRGDPPC	0.685***	0.001	0.917***	0.000
LRGDPPC2	-0.033***	0.004	-0.049***	0.000
LENERGY	0.897***	0.000	0.911***	0.000
TRADE	---	---	-0.075***	0.009
(B) Short-run estimates				
ECT	-0.467***	0.000	-0.473***	0.000
SHTRAD	-36.915	0.322	-35.248	0.329
SHMOD	1.504	0.524	1.482	0.528
LRGDPPC	7.106	0.111	4.998	0.273
LRGDPPC2	-0.417	0.139	-0.295	0.303
LENERGY	0.172	0.291	0.136	0.430
TRADE	---	---	-0.018	0.724
Constant	-2.130***	0.000	-2.620***	0.000
No. of obs.	806		806	
No. of countries	31		31	

*** p<0.01, ** p<0.05, * p<0.10.

10 Table A3. Robustness check (using 23 upper-middle-income countries).

	Model 1		Model 2	
	Coef.	p-value	Coef.	p-value
(A) Long-run estimates				
SHTRAD	-0.910***	0.000	-0.762***	0.001
SHMOD	-1.583***	0.000	-1.280***	0.002
LRGDPPC	0.044	0.113	0.634	0.207
LRGDPPC2	---	--	-0.034	0.240
LENERGY	0.895***	0.000	0.926***	0.000
TRADE	---	--	-0.056*	0.096
(B) Short-run estimates				
ECT	-0.454***	0.000	-0.451***	0.000
SHTRAD	-46.013	0.287	-50.572	0.300
SHMOD	-0.482	0.453	-0.498	0.540
LRGDPPC	0.194**	0.030	-1.104	0.706
LRGDPPC2	---	---	0.086	0.618
LENERGY	0.153	0.449	0.209	0.212
TRADE	---	--	-0.034	0.606
Constant	-0.673***	0.000	-2.012***	0.000
No. of obs.	598		598	
No. of countries	23		23	

*** p<0.01, ** p<0.05, * p<0.10.

Chapter 3: Public attitudes toward hydropower projects along the Mekong River: a vignette experiment

1. Introduction

Hydropower plays a pivotal role in supporting communities, regions, and countries through its multifaceted contributions, including energy generation, electricity trade, infrastructure development, promotion of green energy, and facilitation of international cooperation (Hartmann, 2019; Mayer et al., 2021; Schulz et al., 2019; Skinner et al., 2014; Wang, 2012; Wojczynski, 2021). Many people view hydropower as a reliable and clean source of renewable energy, offering the potential to reduce reliance on fossil fuels and effectively mitigate greenhouse gas emissions. This view is more substantial, particularly for developing countries blessed with large rivers. The Mekong River, the largest international river in Southeast Asia, provides a vital source of economic benefits for six countries in the region, namely, China, Myanmar, Laos, Thailand, Cambodia, and Vietnam, and supports one of the most diverse ecosystems on the planet (Campbell, 2009). Recently, there has been a surge in hydropower development along the Mekong River, spurred by the increase in energy demand in the region.

Despite the considerable benefits of hydropower, the rapid expansion of hydropower dams along the river has raised concerns regarding their potential impact on the environment and the well-being of local communities. This development has sparked intense debate and controversy, as some stakeholders contend that these projects may have adverse effects on the ecological balance, disrupt the livelihoods of local communities, and create wider regional concerns (Boyd, 2015; Kumar Sharma and Thakur, 2017; Owusu et al., 2017; Siciliano et al., 2018). To solve this problem, incorporating public opinion is essential for the sustainable development of hydropower projects. The formulation of effective strategies and policies for renewable energy projects requires active public participation and consultation practices, which are of utmost importance in ensuring successful sustainable development implementation (Mayeda and Boyd, 2020). Hence, prior to implementing such projects, it is imperative to consider the diverse perspectives and concerns expressed by local communities, environmentalists, and other stakeholders and to incorporate these inputs into the decision-making processes.

Numerous studies have been conducted to assess public attitudes toward hydropower development in developed countries (Andrews et al., 2018; Klinglmair et al., 2015; Tabi and Wüstenhagen, 2017) and developing countries (Baird et al., 2015; Rojanamon et al., 2009; Siciliano et al., 2018; Wiejaczka et al., 2018). There are also several studies on dams in Cambodia (Leong and Mukhtarov, 2018; Siciliano et al., 2016, 2015). The majority of previous studies have utilized qualitative approaches, revealing that local communities exhibit diverse attitudes toward potential unfavorable impacts on the local environment, livelihoods, and funding sources (Mayeda and Boyd, 2020). They also emphasize that the local community exhibits various concerns about the long-term sustainability of hydropower projects along with ownership and international assistance. However, to gain a more comprehensive understanding, there is a growing need to complement these qualitative findings with quantitative or evidence-based research that can provide a broader and more quantifiable perspective on the multifaceted impacts of hydropower dams on the affected communities. Exploring these diverse opinions is crucial for fostering effective dialog and ensuring that decision-making processes regarding a dam align with the interests and aspirations of the local community.

The objective of this study is to investigate how information regarding hydropower projects affects the attitudes of rural people residing in the lower region of the Mekong River. In particular, this study aims to address four research gaps. First, there are limited empirical studies on residents' opinions, especially concerning the comprehensive assessment of the positive and negative environmental information of hydropower projects (Mayeda and Boyd, 2020). Thus, we empirically evaluate how people's attitudes toward hydropower projects are influenced by the provision of the positive and negative environmental information of the projects in a single framework.

Second, we extend our empirical evaluation to encompass two additional crucial factors: funding sources of and international assistance for hydropower projects. There are limited studies on the connection of public attitudes to a hydropower project's funding source and international assistance. The funding source of hydropower projects has been identified as a significant factor influencing the project process and public acceptance (Crootof et al., 2021; Tabi and Wüstenhagen, 2017). Hydropower projects can be funded through various sources, including public funds and private investment funds (Siciliano et al., 2018). Public funds often rely on taxpayers' money, which can place a financial burden on taxpayers. In contrast, private investment funds come from private investors, such as corporations or individuals, which are not directly related to the burden on taxpayers. Regarding international assistance, China and the World Bank play influential roles in hydropower development in developing countries, particularly the Mekong River areas, as major investors and creditors.

Third, most studies on people's attitudes on hydropower projects have applied qualitative methods, with a few works conducting experimental studies in developed countries (Andrews et al., 2018; Tabi and Wüstenhagen, 2017). In developing countries, there is often a lack of policy discussion about clean energy projects due to the large demand for energy use, despite their potentially negative impacts on society. Thus, empirical studies of public attitudes on hydropower projects remain limited in developing countries. This study applies an experimental approach, a vignette experiment, allowing us to evaluate the causal effects of vignette stories on people's attitudes toward hydropower projects.

Fourth, there are no experimental studies on the case of the Mekong River region. The Mekong River provides a vital resource for six countries in the region, while the hydropower dams along the river have been found to have some unfavorable impacts on livelihood, ecosystems, and environmental issues. Conducting experimental investigations in the region would provide valuable insights into possible factors influencing households' willingness to support or oppose implementation in the future.

To achieve this objective, this study evaluates how people's attitudes in the lower region of the Mekong River are affected by three types of information regarding hydropower projects: (i) the positive and negative environmental consequences, (ii) funding sources, and (iii) international assistance. To do so, we conducted a vignette experiment with 506 rural people in 18 communes in Kampong Cham Province, Cambodia. In the experiment, we use a piece of information as the treatment that frames the issue in a particular way (Alexander and Becker, 1978). Each of the three types of information contains two scenarios. The first contrasts the impacts of framing in a positive environmental context with those in a negative environmental context. The second group related to funding sources is to identify the distinctions between framing the projects as using public or private investment funds. The third group evaluates how the respondents' views on hydropower projects depend on information about China and the World Bank's engagement in international assistance.

This study has two main findings. First, concerning the environmental consequences, positive environmental information about hydropower projects has a less clear effect on people's support for hydropower projects. In contrast, people exposed to negative environmental information are less likely to support hydropower projects than those without any information. Thus, it is necessary to mitigate these negative effects to sustain future projects. Second, concerning international assistance, households that have been exposed to information about a project initiated by Chinese firms are less likely to support hydropower projects compared to those who have not received any information. However, China has been a key contributor to the global green energy sector, rapidly expanding its investments in renewable energy projects and infrastructure development in various developing countries as part of its efforts to foster economic growth and inclusivity. Thus, building public trust in China-initiated projects and ensuring their successful implementation in developing countries are crucial to enhance China's engagement in Cambodia. On the other hand, funding source information does not affect households' attitudes toward hydropower projects. The results of a subsample analysis reveal significant heterogeneity in people's attitudes between those living with and without grid connections and between the high and low levels of household expenditures.

The remainder of this study is structured as follows. Section 2 provides reviews of previous studies related to people's attitudes toward hydropower projects. Section 3 explains the empirical method and data used in the analysis. Section 4 presents the results and discussion. In the final section, we provide a conclusion with some policy implications and suggestions.

2. Literature review and hypotheses

To deepen the assessment of public attitudes toward hydropower projects, this study assesses the impact of three factors: environmental factors, funding sources, and international assistance from both Chinese firms and the World Bank. Each factor consists of two framings. First, we consider a positive and a negative environmental framing. Second, we consider public fund source framing and private investment source framing. Third, regarding international assistance, we consider framings including Chinese firms and the World Bank.

Mayeda and Boyd (2020) highlight the importance of environmental impacts, socioeconomic factors, and public consultation when examining public attitudes toward hydropower projects. The provision of environmental information is crucial for renewable energy. Furthermore, not that the funding source associated with hydropower projects has been recognized as a significant factor that can impact both the project's progress and its level of public acceptance (Crootof et al., 2021). The funding source is one of the important factors in household perception, as it pertains to whether the project relies on public funds supported by taxpayers' contributions or if it is handed over to private investment. Additionally, in the context of international assistance, China and the World Bank are the top influencers in the financial assistance and technical assistance in hydropower projects in developing nations, particularly in the Mekong River region.

2.1 Environment: positive and negative environmental consequences

The environment is a significant concern in the social acceptance of hydropower development (Siciliano and Urban, 2017). Previous studies have highlighted the advantages of hydropower, including its favorable environmental factors, such as its potential to mitigate climate change and promote sustainable development (IEA, 2021; Li et al., 2015; Yüksel, 2010). Despite recognizing the potential benefits of hydropower in Africa and Asia, Siciliano and Urban (2017) reveal the prevailing negative perspectives held by community members residing in affected areas. Furthermore, several studies have also indicated that households living near hydropower projects tend to harbor negative attitudes regarding the environmental impacts of such projects (Leong and Mukhtarov, 2018; Murni et al., 2013; Okuku et al., 2016; Owusu et al., 2017; Pagnussatt et al., 2018; Rousseau, 2017; Schulz et al., 2019; Sherren et al., 2016; Siciliano et al., 2018). Common indicators of these negative attitudes include the impacts on livelihoods due partly to flooding or water scarcity. Overall, there are limited studies that compare households' attitudes toward both positive and negative framing in relation to environmental framing. Therefore, we set a pair of hypotheses to compare both positive and negative information regarding the environmental effects:

Hypothesis 1. People exposed to positive information about the environment exhibit more positive attitudes toward a hydropower project than those who receive no information about the project.
Hypothesis 2. People exposed to negative information about the environment exhibit more negative attitudes toward a hydropower project than those who receive no information about the project.

2.2 Funding source: public funds and private investment funds

The funding source of hydropower projects has been identified as a significant factor influencing the project process and public acceptance, as highlighted in previous studies (Crootof et al., 2021; Tabi and Wüstenhagen, 2017). To examine the public's opinion on the funding source of the hydropower project, this study compares the framing of information related to the funding source associated with public funds and private investment funds. Public funds generally impose a financial burden on taxpayers, whereas private investment does not directly impose a large burden on taxpayers. Hydropower dams are known to be high-cost infrastructure projects that require substantial budgets for completion (International Hydropower Association, 2022). In cases where the hydropower project is funded through the government budget, i.e., public investment, people may perceive that the project cost will be covered through increased taxation or electricity fees in the future, which may reduce public support for the project.

In contrast, some studies suggest that private investment in hydropower projects can improve public support for the project (Graham, 2017; Scheyvens et al., 2016). Private investment funds come from the capital of the company. Private investment in hydropower projects can help reduce the funding from the government and increase public support for the project by creating economic opportunities and improving the standard of living for local communities (Schulz and Saklani, 2021). To verify these arguments, we examine how households' attitudes toward hydropower projects depend on the primary source of investment, public funds, or private investment funds. Thus, we establish the following hypotheses:

Hypothesis 3. People exposed to information that a hydropower project is financed mainly through the government budget exhibit more negative attitudes toward the project than those who receive no information about the project.

Hypothesis 4. People exposed to information that a hydropower project is financed mainly through private investment exhibit more positive attitudes toward the project than those who receive no information about the project.

2.3 International assistance: Chinese firms and the World Bank

China and the World Bank play influential roles in hydropower development in developing countries as international financial and technical assistance. Both of them initiate hydropower projects in developing countries, assisting local governments in constructing hydropower dams. However, they have distinct approaches and priorities. China tends to focus on financing and construction for commercial interest, while the World Bank emphasizes sustainability, environmental protection, and poverty reduction (Chen and Landry, 2018).

China has experienced rapid growth in green energy development, including solar, wind, and hydropower projects. In terms of international relations, China has provided development financing to many developing countries on infrastructure development and renewable energy development from small to large projects (Li et al., 2022). China has made substantial direct investments in these countries, thereby contributing to the economic development of these host nations across a wide range of economic sectors. China's foreign direct investment stands out as a crucial means to advance economic growth and foster inclusive development in Africa (Yanne Sylvaire et al., 2022). However, hydropower projects in China have faced criticism for displacing millions of people and altering river ecosystems (Huang and Yan, 2009; Jackson and Sleigh, 2000; Zhao et al., 2020). Although people have a negative perception of hydropower projects, it is expected that local people positively support China because China is a large contributor to infrastructure development, which helps promote economic development in developing countries.

The World Bank, as a reputable international organization, actively supports the development of hydropower dams through project implementation and financial loans. The World Bank emphasizes importance of the comprehensive effects of the projects, including the potential benefits these projects can bring to local communities, the environmental effects, and the global effort toward sustainable energy (Awojobi and Jenkins, 2015). To ensure responsible development, the World Bank has established high levels of safeguards and standards for hydropower projects. However, the bank has also faced criticism in the past for financing hydropower projects that result in adverse environmental and social impacts (Baird et al., 2015). To examine how households' attitudes are influenced by international assistance coordinated by Chinese firms or by the World Bank, this study sets the following hypotheses:

Hypothesis 5. People exposed to information that the hydropower project is initiated by Chinese firms exhibit more positive attitudes toward the project than those who receive no information about the project.

Hypothesis 6. People exposed to information that the hydropower project is initiated by the World Bank exhibit more positive attitudes toward the project than those who receive no information about the project.

3. Research design

This section describes the research design and sampling procedures. Understanding the perspectives of households regarding hydropower projects along the Mekong River is crucial in determining factors influencing acceptance or opposition for future projects along the Mekong River. Thus, this study purposely selects rural areas along and in the lower part of the Mekong River in Kampong Cham Province in Cambodia. There are three districts in the province (namely, Kang Meas, Kaoh Soutin, and Srei Santhor), which are along the Mekong River. Within those districts, there are 18 communes and 30,366 households. The households' major livelihood activity is agriculture. To achieve a representative sample, the stratified sampling method was utilized within each commune in the study areas, which encompassed rural households placed along and in the lower part of the Mekong River in Cambodia. A total of 506 households were selected for sampling. Within each commune, the head of household was randomly chosen for the interview based on the proportions specified in Table 1. This sampling strategy ensures a diverse and balanced representation of households, allowing us to draw meaningful conclusions about public attitudes toward hydropower development in these specific regions.

11 Table 1. Sample size of the study

District/Commune	Total Households	Proportion of Households	Number of Households in survey
Kang Meas (district level)			
Angkor Ban (Commune level)	1,923	6.33%	33
Kang Ta Noeng	2,061	6.79%	35
Khchau	2,025	6.67%	34
Peam Chi Kang	1,600	5.27%	25
Roka Ar	1,565	5.15%	27
Roka Koy	1,760	5.80%	27
Sdau	1,188	3.91%	14
Sour Kong	2,082	6.86%	34
Kaoh Soutin (district level)			
Kampong Reab	1,405	4.63%	22
Moha Khnhoung	1,609	5.30%	26
Peam Prathnuoh	1,780	5.86%	31
Srei Santhor (district level)			
Kaoh Andaet	1,026	3.38%	25
Mean Chey	1,869	6.15%	31
Phteas Kandal	1,084	3.57%	17
Preaek Dambouk	2,261	7.45%	39
Preaek Pou	2,780	9.15%	46
Ruessei Srok	1,248	4.11%	21
Svaysach Phnum	1,100	3.62%	19
Total	30,366	100.00%	506

To test our hypotheses, we conducted a vignette experiment. Vignette experiments are widely used to examine human preferences in many fields, including energy and sociology(Bentsen et al., 2023; Brannstrom et al., 2022; Campos et al., 2023; Kootstra, 2016; Wallander, 2009). In our vignette experiment, we use a piece of information as the treatment that frames the issue in a particular way (Alexander and Becker, 1978). This experiment could reduce the social desirability effect and identify the causal effect (Walzenbach, 2019). The advantage of using the vignette experiment over observational data is that the effect of confounding factors is ruled out by design (Chong and Druckman, 2007).

Drawing from extensive prior research, the present study is designed to explore public attitudes toward hydropower development across three critical factors: the environment, funding source, and international assistance. To ensure a comprehensive analysis of different situations, we created three pairs of scenarios for each factor, as mentioned in the previous section. The first pair is the information framing regarding positive and negative environmental effects, the second is the information framing regarding funding sources, public funds and private investment funds, and the third is the information framing regarding international assistance related to Chinese firms and the World Bank. These settings enable us to compare Hypotheses 1 and 2, Hypotheses 3 and 4, and Hypotheses 5 and 6. As a result, we have six treatments and one control without any information regarding the hydropower project. In total, we have seven vignettes (groups). The control vignette serves as a foundational reference point for comparison. During the interview phase of the study, each head of household was randomly assigned to one of the seven vignettes.

The interviews were conducted by a trained team over a period spanning from July 2022 to November 2022 utilizing online software. Respondents were asked to express their preferences regarding support for a hydropower project. The primary outcome variable under investigation was the respondents' attitude toward hydropower development, which was assessed using the following question: "How much do you support this hydropower project?" Respondents provided their answers on a seven-point Likert scale, with options ranging from 1 (Strongly do not support) to 7 (Strongly support). Accordingly, lower scores indicate lower support for hydropower development. As part of the data collection process, we also gathered relevant information from households, including gender, age, education, expense, income, location, and sources of energy use. Each vignette title is shown in Table 2, and the full vignettes are in the appendix (see Table A.1 in the appendix).

12 Table 2. Vignette design

Issue domain	Framing	Vignettes
Environment	• Positive	• Hydropower produces energy without air pollution, which has a favorable impact on climate change. It is an environmentally friendly energy source.
	• Negative	• Hydropower causes unexpected floods and droughts that have an unfavorable impact on people's lives. It is not an environmentally friendly energy source.
Financing source	• Negative	• This project places a large burden on taxpayers because it will be financed mainly from the government budget.
	• Positive	• This project does not place a large burden on taxpayers. Because this project will be financed and owned mainly by private companies.
International assistance	• Positive	• The hydropower project is initiated by Chinese firms.
	• Positive	• The hydropower project is initiated by the World Bank.

4. Results and discussion

4.1. Main results

Table 3 shows balance statistics for all seven groups (comprising 6 treatment groups and 1 control group) using ANOVA. Across each covariate, including household head's gender and age, household members, household monthly expenditures, and income, the p-values for all seven groups demonstrate statistical insignificance. These results confirm the balance of our sample, which was achieved through randomization programmed using the Qualtrics platform.

Table 4 presents the ordinary least squares (OLS) estimations of models with and without respondents' characteristics or covariates. Drawing upon the results of the model without the covariates, we generate Figure 1 to visually represent the coefficient plots with their corresponding 95 percent confidence intervals for each treatment. If the confidence intervals cross the zero mark on the x-axis, it indicates that the variable is not significantly different from the control group or the reference category. A negative coefficient value suggests that participants express a preference for less support (or more disagreement) toward hydropower development compared to the control condition. The analysis shows several clear results.

13 Table 3. Balance test of randomization.

These are the mean of each variable in the 7 groups. The p-value is derived from the ANOVA test.

	Variables	Control (Mean)	Positive environment	Negative environment	Public fund	Private fund	Chinese	World Bank	p-value
Head of household information	Gender (Male=1)	0.49	0.42	0.41	0.39	0.44	0.46	0.46	0.9104
	Age	45.64	43.92	43.90	44.35	45.27	44.50	46.30	0.8435
Household information	Family members	4.53	4.45	4.03	4.46	4.41	4.24	4.39	0.5080
	Monthly expendit ure (usd/HH)	242.88	252.50	250.50	248.19	240.29	215.86	238.88	0.8285
	Monthly income (usd/HH)	435.62	525.07	520.44	471.88	442.43	425.79	438.09	0.5909

Note: When $p<0.05$, we can reject the null hypothesis that all group means are statistically equal.

14 Table 4: Main results

Treatments	Model 1 (without covariates) Coef. (robust S.E)	Model 2 (with covariates) Coef. (robust S.E)
Positive environment	0.365*	0.364*
	(0.191)	(0.190)
Negative environment	-1.415***	-1.463***
	(0.237)	(0.241)
Public fund	0.027	-0.061
	(0.182)	(0.182)
Private fund	-0.002	-0.060
	(0.182)	(0.186)
Chinese firms	-0.959***	-1.003***
	(0.205)	(0.198)
World Bank	0.133	0.102
	(0.186)	(0.183)
Constant	4.959***	4.801***
	(0.132)	(0.341)
Include covariates	No	Yes
R-squared	0.1939	0.2022
N	506	506

Note: (1) The dependent variable uses a Likert scale from 1 (strongly not support) to 7 (strongly support). (2) Covariates are gender, ages, family members, household expenditure, income, and locations by communes. (3) Cluster-robust standard errors are in brackets. (4) ***p<0.01, **p<0.05, *p<0.10.

First, concerning the information regarding positive and negative environmental consequences, the coefficient of positive environment-related information is weakly positive at the 10 percent level, while that of negative environment-related information is significantly negative at the 1 percent level. Positive information about the environment increases supportive attitudes toward the hydropower project, although it is less significant, which weakly supports Hypothesis 1. On the other hand, negative information about the environment reduces supportive attitudes toward the project, which supports Hypothesis 2. These results suggest that people's acceptance of hydropower projects is more sensitive to negative information than to positive information.

Second, for the information regarding funding source, the coefficients of public funds and private investment funds are insignificant. The information regarding funding source, irrespective of whether they are public or private investment funds, does not affect people's attitudes toward the project, which fails to support Hypotheses 3 and 4. Third, concerning international assistance framing, the coefficient of the World Bank is insignificant, while that of Chinese firms is significantly negative. The results indicate that having information that the project is initiated by Chinese firms reduces people's supportive attitudes toward the project, while the information that the project is initiated by the World Bank does not influence people's attitudes toward the project, which does not support Hypotheses 5 and 6.

4.2. Subsample results

We next examine how the effects of information framing on people's attitudes relate to three respondent characteristics: (i) gender, (ii) accessing grid electricity, and (iii) household welfare. To do so, we divide the full sample into two subsamples from each of the three characteristics: (i) males and females, (ii) respondents with and without access to grid electricity (on-grid and off-grid electricity), and (iii) respondents with relatively high and low levels of household expenditure (the cutoff is the average). Table 5 presents the OLS results for each subsample analysis and shows the OLS results of the models with the interaction terms of the randomized treatment and each of the three respondent characteristics. Figures 2, 3, and 4 show the coefficient plots for gender, access to grid electricity, and household expenditure, respectively.

15 Table 5: Subsample results

	Gender			**Access to Grid**			**Household Expenditure**		
	Male	Female	Treatments and gender	Have grid-connection	No grid-connection	Treatment and grid	Higer expenditure	Lower expenditure	Treatment and expenditure
	Coef. (robust S.E)	Coef. (robust S.E)	Coef. (robust S.E)	Coef. (robust S.E)	Coef. (robust S.E)	Coef. (robust S.E)	Coef. (robust S.E)	Coef. (robust S.E)	Coef. (robust S.E)
Positive environment	-0.009	0.498**	0.579***	0.412*	0.451	0.384	0.244	0.487*	0.371
	(0.321)	(0.224)	(0.213)	(0.215)	(0.352)	(0.332)	(0.236)	(0.275)	(0.281)
Negative environment	-1.693***	-1.396***	-1.406***	-1.606***	-0.968**	-1.168***	-2.132***	-0.952***	-1.061***
	(0.348)	(0.333)	(0.332)	(0.295)	(0.430)	(0.401)	(0.344)	(0.336)	(0.321)
Public fund	-0.437	0.219	0.191	0.065	-0.176	-0.188	-0.215	0.020	-0.000
	(0.312)	(0.223)	(0.226)	(0.216)	(0.329)	(0.307)	(0.215)	(0.282)	(0.268)
Private fund	-0.097	-0.035	0.006	0.017	-0.143	-0.173	-0.396	0.308	0.215
	(0.303)	(0.242)	(0.232)	(0.218)	(0.371)	(0.350)	(0.258)	(0.273)	(0.269)
Chinese firms	-0.729**	-1.211***	-1.204***	-1.329***	-0.452	-0.431	-1.625***	-0.523*	-0.606**
	(0.312)	(0.278)	(0.265)	(0.245)	(0.333)	(0.320)	(0.272)	(0.290)	(0.280)
World Bank	0.295	0.238	0.129	0.227	0.328	0.092	0.256	0.257*	0.376
	(0.295)	(0.238)	(0.228)	(0.227)	(0.328)	(0.306)	(0.256)	(0.257)	(0.260)
Positive environment*Gender			-0.496						
			(0.414)						
Negative environment*Gender			-0.111						

			(0.484)						
Public fund*Gender			-0.607						
			(0.401)						
Private fund*Gender			-0.128						
			(0.391)						
Chinese firms*Gender			0.463						
			(0.411)						
World Bank*Gender			-0.044						
			(0.380)						
Positive environment*Grid						-0.060			
						(0.391)			
Negative environment*Grid						-0.541			
						(0.494)			
Public fund*Grid						0.176			
						(0.382)			
Private fund*Grid						0.134			
						(0.412)			
Chinese firms*Grid						-0.961**			
						(0.401)			
World Bank*Grid						-0.001			
						(0.382)			
Positive environment*Expenditure									-0.093
									(0.376)
Negative environment*Expenditure									-0.993**
									(0.497)
Public fund*Expenditure									-0.204
									(0.360)
Private fund*Expenditure									-0.620*
									(0.374)
Chinese firms*Expenditure									-0.948**
									(0.393)
World Bank*Expenditure									-0.604
									(0.375)
Constant	4.726***	5.360***	5.023***	4.900***	5.282***	5.007***	5.282***	4.689***	4.958***
	(0.489)	(0.392)	(0.371)	(0.613)	(0.519)	(0.368)	(0.519)	(0.678)	(0.350)
Include covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.2361	0.3739	0.260	0.409	0.2113	0.266	0.408	0.2117	0.264
N	223	283	506	294	212	506	230	276	506

Note: (1) The dependent variable uses a Likert scale from 1 (strongly not support) to 7 (strongly support). (2) Regression includes covariates such as gender, ages, family members, household expenditure, income, and locations by communes. (3) Cluster-robust standard errors are in brackets. (4) ***p<0.01, **p<0.05, *p<0.10.

First, concerning respondents' gender, the results generally show no clear differences in the effects of information framing across respondents' gender. Nonetheless, the coefficient of positive environment-related information is insignificant for the male group, while it is significantly positive for the female group. This implies that females are more sensitive to positive information than males, although there is less significant difference between males and females in the estimated model with the interaction term. Second, regarding the accessibility of grid electricity, the analysis shows a clear difference in the effects only for the information related to Chinese firms. The coefficient on having information that the project is initiated by Chinese firms is significantly negative for respondents with access to grid electricity, while it is insignificant for those without access to grid electricity. People connected to grid electricity demonstrate lower support for the Chinese firms' initiated hydropower project compared to those in the off-grid electricity group. Third, for household expenditure, the estimations reveal clear differences in the effects of negative environment-related information and project initiation by Chinese firms between the groups with high and low levels of household expenditure. Relatively wealthy people tend to be more concerned about unfavorable environmental consequences and project initiation by Chinese firms than relatively poor people.

4.3. Discussion

The results of this study suggest that information framing regarding the environment and international assistance affects the degree of public support for hydropower projects in the Mekong River in Cambodia. Regarding environmental framing, the results support Hypotheses 1 and 2, which show the significant effects of positive and negative environmental framing on hydropower development. A significant portion of people support hydropower as an environmentally friendly energy source. This result is in line with previous studies emphasizing that hydropower mitigates climate change and has the ability to promote sustainable development (Klinglmair et al., 2015). In addition, a substantial number of people express concerns regarding the potentially unfavorable impacts of dams on their livelihoods. This finding aligns with previous studies that have identified negative attitudes among households who live near hydropower project sites due to the environmental consequences associated with such initiatives (Leong and Mukhtarov, 2018; Pagnussatt et al., 2018; Rousseau, 2017; Schulz and Saklani, 2021; Siciliano et al., 2018, 2015).

The comparison of the results related to both Hypotheses 1 and 2 provides valuable insights into their respective effects. Notably, negative environmental framing exhibits a more pronounced effect than positive environmental framing. People tend to be more sensitive to negative information than to optimistic information. This result provides confirmation of the 'risk aversion' theory, which has already been mentioned in the literature (Chassot et al., 2014; Igarashi and Ono, 2022; Kahneman and Tversky, 1979). In summary, this observation becomes evident in the context of hydropower development, where people express support for new hydropower projects as a clean renewable energy source; however, this support diminishes when people are informed about the negative environmental impact of the projects.

Regarding funding source framing, our data support neither Hypotheses 3 nor 4. One possible reason is that funding sources may primarily be a concern for developers or investors rather than residents. These findings highlight the possibility that the local population may prioritize other factors, such as environmental impact, when evaluating the implications of a project.

Concerning international assistance, the findings contrast with Hypothesis 5 and do not support Hypothesis 6. The negative perception of people regarding a project initiated by Chinese firms is in line with the findings of several previous studies. For example, (Jackson and Sleigh, 2000) find that the Three Gorges Dam, while having the potential to mitigate damage from floods, enhance national electricity generation, and stimulate economic development in China, gives rise to social issues such as compensation and voluntary resettlement. (Zhao et al., 2020) also emphasized the importance of employing an energy justice framework during the preconstruction assessment of hydropower projects in China. One possible reason for the negative perception of China-initiated projects may relate to their enforcement mechanisms and institutional relations with local governments (Chen and Landry, 2018). However, China's involvement is important for economic development in many developing countries to obtain new advanced green technologies because these countries are unable to domestically obtain such technologies. China has contributed to various projects in developing countries through development finance in the areas of infrastructure and renewable energy development (Li et al., 2022). Furthermore, China has played a significant role in direct investment in developing countries, making a substantial contribution to their economic growth and fostering inclusive development (Yanne Sylvaire et al., 2022). Thus, mitigating people's negative attitudes is crucial for more effective Chinese involvement in Cambodia. To do so, the government negotiates with China about various issues, including transparency, resettlement, and compliance with international best practices in environmental and social sustainability, while emphasizing positive aspects of China-initiated projects.

5. Conclusion

This study employed a vignette experiment to evaluate the impacts of different information framing (positive versus negative environmental framing, public versus private investment framing, and international assistance framing related to Chinese firms and the World Bank) on the attitudes of rural people living in the lower Mekong River region with respect to hydropower projects. This research addressed four research gaps. First, we evaluated how positive and negative environmental information affects people’s attitudes toward such projects in a single framework. Second, we additionally assessed different framing of hydropower development on funding sources and international assistance. Third, this study mitigated response biases, which conventional survey techniques suffer from, by conducting a vignette experiment to evaluate the causal effects of vignette stories on people's attitudes. Fourth, this is the first survey experiment on the case of the Mekong River regions in Cambodia.

This study presented three key findings. First, negative environmental framing exhibits a more substantial effect than positive environmental framing. Rural communities in the lower Mekong River region generally support the development of environmentally friendly hydropower projects. However, they express more concerns about the negative effect of hydropower on their livelihood. Second, information regarding international assistance significantly influences people’s attitudes. Last, the information regarding funding source (more or less burden on taxpayers) does not have a significant impact on people’s attitudes.

These findings highlight the necessity for policymakers and project developers to proactively mitigate the adverse effects of hydropower on environmental issues to increase public support for future projects. Additionally, it is important for policy makers to promote trust from the public and emphasize positive aspects of China's involvement in Cambodia. In short, the presence of China's development funds and direct investments plays a pivotal role in stimulating economic growth and promoting inclusive development in developing countries. Therefore, prioritizing the promotion of sustainable development between China and these developing nations is of utmost significance. As a result, it is advisable for the host government to enhance cooperation with China by simultaneously improving transparency in information sharing, implementing appropriate resettlement procedures, and adhering to international standards for environmental and social sustainability.

As final remarks, the limitations of the study include the omission of certain factors that could influence public attitudes toward hydropower development. Factors such as risk management, communication strategies, and economic considerations are important aspects that can shape public attitudes and perceptions. These additional factors may enhance the applicability and relevance of the future findings, providing policymakers and stakeholders with a broader perspective to inform decision-making processes.

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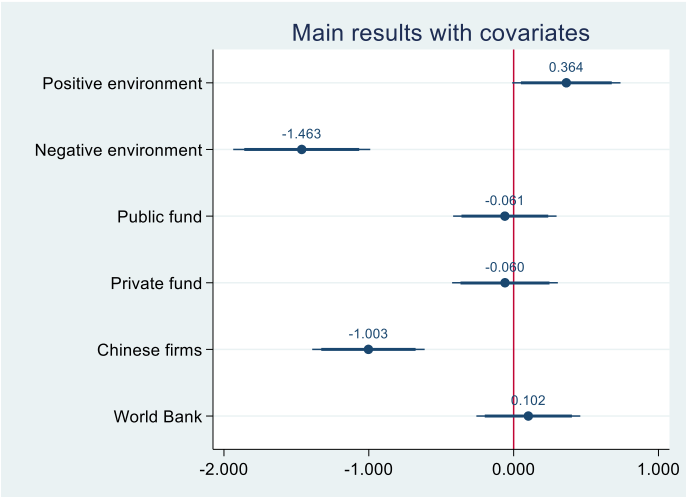
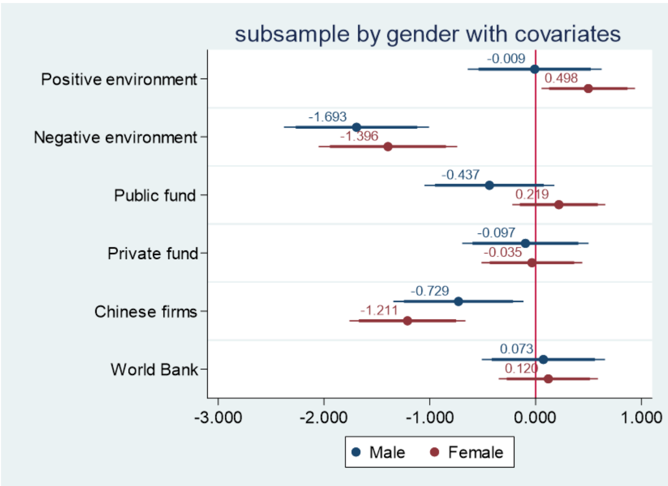
2 Figure 1: Main results



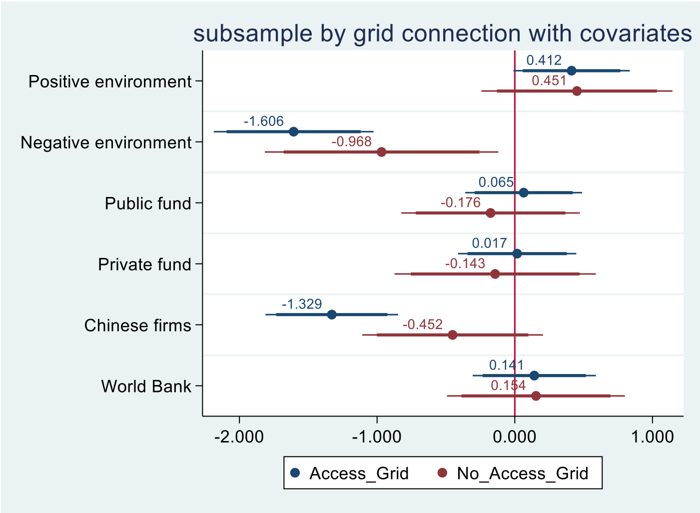
Note: the confidence interval levels are 90% and 95%.

3 Figure 2. Subsample results: Male and female respondents



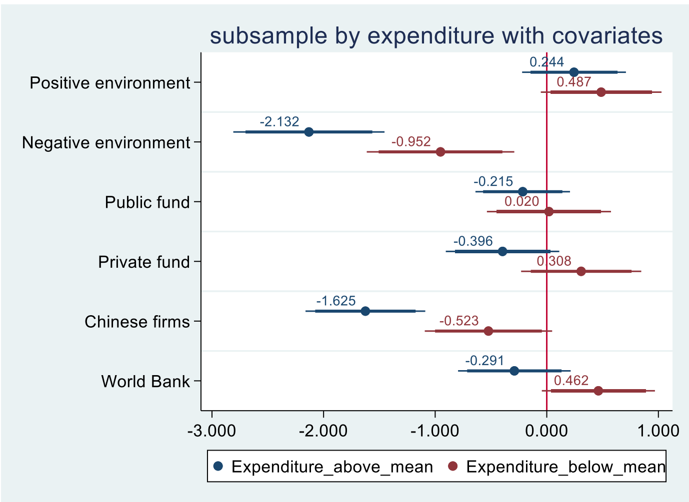
Note: the confidence interval levels are 90% and 95%.

4 Figure 3. Subsample results: Households with and without grid electricity



Note: the confidence interval levels 90% and 95%.

5 Figure 4. Subsample results: High and low levels of household expenditure (the cutoff is the average)



Note: the confidence interval levels 90% and 95%.

Appendix

16 Table A.1. Full experimental stories

Group/Statement	Introductory statement: "An additional hydropower project will be constructed along the Mekong River."
Control group	No additional statement
Treatment 1	Hydropower produces energy without air pollution, which has a favorable impact on climate change. It is an environmentally friendly energy source.
Treatment 2	Hydropower causes unexpected floods and droughts, which have an unfavorable impact on people's lives. It is not an environmentally friendly energy source.
Treatment 3	This project places a large burden on taxpayers because it will be financed mainly from the government budget.
Treatment 4	This project does not place a large burden on taxpayers. Because this project will be financed and owned mainly by private companies.
Treatment 5	The hydropower project is initiated by Chinese firms.
Treatment 6	The hydropower project is initiated by the World Bank.
Question: How much do you support this hydropower project? Answer: Likert scale: ranging from 1 (Strongly not support) to 7 (Strongly support)	

Chapter 4: Market adoption of solar home systems in rural Cambodia: a vignette experiment

1. Introduction

The United Nations Agenda 2030 highlights access to energy in its Sustainable Development Goal (SDG) 7, which aims for "affordable, reliable, sustainable and modern energy for all by the year 2030". Modern renewable energy sources have been promoted in many countries in the globe to reduce air pollution and greenhouse gas emissions. Solar power is a one of the popular modern renewable energy providing each household's independent energy sources (López-Vargas et al., 2021). One of those solar power called solar home system (SHS) consists of a solar panel and the supplementary equipment–typically batteries, charge controllers, wiring, and electric appliances–needed to generate electricity for household uses, such as lighting and mobile charging (Urpelainen and Yoon, 2015). To promote solar home system (SHS) to end users, there are several efforts from stakeholders including government and private sectors (SHS's supplier and distributors). Besides, the efforts from policy makers and suppliers of SHS, the understanding of market perceptions is also important to promote the right target. To be successful in promoting modern renewable energy, there should be SHS's experimental study for end users (Mayeda and Boyd, 2020).

The few previous studies focus on social acceptance of solar energy technologies in developing countries (Mallett, 2007; Yuan et al., 2011). A recent paper also analyzed the perception towards the rooftop solar system in Indonesia's policy (Setyawati, 2020). All of them conduct quantitative surveys to access the public perception of solar system. However, vignette experiments offer distinct advantages over traditional structural surveys (Alexander and Becker, 1978). Vignette experiments can assess the causal effects resulting from exposure to vignette stories on individuals' judgement on the topic (Wallander, 2009). This methodology is more appropriately aligned with the examination of the situational and environmental factors impacting human assessments of social objects (Wallander, 2009). Indeed, vignette surveys offer a flexible approach to customizing information for each factor believed to influence the judgement, allowing for a direct comparison of the responses with those collected in a benchmark survey (Stantcheva, 2023). This simultaneous comparison greatly enhances the capacity for a more comprehensive analysis.

In addition to this storyline, another study delved into the topic of the social acceptance of solar power as a viable alternative to grid electricity in India, employing a vignette experiment (Aklin et al., 2018). This investigation contrasts government subsidies for solar power with those for the national grid, evaluating aspects such as the cost of solar power, issues of inequality, and the role of the state in facilitating solar adoption. It is important to note that their study primarily focuses on assessing people's support for government subsidies for solar power. Accordingly, we have identified two primary research gaps: [i] It remains unclear whether the experiment was conducted within a broader context, encompassing scenarios without government subsidies. [ii] The study does not take into account considerations related to accessibility and environmental factors within the scope of its survey. Therefore, it is essential to conduct a more comprehensive survey experiment that considers a broader context and incorporates factors such as price, accessibility, and environmental aspects. This approach enables a deeper understanding of the general public's perceptions of and support for solar home systems (SHS) influenced by various factors.

In order to address these two specific research gaps, this study aim to explore the effect of information relating to SHS on the attitudes of rural households in Cambodia concerning the late extension of the national grid electricity. The study focuses on three factors: (i) price of installing SHS, (ii) accessibility of grid-connection between rural and urban areas, and (iii) environment (green energy). The cost of installing solar home systems (SHS) represents a substantial barrier to their widespread adoption. Additionally, disparities in electricity grid accessibility between rural and urban areas often result in insufficient access to a reliable electricity supply for many individuals residing in rural regions. The introduction of SHS in rural areas could potentially offer significant advantages to these remote communities. Furthermore, it is important to underscore that information related to the environmental benefits associated with SHS has been recognized as a pivotal factor influencing acceptance. To empirically investigate these dimensions, a vignette experiment was conducted involving 351 rural households residing in 12 communes within the Kampong Cham province of Cambodia.

This study has two main findings. Firstly, with regard to the cost associated with installing a solar home system (SHS), the provision of pricing information concerning SHS exerts a negative influence on households' support for this technology. Secondly, individuals who are exposed to information highlighting the environmentally friendly aspects of SHS tend to be more inclined to support the adoption of SHS. These results confirm that among the various significant determinants affecting support for SHS in rural areas of Cambodia, the price of SHS is the most pivotal factor. These findings also suggest that providing information about the environmentally friendly features of SHS has a positive influence on households' attitude, partially mitigating the negative impact of other factors.

In the sub-sample analysis, gender emerged as a significant determinant of Solar Home System (SHS) acceptance, with female respondents shifting from initial skepticism to strong support when informed about green energy, while male attitudes remained unchanged. Households with SHS demonstrated higher overall support, likely driven by perceived benefits, particularly in areas with limited grid access. Notably, the cost of SHS had a more profound impact on rural households without grid connection, suggesting financial constraints may deter adoption in favor of awaiting government-provided grid electricity.

The remainder of this study is organized as follows: Section 2 provides a comprehensive review of prior research pertaining to individuals' attitudes towards solar home systems. Section 3 explains the empirical method and the data used in the analysis. Section 4 presents results and discussion. In the final section, we provide the conclusion with some policy implications and suggestions.

2. Literature review

Many studies contribute to many strands of literature using surveys to study social acceptance of solar energy technologies in developing countries. First, the previous studies employ structural survey in Mexico focus on Rogers' technology adoption model through relevant factors such as awareness, cost, culture, ability to understand, and tribality (Mallett, 2007). Second, (Yuan et al., 2011) conducted a quantitative survey to investigate the social acceptance of solar water heater and solar PV from end users. Their survey requested respondents to rate the awareness and public support for SWH and solar PV. Another recent study, (Setyawati, 2020) explored public's acceptance of the Indonesian government policy (Rooftop Photovoltaic Solar Systems policy), and the survey asked respondents read the summary of the policy and answer one of the following choices: 1. Interested in installing PV systems under the current scheme 2. Interested but waiting for other options and 3. Not interested. In short, the literature considers the most relevant factors to promote solar home system is cost of installation of solar power. It is not surprising that cost is associated with welfare and endogenous among economic activities. Given these considerations, it is useful to begin by evaluating cost associated with solar power by introducing the following hypothesis:

Hypothesis 1. People exposed to information that solar home system's cost is higher than the grid connection's tariff exhibit more negative attitudes toward the solar home system than those who receive no information about it.

Additionally, Aklin et al., (2018) conducted a vignette experiment to investigate the social acceptance of solar power in the context of the Indian government's subsidy policy for solar power. Their survey introduced the hypothesis that framing the inequality between rural and urban areas would have a negative impact on social acceptance. Difference, we use a positive statement for framing accessibility of grid connection in urban and accessibility of solar in rural areas would have a positive impact on household's attitude. Thus, we evaluate this positive statement by introducing the following hypothesis:

Hypothesis 2. People exposed to information that compare accessibility of solar home system in rural and urban exhibit more positive attitudes toward the solar home system than those who receive no information about it.

Although previous studies have not conducted survey experiments to examine the social acceptance of solar power through the framing of it as a green technology, several of them have indicated that solar power is a green energy source (Almulhim, 2022; Arroyo and Carrete, 2019; Mohylevska et al., 2023; Vuichard et al., 2021). These studies suggest that solar power, being recognized as a green technology contributing to the reduction of climate change, plays a crucial role in shaping public perceptions. Therefore, understanding how framing solar power as a green technology influences individuals is of paramount importance in assessing their awareness, knowledge, and acceptance of solar technology as a sustainable and environmentally friendly option. To assess the effect of framing green energy on household' attitude, we introduce the following hypothesis:

Hypothesis 3. People exposed to information that solar home system is an environmentally friendly energy source exhibit more positive attitudes toward the solar home system than those who receive no information about it.

3. Empirical method

This section outlines the research design and sampling methods employed in the study. The study specifically targets rural areas within the Kampong Cham province in Cambodia, characterized by their limited access to the national grid electricity. The selected study area encompasses three districts, namely Kang Meas, Kaoh Soutin, and Srei Santhor, all situated along the Mekong River. Within these districts, there are a total of 12 communes and an estimated 21,622 households.

To ensure a sample that accurately represents the population of the selected areas, we employed the stratified sampling method within each commune in the study areas, which included rural households in the three districts. A total of 351 households were selected for the sample. Within each commune, the head of the household was randomly selected for the interview, following the proportions outlined in Table 1. This sampling approach guarantees a diverse and equitable representation of households, enabling us to derive meaningful insights specific to these regions.

17 Table 1. Sample size of the study

Location		Households in the areas	Proportion of Households	Households in survey
Kang Meas (district level)				
	Angkor Ban (commune level)	1,923	8.89%	33
	Kang Ta Noeng	2,061	9.53%	35
	Peam Chi Kang	1,600	7.40%	25
	Raka Ar	1,565	7.24%	27
	Roka Koy	1,760	8.14%	27
	Sdau	1,188	5.49%	14
	Sour Kong	2,082	9.63%	34
Kaoh Soutin (district level)				
	Kampong Reab	1,405	6.50%	22
	Moha Khnhoung	1,609	7.44%	26
	Peam Prathnuoh	1,780	8.23%	31
Srei Santhor (district level)				
	Preaek Pou	2,780	12.86%	46
	Mean Chey	1,869	8.64%	31
Total		21,622	100%	351

To examine our hypotheses, we conducted a vignette experiment, a widely employed method to investigate human preferences in various domains, including energy studies and sociology (Bentsen et al., 2023; Brannstrom et al., 2022; Campos et al., 2023; Kootstra, 2016; Wallander, 2009). In a vignette experiment, a specific piece of information is utilized as a treatment to present the issue in a particular context (Alexander and Becker, 1978). This approach helps mitigate the social desirability effect and enables the identification of causal effects (Walzenbach, 2019). One of the key advantages of using vignette experiments over observational data is that they are designed to eliminate the influence of confounding factors (Chong and Druckman, 2007).

The current research investigates households' attitudes regarding solar home systems, considering three informational factors: information related to high price, accessibility between rural-urban, and environmental. To ensure a thorough examination of diverse scenarios, we formulated three hypotheses for each of these factors, as documented in the literature review. Consequently, we have developed three treatments, alongside one control group. In total, we have four vignettes or groups.

The control vignette serves as an essential baseline for comparative analysis. During the interview phase of the study, each household head was randomly allocated to respond to one of the four vignettes generated by an online survey platform.

Between July 2022 and November 2022, our trained research team conducted interviews. Participants were specifically invited to shows their preferences, with a particular emphasis on the question "How much do you agree that for rural development, the government should put more emphasis on solar power than extending the national electricity grid?" The primary focus of this inquiry centered on assessing participants' attitudes regarding solar home systems with the national grid extensions. Respondents conveyed their responses using a seven-point Likert scale, which ranged from 1 (Strongly Disagree) to 7 (Strongly Agree). Lower numerical scores were indicative of diminished support for the incorporation of solar home systems in rural development initiatives. Simultaneously, within the data collection process, household information was obtained, such as gender, age, educational background, expenditure patterns, income levels, geographical location, and the primary sources of energy utilization. The titles corresponding to each vignette used in the study are detailed in Table 2, while the complete vignettes are available in the appendix (refer to Table A1 in the appendix).

18 Table 2. Vignettes designs

Issue domain	**Framing**	**Vignettes**
High Price	• Negative	The installation cost of solar home system is higher than the tariffs of grid electricity.
Accessibility	• Positive	The installation of solar home system helps your rural areas substantially for stable energy supply because grid electricity is accessible mainly in urban areas but not in rural areas.
Green energy	• Positive	Solar home system is an environmentally friendly energy source, which reduces air pollution and climate change, while grid electricity uses mainly coal and fossil fuel, which increases air pollution.

4. Results

4.1 Main results

Table 3 presents the balance statistics for household demographics (gender, age, household members, household monthly expenditures, and income) across four groups (3 treatment groups and 1 control group) using the ANOVA test. The results indicate no significant difference in households' demographics in the control group and those in the treatment groups. The results show the success of our randomization.

19 Table 3. Balance test of randomization.
These are the Mean of each variable in the 4 groups.

Variables		Control (Mean)	High price	Accessibility	Green energy	p-value
Head of Households	Gender (Male=1)	0.43	0.49	0.50	0.43	0.691
	Age (years)	45.18	45.91	47.58	44.58	0.300
Households Information	Family members	4.22	4.32	4.41	4.20	0.743
	Monthly expenditure (USD/HH)	222.69	227.28	239.88	256.11	0.176
	Monthly income (USD/HH)	431.46	440.76	443.25	475.22	0.406

Note:
1. The p-value is derived from the ANOVA test.
2. When p<0.05, we can reject the null hypothesis that all group means are statistically equal.

Table 4 in this study presents the results obtained from a vignette experiment using ordinary least squares (OLS) analysis for both Model 1 (without covariates) and Model 2 (with covariates). Figure 1 displays the outcomes of Model 2, presenting coefficient estimates alongside their corresponding 90 and 95 percent confidence intervals for each treatment. When the confidence intervals intersect with the zero mark on the x-axis, it signifies that the variable is not statistically different from the control group or the reference category at a conventional significance level. A negative coefficient value implies that participants express a preference for less support (or more disagreement) towards hydropower development compared to the control condition, and vice versa.

*20 Table **4**. Main results*

Treatments	Model 1 (without covariates)	Model 2 (with covariates)
	Coef. (robust S.E)	Coef. (robust S.E)
High price	-1.223***	-1.269***
	(0.181)	(0.178)
Accessibility	0.108	0.070
	(0.158)	(0.159)
Green energy	0.276**	0.266**
	(0.134)	(0.133)
Constant	5.180***	4.875***
	(0.110)	(0.321)
Include covariates	No	Yes

R-squared	0.2448	0.2587
N	351	351

Note:

1. The dependent variable is a Likert scale from 1 (strongly not support) to 7 (strongly support)

2. The covariates are gender, ages, family members, household expense, income, and 3 districts.

****p<0.01, **p<0.05, *p<0.10*

Firstly, in relation to Treatment 1, labeled as "High Price," the coefficient exhibits a statistically significant negative value of -1.223 points. This signifies that providing information indicating a high price has an unfavorable impact on households' inclination to support the adoption of SHS as an alternative to extending grid electricity in rural areas. This result supports our hypothesis 1. This outcome aligns with our first hypothesis. It is consistent with prior research (Arroyo and Carrete, 2019) that identified the cost of solar power systems as a major hindrance to the renewable energy market in Mexico. However, it diverges from the findings of (Aklin et al., 2018) whose research on high tariff framing did not influence the social acceptance of solar power among Indian households. (Arroyo and Carrete, 2019) proposed a set of recommendations encompassing both public and private strategies aimed at reducing the cost of the solar power system and enhancing financing programs for both individual and community-based projects. Hence, it is crucial to address the cost of solar home systems to promote green electricity in rural areas and enable remote rural communities to gain access to electricity.

Regarding Treatment 2, designated as "Accessibility," the estimated coefficient shows no significance. This result does not support our hypothesis 2. There are no previous studies related to the framing of the accessibility of solar home systems in rural and urban areas.

Lastly, in connection with Treatment 3, wherein Solar Home Systems (SHS) are represented as an environmentally friendly energy source, the coefficient demonstrates a statistically significant positive value of 0.276 point. This positive coefficient implies that presenting SHS as an environmentally friendly energy source serves as an encouragement, prompting households to lend their support to SHS as a preferable option over the extension of grid electricity in rural areas. Previous studies suggest that solar power is an eco-friendly technology instrumental in mitigating climate change, exerts a significant influence on the formation of public perceptions (Almulhim, 2022; Arroyo and Carrete, 2019; Vuichard et al., 2021).

In sum up, treatment 1, high price of SHS exerted a negative influence on household perceptions. This contrasts with a previous study by Aklin et al. (2018), where elevated costs did not affect perceptions, largely because their research query focused on respondents' attitudes towards government subsidies for solar power. Conversely, Treatment 3, which characterized SHS as a form of green energy, engendered a positive impact on household perceptions, thereby affirming its effectiveness in enhancing support for SHS as an alternative to traditional grid electricity in rural areas. The divergent outcomes indicate that although a high price obviously diminishes support for SHS, preference for information related to green energy can partially mitigate the impact of price.

4.2 Subsample analysis

We next explore how information framing impacts people's attitudes in relation to three key respondent characteristics: (i) gender, (ii) usage of SHS, and (iii) access to grid-electricity. To accomplish this, we divide the full sample into two subgroups for each of these three characteristics: (i) males and females, (ii) respondents with and without SHS, and (iii) respondents with and without access to grid-electricity (on-grid and off-grid electricity).

Table 5 displays the OLS results for each of these subgroup analyses. Additionally, it presents the OLS results of models featuring interaction terms between the randomized treatment and each of the three respondent characteristics. For a visual representation of these findings, Figures 2, 3, and 4 show the coefficient plots for gender, possession of SHS, and access to grid-electricity, respectively.

21 Table 5. Subsample analysis

Treatments	Main Results	Gender		Use SHS		Access to Grid	
		Male	Female	Have SHS	No SHS	Have grid-connection	No grid-connection
		Coef. (robust S.E)	Coef. (robust S.E)	Coef. (robust S.E)	Coef. (robust S.E)	Coef. (robust S.E)	Coef. (robust S.E)
High price	-1.269***	-1.274***	-1.271***	-1.157***	-1.297**	-1.089***	-1.620***
	(0.178)	(0.276)	(0.236)	(0.446)	(0.192)	(0.217)	(0.305)
Accessibility	0.070	0.096	0.018	0.793**	-0.004	0.073	0.075
	(0.159)	(0.223)	(0.227)	(0.382)	(0.170)	(0.204)	(0.274)
Green energy	0.266**	0.125	0.351**	0.293**	0.248*	0.234	0.403**
	(0.133)	(0.216)	(0.170)	(0.314)	(0.144)	(0.171)	(0.214)
Constant	4.875***	4.820***	5.044***	4.786***	4.954***	5.133***	4.551***
	(0.321)	(0.482)	(0.435)	(0.811)	(0.355)	(0.448)	(0.475)
Include covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.2587	0.2791	0.2864	0.4454	0.2756	0.2356	0.3787
N	351	162	189	43	308	214	137

Note: 1. The covariates are gender, ages, family members, household expense, income, and districts.
****p<0.01, **p<0.05, *p<0.10*

First, regarding the respondents' gender, the analysis indicates that there is no statistically significant difference in the treatment effect between different genders. However, both male and female respondents exhibit a negative attitude toward SHS when presented with high price information. Regarding the information about green energy, female respondents express positive support for SHS, while males show no significant results. This suggests that the main source of support for the installation of SHS over the extension of the grid was the female group. From a gender perspective, Camou-Guerrero et al. (2008) have reported that preferences for men and women have different general interests in forest resources. Women—especially those residing in households led by females—are more essentially dependent on both the consumption and sale of forest resources compared to men (Vodouhê et al., 2009). Meanwhile, in Cambodia, females who serve as household heads generally make decisions concerning household matters, such as expenditures. In this context, the advocacy for the installation of SHS should be effectively communicated to female household heads to facilitate the broader adoption of SHS within the household.

Secondly, concerning respondents' use of SHS, the analysis reveals less distinct differences in the effects of information related to electrification accessibility between households that use SHS and those that do not. Households equipped with SHS tend to exhibit higher levels of support compared to households without SHS. One possible explanation for this finding is that households with SHS may have more favorable views of this technology and believe that the installation of solar home systems brings substantial benefits, especially in rural areas where grid electricity access is limited compared to urban areas.

Thirdly, concerning the respondents' access to grid connection, the analysis suggests that there is no statistically significant difference in the treatment effect between different categories of grid connection users. However, households without grid connection tend to express less support compared to their counterparts with grid access. Interestingly, this result indicates that the primary impact of the high cost of SHS was observed among households without grid connection. This observation could be attributed to the substantial cost associated with SHS. Households in rural areas lacking grid access often face financial challenges in adopting this technology and, as a result, may choose to await government-provided grid electricity rather than invest in a solar home system.

To sum up, the results from sub-sample analysis reveal that gender played a significant role in the acceptance of Solar Home Systems (SHS). While both males and females initially exhibited negative attitudes toward SHS when presented with high prices, female respondents showed a significant shift toward positive support when information about green energy was introduced, while males did not. Additionally, households with SHS generally expressed greater support for the technology compared to those without it, potentially due to their recognition of the benefits, especially in areas with limited grid access. Finally, the information regarding the cost of SHS had a more impact on households without grid connection, suggesting that financial challenges in rural areas may discourage adoption, with some households preferring to await government-provided grid electricity.

5. Conclusion

The present study investigates the effect of three key factors related to solar home systems (SHS) on the attitudes of rural households regarding the delayed expansion of the national grid electricity. Specifically, this research focuses on three factors: (i) The high installation cost of SHS, (ii) The accessibility of grid connections between rural and urban areas, and (iii) The environmentally friendly nature of the energy source. The primary objectives of this study are as follows: [i] To provide a more comprehensive understanding of the policy landscape promoting solar home systems in rural areas, including scenarios without government subsidies. [ii] To evaluate the influence of accessibility and environmental factors on household attitudes. To achieve these objectives, the study employs vignette experiments to present information about these three factors and assess how they impact households' support for SHS.

The study reveals two findings. Firstly, it indicates that when individuals are informed about the high cost of Solar Home Systems (SHS), their support for SHS decreases. This underscores the pivotal role of price as a determining factor in the decision to adopt SHS. Secondly, the study demonstrates that when SHS are presented as environmentally friendly, people are more inclined to support their adoption. This highlights the positive influence of environmental concerns on individuals' willingness to embrace SHS technology. These findings suggest that green energy information can partially mitigate the cost information.

A limitation of this study is the absence of an assessment of households' actual behavior in adopting solar home systems. While this study effectively evaluates households' attitudes toward the adoption of SHS, it does not investigate the practical aspects of household behavior in using SHS. For future research, it is better to understand both attitudes and behavior would provide valuable insights seeking to comprehensively assess the factors influencing the adoption and utilization of SHS among households.

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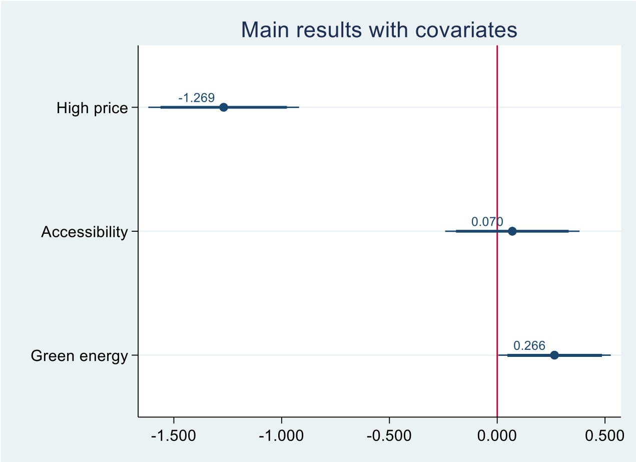
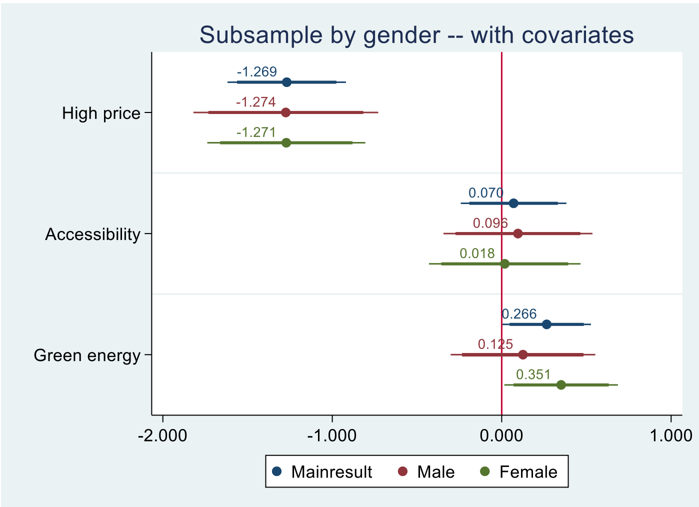
6 Figure 1. Main results



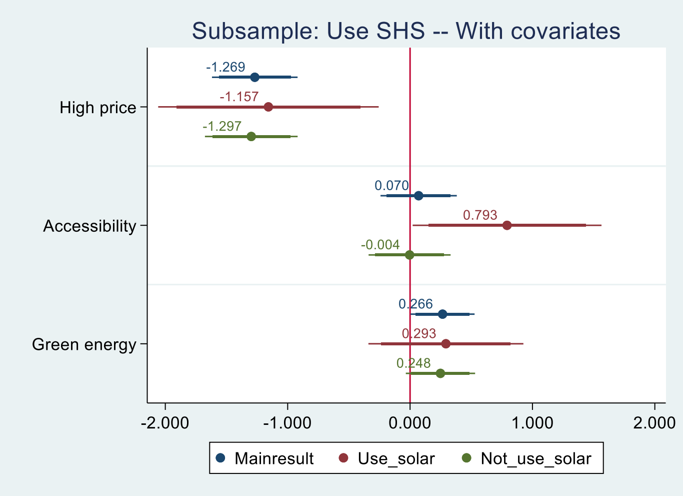
Note: the confidence interval levels 90% and 95%.

7 Figure 2. Sub sample results by Gender



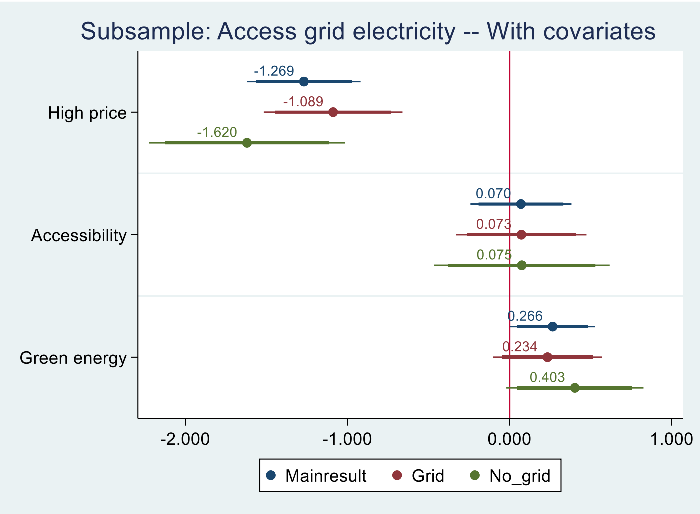
Note: the confidence interval levels 90% and 95%.

8 Figure 3. Sub sample results by have solar power vs no Solar power.



Note: the confidence interval levels 90% and 95%.

9 Figure 4. Subsample results by grid-connection vs no grid-connection.



Note: the confidence interval levels 90% and 95%.

Chapter 5: Conclusion

Considering ongoing global climate change, both regulatory agencies and private enterprises are increasingly focusing on green technologies, now widely acknowledged as a key solution to climate change and global warming.

The first research study in the essay examined the relationship between CO2 emissions and renewable energy, specifically focusing on its two main categories: modern and traditional renewable energy. The study employed a PMG-ARDL (Pooled Mean Group - Autoregressive Distributed Lag) model to estimate long-term associations. This model made use of panel data from 31 emerging countries spanning the years 1990 to 2015. The principal findings confirm that modern renewable energy sources are more effective in reducing CO2 emissions, owing to their utilization of advanced green technologies to generate clean energy. These results underscore the need for the development of green technologies as a strategy to mitigate environmental degradation and the need for the technological progress of renewable energy sources, such as solar energy, hydropower and wind energy. Additionally, this study offers valuable policy implications for emerging nations, emphasizing the importance of tackling environmental degradation and fostering sustainable energy sources.

The second research study utilized a vignette experiment to assess the impact of various types of information framing (positive versus negative environmental framing, public versus private investment framing, and international assistance framing related to Chinese firms and the World Bank) on the attitudes of rural residents in the lower Mekong River region toward hydropower projects. This study yielded three key findings. First, negative environmental framing has a more pronounced impact than positive environmental framing. While rural communities in the lower Mekong River region generally favor the development of environmentally friendly hydropower projects, they express heightened concerns about the potential negative effects of hydropower on their livelihoods. Second, information concerning international assistance exerts a significant influence on people's attitudes. Lastly, details about the funding source, specifically the relative burden on taxpayers, do not significantly affect public attitudes. These insights emphasize the need for policymakers and project developers to proactively address the environmental drawbacks of hydropower projects to garner greater public support. Additionally, it is crucial for policymakers to cultivate public trust and emphasize the positive contributions of China's involvement in Cambodia.

The third research study examines the market adoption of solar home systems in rural Cambodia. Utilizing a vignette experiment, the study evaluates household attitudes toward solar home systems as an alternative to grid extension. It focuses on the impact of various framings, specifically those related to price, accessibility, and green energy. The primary findings suggest that green energy framing positively affects household perceptions, while framing that emphasizes high prices leads to negative perceptions. Additionally, females tend to be more supportive of solar home systems than males, particularly in the context of green energy framing. These results highlight the urgent need for a robust communication strategy to promote solar power. Policymakers and project developers should prioritize the dissemination of clear and comprehensive information that addresses both the benefits and costs of solar power. The communication strategy should particularly target female heads of households.

In summary, in response to the escalating concerns about global climate change, a series of research studies explore various facets of renewable energy and public attitudes toward its adoption. The first study employs a PMG-ARDL model to demonstrate that modern renewable energy sources, enabled by advanced green technologies, are more effective in reducing CO2 emissions than traditional ones, particularly in 31 emerging countries. This underlines the need for further development of green technologies and offers policy guidelines for emerging economies. The second study utilizes a vignette experiment to gauge rural attitudes toward hydropower projects in the lower Mekong River region. It reveals that negative environmental framing and international assistance significantly influence public opinion, whereas funding sources do not. This calls for policymakers to mitigate environmental impacts and build public trust. The third study examines the adoption of solar home systems in rural Cambodia, finding that green energy framing positively influences household perceptions, especially among females. This highlights the pressing need for a robust marketing strategy that targets specific demographics. Collectively, these studies emphasize the critical role technological advancements play in addressing climate change and promoting sustainable energy solutions.

Lastly, it is important to promote renewable energy technology development through the support from finance (green finance). Policy makers should foster the development of green finance initiatives in the national policy, particularly in contemporary renewable energy sectors, including photovoltaic (solar) power and hydropower projects. Furthermore, it is important to incentivize banking institutions and Financial Intermediaries (FIs) to advance green finance schemes, targeting both consumers and investors in the solar energy domain.