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Facilitating sustainable energy transition of Nepal: A best-fit model to prioritize influential socio-economic and climate perception factors on household energy behaviour

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ABSTRACT

Our study investigates the relatively unexplored relationships between socio-economic factors and perceptions of climate change and their influence on household energy preferences in developing contexts, taking the case of Nepal. We aim to achieve two objectives: to create a robust model identifying key socio-economic and climate perception variables affecting household energy behaviour; and to compare the respective impacts of these factors. Applying a mixed-method approach, we surveyed 323 households across 49 districts and three physiographic regions (high hills, mid hills and Terai plains) of Nepal. We fixed the explanatory and response variables through literature review and evaluated three ordinal logistic regression models: one focused solely on socio-economic factors, the second only on climate perception and the third a composite model integrating both. Data statistics showed that 47 % of the respondents preferred no change to their existing energy status, 23 % opted to rely completely on grid-electricity, 14 % favoured switching to renewables, while 16 % preferred an optimal combination of grid-electricity and renewables for their household use. The *Composite-model* was found to be the best fit model for our dataset. The identified key socio-economic factors include urbanization, education levels, and the availability of energy alternatives indicating a wide disparity in the energy access and use across the different socio-economic categories of Nepal. Likewise, magnitude and timing of summer and winter rainfall, changes in the household energy demands and community level subsidies were found to be the significant climate change perception variables. Hence, our findings highlight the need for better access to modern energy and financial incentives, mostly to the rural remote areas, and community-awareness initiatives throughout the country supported by comprehensive energy policies for sustainable renewable energy transition at the household level as well as in mitigation of the impacts of climate change. By enhancing this policy-science-society interface, our research contributes valuable insights for developing effective strategies to promote renewable energy adoption in similar developing contexts.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) has reported that it would be difficult to achieve the pre-industrial warming levels of 1.5 °C globally unless immediate steps, primarily pertaining to energy consumption, are strictly implemented to reduce the impacts of climate change (Masson-Delmotte et al., 2019). Adoption of energy technologies by a country is directly dependent on its infrastructural, environmental, and technical conditions (Baniya et al., 2023; Manasi & Mukhopadhyay, 2024). Moreover, the energy consumption landscape is governed by its socio-economic settings, people's awareness, and capacity to adopt modern technologies (Franco & Taeighagh, 2024; Israel & Jehling, 2019; Liao et al., 2021; Mukhtarov et al., 2020). For instance, the energy consumption of China was 40,207 TWh in 2019, which was considerably

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higher than US (26,575 TWh) – the largest economy in the world, and India at 9,311 TWh; smaller economies recorded much lower figures (Ritchie et al., 2022). However, there are distinct North-South disparities in energy consumption patterns globally (Lin & Omoju, 2017; Weko & Goldthau, 2022). Energy consumption of the Global North is more concentrated in the transportation and industrial sectors (McGreevy et al., 2021). But the household energy consumption contributes considerably to the total energy use of the Global South (Nepal et al., 2018).

Making the transition to renewables has been a high priority worldwide. For instance, the climate and energy framework adopted by the European Commission (EC) targeting at 27 % share of renewables by 2030 is an important commitment (EC, 2014). Sustainable development in line with SDG 7, European Green Deal, Agenda 2030 and other global efforts have provided some impetus to renewable energy transition (Borozan, 2022). Studies have shown that Europe is leading the transition while the rest of the world is following its lead in terms of technological development (Bhattarai et al., 2022; Bigerna et al., 2021). Moreover, it is established that countries with larger investment in research and development of energy systems are able to promote renewable sources, meet the energy demands sustainably, improve the living standards of the people and enhance economic growth (Adedoyin et al., 2020; Gümüş, 2015). Interestingly, studies have shown that renewable energy transition will not occur instantaneously (Johnstone et al., 2020). In fact, the global diffusion of renewables in the energy mix is more of an addition to the conventional generation systems rather than transitioning from it (York & Bell, 2019). Some energy scholars are doubtful whether the current renewable energy transition efforts are enough to sustain the growing demands (Johnstone et al., 2020). Studies have even raised concerns whether transitioning to renewables actually benefit decarbonization (Debnath & Mourshed, 2024). Due to these reasons, researchers have highlighted the need for a more radical and urgent change in the energy behaviour promoting transition to renewables globally in order to mitigate the impacts of climate change (Johnstone et al., 2020; Millot et al., 2020). Moreover, expanding and modernizing energy systems in the global south has been the focus of the Sustainable Development Goal (SDG-7) (UN, 2015).

Energy plays an indispensable role in supporting the overall development of a nation, more importantly in the case of developing countries. Furthermore, energy transition and economic growth have a bidirectional relationship (Mohsin et al., 2021). As a result, researchers highlight the need to focus on increasing the accessibility to energy and efficiency considering the variations in the supply and demand sides (Verma et al., 2024). Abbas et al. (2022) identified common key socioeconomic determinants of multidimensional energy poverty among a panel of developing countries. People tend to switch to modern and efficient technologies as well as increase the energy consumption as they climb up the energy ladder (Dominguez et al., 2021) and renewable sources become more desirable (Shahzadi et al., 2022). Adha et al. (2024) demonstrate that the current high levels of energy inefficiencies in the ASEAN countries are hindering their economic growth. Franco and Taeighagh (2024) assessed the interlinkages between the renewable energy technology adoption process and how they are perceived by the community in the Philippines. Shakya et al. (2022) show that diesel generated electricity still plays a critical role in substantiating the supply of national grid electricity in Nepal. Haldar et al. (2023) show the dynamic roles of rising renewable-energy share in the energy mix directly impacting energy poverty taking the case of sub-Saharan Africa. Karatayev et al. (2016) underscore the importance of policy as drivers of renewable energy adoption in Kazakhstan.

On a positive role, studies have identified ways to overcome the energy related challenges in the Global South. For instance, Raza et al. (2022) highlights the need for increased renewables in the energy mix for a sustainable energy future in Pakistan. Gautam and Bolia (2024) demonstrate the adoption of electric vehicles as a promising intervention for sustainable transportation development in India. Likewise, Kapoor and Garg (2021) present the use of solar panels over irrigation canals in India as a feasible co-benefit of technologies to increase clean energy generation. Floating solar power station has been studied with scaling up possibilities in Azerbaijan (Mukhtarov et al., 2020). Nshimiyimana et al. (2024) highlight the importance of cooking-related awareness, behaviour change and marketing campaigns for switching to cleaner cooking energy technologies in Rwanda. Shakya et al. (2022) identified possible co-benefits of demand side energy management combining microgrids of diesel generators and solar PV for achieving energy security in Nepal. Bhattarai et al. (2022) focus on developing an 'energy ecosystem' for sustainable use of energy while Bhattarai et al. (2024a) recommend increasing the 'suppressed demand' by strengthening the domestic renewable energy generation capacity of Nepal in the near future. Hussain et al. (2019) demonstrate how hydropower remains an important option for achieving renewable energy goals in the Hindu Kush Himalayan region by promoting micro-hydropower and fostering regional energy development and sharing programs. Likewise, Huda and McDonald (2016) underscore the importance of regional energy sharing in South Asia. Moreover, studies highlight the potential of the developing Asian economies in mitigation of greenhouse gas emissions and climate change impact minimization provided public awareness on the availability and adoption of renewable technologies is effectively created (Mohsin et al., 2021).

People's energy use behaviour and climate change are inter-related. Therefore, understanding people's views and managing household energy consumption as an adaptation strategy to minimize the impacts of climate change is a major challenge for policy makers, especially in the developing world (Amrutha et al., 2018; Bahn et al., 2019; Bhat et al., 2019; Ramagoma & Adendorff, 2016; Raza et al., 2022). This requires a proper understanding of the people's energy use perceptions and preferences holistically (Sovacool, 2014). However, Windemer (2023) warns against assuming uniform energy use behaviours among people while Shrestha et al. (2019) cautions about the likely mismatch between science and people's perceptions.

Numerous studies have investigated socio-economic factors influencing people's energy perceptions. For instance, Koirala and Acharya (2022), Paravantis et al. (2018) and Dominguez et al. (2021) show how people's choice of fuel varied at the household level in Nepal, Greece, and Kenya, respectively. Taking the case of Canada, Hurlbert et al. (2020) underscore how the existing energy technologies and people's energy behaviour are not likely to be substituted by renewables until strong actors surface. Andreas et al. (2018) demonstrates how disproportionate burdening of the energy consumers in Bulgaria undermined its renewable energy transition. Across many Asian countries, energy security is largely dependent on common socioeconomic determinants (Abbas et al., 2022). Li et al. (2021) highlight the importance of renewable energy policy-relevant treatments in household fuel saving in China. Hess and Mai (2014) point out the reluctance of developing countries to formulate policies which are supportive of renewable energy transition. Studies such as Proka et al. (2018) and Martinez and Komendantova (2020) analyze various aspects of social resistance to renewable energy transition in different parts of the world.

A wide range of literature have examined how people perceive climate change and the consequent impacts on different socio-economic sectors. Recent studies have focused on agriculture (Chhogyel et al., 2020; Paudel et al., 2020), hazards and adaptation (Devkota et al., 2020; Ghosh & Ghosal, 2020), forest management (Acharya et al., 2019; Dhungana et al., 2020) and socio-psychological assessments (Ballantyne et al. , 2016; Bremer & Linnenluecke, 2017), among others. Additionally, researchers have attempted to standardize public opinions of climate change and their adaptations across different contexts and scales (van Valkengoed et al., 2021).

Contemporary literature presents perception-focused studies on energy and climate change often aimed at specific energy technologies. For instance, Chung and Kim (2018) demonstrate that South Koreans do not support transitioning to nuclear power as a solution to climate change reduction. Likewise, Poortinga et al. (2013) present an interesting case which showed that the Japanese people are reluctant to continue nuclear power plants for climate change mitigation compared to the British after the Fukushima tragedy. Moreover, a diverse set of factors have been found to influence energy use behaviour. For example, Tanti and Yena (2023) show that access to energy sources for irrigation is one of the major determinants of adoption of climate smart agriculture by the local farmers in an Indian state to mitigate climate change issues. Likewise, awareness and existing norms were found to be the most influential factors on the adoption of biofuels for climate change mitigation in the rural context of Iran (Yaghoubi et al., 2019). Interestingly, Karlstrøm and Ryghaug (2014) present political inclination of the people as a governing factor for adoption of renewable energy technologies in Norway in the wake of climate change. Moreover, it was found that the preference of development of new hydropower in Norway as a clean energy source was less impacted by people's pre-existing beliefs and more influenced by the direct benefits and the involvement of the stakeholders in the development process (Saha & Idsø, 2016). Evensen and Brown-Steiner (2018) report that people in the US do not believe that unconventional gas development (as an energy source) will have a considerable impact on global climate change. Moreover, attitudes of the people of Finland were found to be different for the national and global level climate policies underscoring the need for societal context-specific interventions (Sivonen, 2023). Likewise, Cho et al. (2024) mentions that achieving carbon neutrality in the building energy sector of South Korea is largely dependent on the occupants' behavioural characteristics in addition to the proper implementation of building codes. Debnath and Mourshed (2024) identify ensuring tangible outcomes by implementing carbon pricing and removing energy subsidies while maintaining equitable socio-economic impact for all income category people as two important recommendations for decarbonization of Bangladesh's energy sector. Similarly, energy conservation and demand-side management have also been of interest in recent studies in the face of climate change (Han et al., 2022; He et al., 2023; Lacroix & Gifford, 2018). Thus, meticulous assessment of people's behaviours for minimizing energy consumption and the impacts of climate change is seen necessary.

Moreover, studies comprehensively exploring the influential social and climate change-perception related factors on people's current and future energy preferences are scarcer in the developing world, particularly South Asia and almost none in Nepal. In addition to developing a better understanding of the people's views, the findings of this study will be instrumental to the decision makers in identifying the areas of the society that need more attention while devising and implementing energy and climate change policies. Hence, we aim to contribute to this important policy-science-society interface in the energy sector. We take the case of a developing country – Nepal. More specifically, this study aims:

1. to fit an optimal model for identifying the determinant socio-economic and climate change perception parameters impacting people's energy use behaviour at the household level; and
2. to compare the respective influences of the parameters on people's energy transition preferences.

The next section (*Materials and Methods*) explains about the geographical location and the current energy status of Nepal (*Study Area*). The subsequent section is on the adopted methodology in which the different steps are sequentially explained in the respective sub-sections. *Household Questionnaire Survey* explains the sampling strategy and provides additional details of the administration of the household questionnaire survey. Likewise, *Data pre-processing* provides information on data cleaning, basic statistical checks and multicollinearity analysis. *Application of ordinal logistic regression model* is on the categorization of the response variable and the modelling details. This is followed by the results of the data spread, collinearity and the three models. In the Discussion section, we discuss about the socio-economic variables, climate change perception variables and analyse the people's preference of energy transition based on the modelling results. We then conclude with key takeaway messages and policy recommendations in the *Conclusion* section.

Materials and methods

Study area

Nepal lies in the central Hindu Kush Himalayan region landlocked between India and China (Fig. 1). Nepal can be roughly categorized into four distinct physiographic regions: mountains, high hills, mid hills, and Terai plains.

In the fiscal year 2022/2023, Nepal's total energy consumption was 14.943 million tons of oil equivalent (toe) (WECS/GoN, 2023). The country's energy mix comprises three primary sources: traditional (firewood, agricultural residue, and dry dung for direct combustion, 64.2 %); commercial (petroleum, coal, and grid electricity, 33.3 %); and other off-grid renewable sources (micro-hydro, solar and biogas, 2.5 %) (WECS/GoN, 2023). Although overall access to electricity has increased from 29 % in 2000 to 92 % of the population in 2023 (NEA/GoN, 2023), 51 % of the rural population still rely on firewood for cooking, 2.9 % use dried dung while only 1.2 % use bio-gas and <1 % use kerosene or other sources (CBS, 2021). Likewise, electricity, solar, kerosene, biogas and other sources are used by 92.1 %, 6.6 %, 0.6 %, 0.03 % and 0.62 % of the total population, respectively for household lighting (CBS, 2021).

The annual electricity consumption of Nepal was 6789 GWh with a peak demand of 1870 MW in 2022/2023 (MoF/GoN, 2023; NEA/GoN, 2023). Nepal's total installed power capacity was 2666 MW in the end of the FY 2022/2023, out of which large hydropower projects, solar, thermal, smaller renewable technologies and co-generation technologies from sugar mills contributed 2499 MW, 75 MW, 53.4 MW, 82 MW and 6 MW, respectively (MoF/GoN, 2023). Moreover, the private sector contributes significantly (55 %) to the total power installed capacity of Nepal (NEA/GoN, 2023). Nepal faces a loss (due to theft and transmission losses) of about 13.5 % in the power sector (NEA/GoN, 2023). The total installed capacity of rooftop solar PV is 10.1 MW, that of micro- and mini-hydropower is 38.8 MW and local hybrid grids is 2.7 MW (AEPC/GoN, 2023). In the FY 2022/2023, Nepal purchased 1855 GWh year-round from India and exported 1333 GWh (~72 % of imported electricity) during June to October (NEA/GoN, 2023).

Methodology

This study adopted a mixed-method approach in which we implemented a series of steps: household survey, data pre-processing, and application of three ordinal logistic regression models to examine people's preferences of energy transition in the household sector of Nepal (Fig. 2).

Household questionnaire survey

Household questionnaire survery was the first step of our research. A cross-sectional questionnaire survey was undertaken in 49 districts of Nepal encompassing 350 households over three physiographic regions, namely, high hills, mid hills and Terai plains. However, there is almost no human habitat in the mountain region (around above 3000 metres above sea level, masl) largely owing to its rugged terrain and harsh climatic conditions. Regions above 4000 masl have permanent snowline where the temperature is below freezing throughout the year, making it almost impossible for human settlement. Moreover, access to these areas is extremely difficult. As a result, our survey was confined to the remaining three regions.

We made sure that the sampled households are representative of certain attributes related to our study aims (Table 1). Thus, capturing the diversity in the household energy use was the major adopted criteria

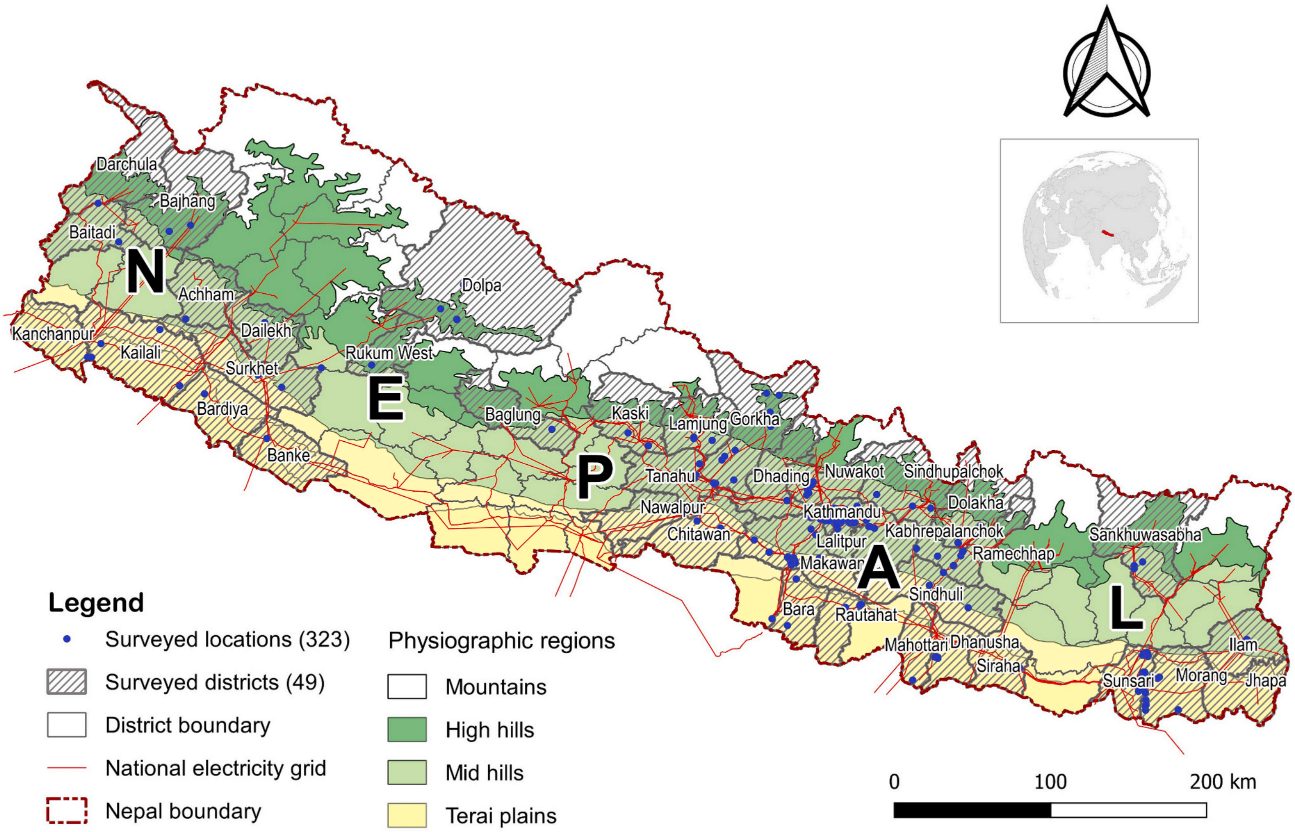

Fig. 1. Geographical setting of Nepal. Dots indicate the locations where household questionnaire survey (n = 323) was carried out.

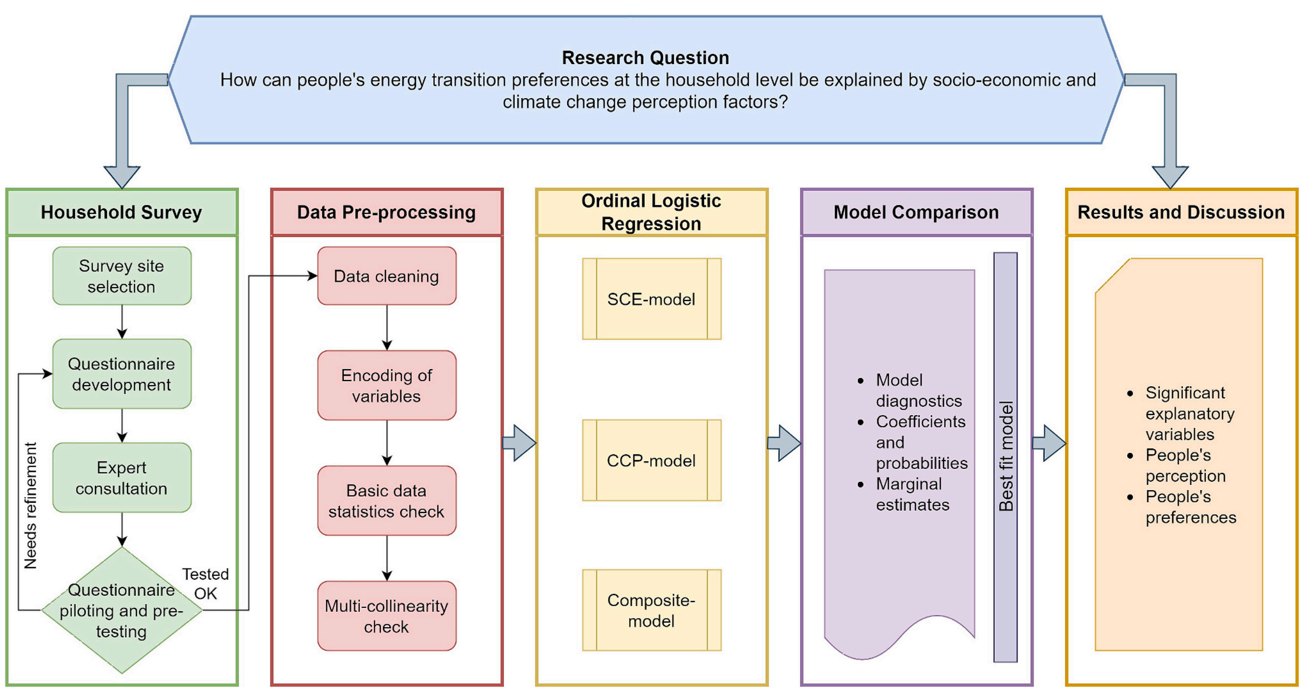

Fig. 2. Research methodology implemented in the study.

during survey site selection. Energy supply and usage varies considerably across the different physiographic regions of Nepal. In addition, the rural, semi-urban and urban areas have varying energy consumption patterns. Therefore, these attributes were chosen as important factors in sites selection. Furthermore, the energy (mainly electricity) generation technologies vary according to different locations. Hence, survey locations were chosen such that the residents would be able to provide information about the industrial areas, major hydropower projects, representative micro-hydropower, solar and other off-grid renewable energy projects and how these projects would impact their energy

Table 1
Survey districts selection criteria.

S. N	Survey districts	Sample size	Physio-graphy	Urbanization	Electri-fication status	Alternate electricity	Remarks
1	Kathmandu/ Bhaktapur / Lalitpur	60	Mid hills	Urban/ semi-urban	Electrified	HH-solar	Core city/ semi-urban areas
2	Makwanpur/ Chitwan / Nawalpur	30	Mid hills / Terai	Semi-urban	Electrified/ non-electrified	HH-/ local grid solar/ micro hydro/ diesel	Kulekhani cascade, Lower Bagmati hydropower and diesel plant areas
3	Gorkha/ Lamjung/ Tanahu/ Kaski/ Baglung	45	High hills/ Mid hills	Semi-urban/ rural	Electrified/ non-electrified	HH-/ local grid solar/ micro hydro	Budhigandaki, Marsyangdi and Tanahu hydropower project areas
4	Rautahat/ Bara / Dhanusha / Siraha/ Mahottari	45	Terai	Semi-urban/ rural	Electrified/ non-electrified	HH-/ local grid solar/ micro hydro	Bagmati multipurpose project & Chandranighapur Solar project areas
5	Dolakha/ Ramechhap/ Kabhrepalanchok/ Sindhupalchok	45	Mid hills/ High hills	Urban/ semi-urban/ rural	Electrified/ non-electrified	HH-/ local grid solar /micro hydro	Upper Tamakoshi, Khimti hydropower & Sunkoshi cascade project areas
6	Sankhuwasabha/ Illam/ Jhapa	30	High hills/ Mid hills/ Terai	Semi-urban/ rural	Electrified/ non-electrified	HH-/ local grid solar/ micro hydro	Arun III/ Kimathanka and many other hydropower project areas
7	Morang/ Sunsari	30	Terai	Urban/ semi-urban	Electrified	HH-/ local grid solar/ diesel	Duhabi industrial corridor/ Biratnagar/ Dharan
8	Dolpa/ Rukum West/ Dailekh / Surkhet / Achham/ Bajhang / Baitadi / Darchula	35	High hills	Rural	Electrified/ non-electrified	HH-/ local grid solar/ micro hydro	
9	Banke/ Bardiya/ Kailali/ Kanchanpur	30	Terai	Urban/ semi-urban/ rural	Electrified/ non-electrified	HH-/ local grid solar/ micro hydro	Biggest solar project, Bhalubang, Naumure & other project areas
	Total	**350**					

Note - HH: Household.

availability choices.

The high hills are less populated (in terms of population density as well as total population) compared to the mid hills while the Terai plains have the largest population. It can be seen from CBS (2021) that each Terai district has a contribution of >1.5 % to the total national population while that of the mid hills range from 0.5 to 1 %. The contribution of each high hill district is <0.5 % in the national population. It has to be noted that 7 % of Nepal's population live in the Kathmandu district where the capital city Kathmandu is situated. We have tried to maintain this proportion in our sample size distribution for the survey. We sampled the 49 surveyed districts such that 14 districts (29 %) were selected from Terai, 11 districts (22 %) from mid hills and 24 (49 %) districts from high hills. More districts were chosen for the high hills to account for their fewer population compared to the other two regions. Moreover, 23 samples (7 % of our total sample size) were chosen from Kathmandu district which lies in the mid hills region. Similarly, CBS (2021) and WB (2024) report that about 22 % of the country's population is located in urban areas, about 46 % in semi-urban areas while 33 % are in rural areas. We have tried to partly maintain this proportion in our sample size distribution as well such that there are 87 samples (27 %) from the urban areas, 63 samples (20 %) from semi-urban areas and 173 samples (53 %) from rural areas. As with the high hill districts, more samples were chosen for the rural and semi-urban areas for two reasons. Firstly, it is to account for their fewer population compared to the urban areas. Secondly, there is a much larger variation in the use of household energy sources across the rural areas (Table 1:) compared to the urban areas which are mostly confined to grid electricity and LPG.

Moreover, our classification was based on the homogeneity within the classes of each explanatory variable as well as the diversity across the classes. Therefore, based on the homogeneity of the sample clusters, the sample size utilized in this study is deemed adequate. Careful measures have been undertaken to ensure at least 30 samples for each group among the variables are maintained, confirming a robust sampling representation. Readers are referred to Bhattarai, Maraseni, Devkota, and Apan (2023) for additional details of the sampling strategy and survey. Hence, 350 was an optimum sample size that we could achieve within our time and other research resource constraints.

Furthermore, randomization is an effective way to remove bias. Hence, the sampling strategy was so designed that first, the population was divided into strata, and then each household was randomly selected from each strata so that each household had an equal chance of being selected. The household database was collected and collated from local government offices. All households were numbered and randomly selected. Moreover, we did not select specific respondents from each household. Rather, selection of the respondents was done such that they were knowledgeable about their household energy related matters and are able to communicate their perceptions about local climatic context. In most cases, it was the household head who fell in this criterion but in other cases, other family members were more aware of the energy and climate contexts and had a stronger say in the household energy related decisions. We strongly believe that adopting these measures are indicative of the reliability of the questionnaire as an instrument and the survey methods as a whole.

Questionnaire was meticulously devised through an extensive review of literature, notably referenced from scholarly works such as Bhandari et al. (2018), Bhattarai, Devkota, Maraseni, et al. (2023), Braito et al. (2017), Cloke et al. (2017), Das et al. (2022), Ghimire and Kim (2018), Jacksohn et al. (2019), Liao et al. (2021), Matavel et al. (2023), Munro (2019), Roberts (2020), Salari et al. (2021), Strazzera and Statzu (2017), Tsvetanov (2019), Wiehe et al. (2021), and Winkler et al. (2018). After undergoing expert consultation and pre-testing, household surveys were conducted during December 2022 to February 2023. The ethical requirements of Human Research Ethical Clearance HREC ID H22REA258 issued by the University of Southern Queensland, Australia were strictly followed by trained enumerators while conducting the surveys. It was made sure that only local enumerators were selected who were well acquainted with the socio-economic, energy and climatic contexts of Nepal. For this, at least undergraduate level educated enumerators were selected for the survey. Moreover, the survey was conducted in Nepali language so as to facilitate easy communication between the enumerators and the respondents throughout the survey locations. The respondents were well-informed about their voluntary contribution to this research through the survey. They were also assured that anonymity would be maintained by coding the responses and that the respondents had no direct or indirect risk of anything beyond their day-to-day activities by participating in this survey. In addition, they were also informed that they could withdraw from the survey at any time without any implications.

Data pre-processing

We collected 350 household questionnaire survey samples based on the distribution shown in Table 1. During data cleaning, 27 samples were found to be incomplete or had irrelevant responses; they were excluded. In this way, a final sample size of 323 was maintained for further analysis. A total of twenty-four predictor variables and one response variable were chosen. The independent explanatory variables were of mixed data types (continuous, binary and categorical) which were converted into logical classes. Detailed description of the variables, their classes and justification of the categorization are given in Annex Table A1. The response (dependent) variable was classified into a logical order. Basic statistics of the surveyed data was checked. Furthermore, we checked the correlation among the 24 explanatory variables (12 socio-economic and 12 climate change perception) and ensured that issues of multi-collinearity did not impact our analysis (Fig. 3). Additionally, the spread for each predictor variable in the different classes was assessed. All the explanatory variables are either binary or categorical. Therefore, Chi-squared test is appropriate for finding the

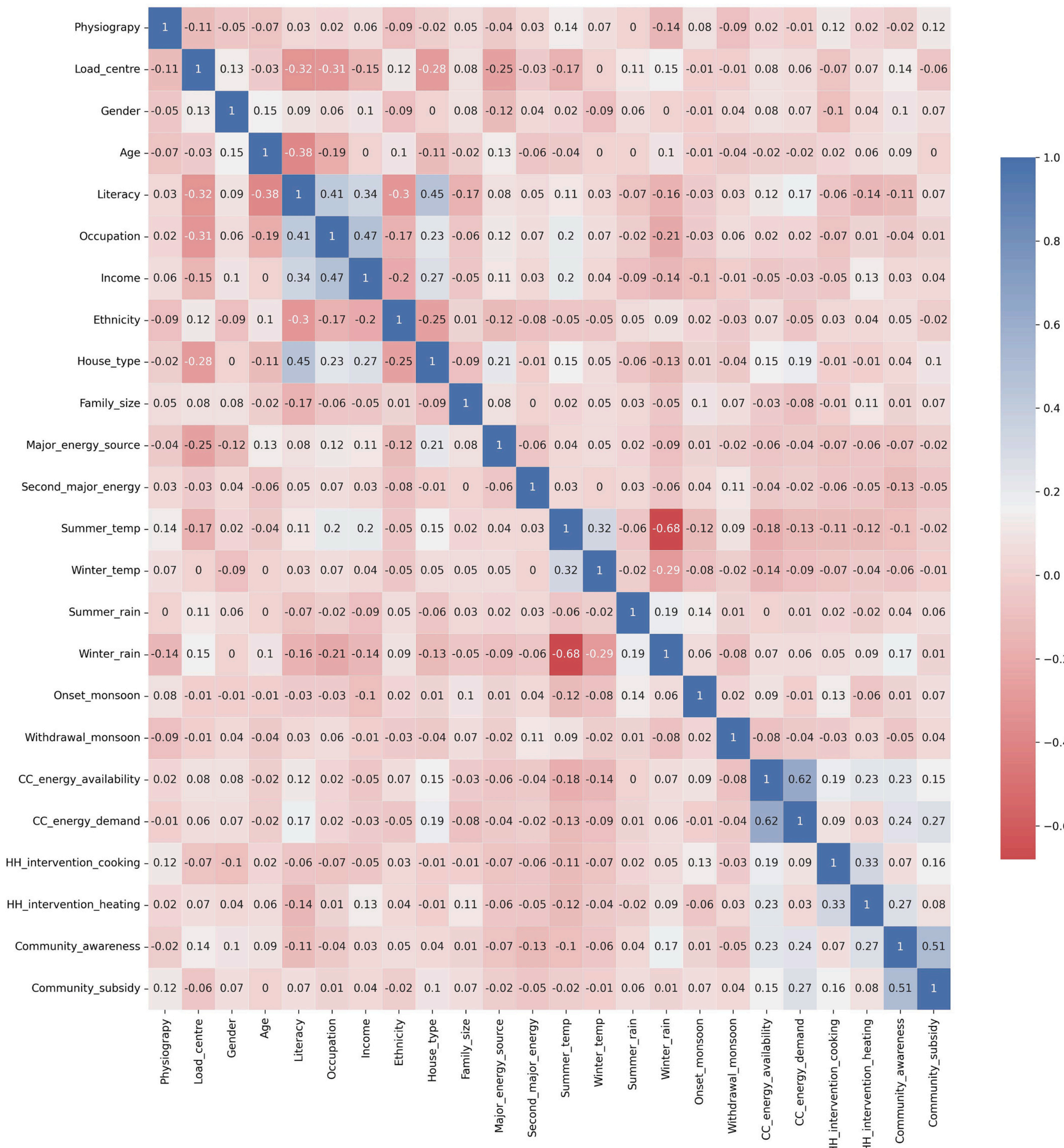

Fig. 3. Correlation matrix of the explanatory variables. The first twelve are the socio-economic variables while the remaining twelve are climate change perception variables.

variation between categorical data (Hamilton, 2012; Sharna et al., 2024).

Application of ordinal logistic regression model

Econometric models are popular among researchers in identifying the determinants of the choices people make. Scholars generally adopt a collection of explanatory independent variables through literature review, consultations with informants and expert evaluations, followed by regression analysis with respect to the reliant variables (Anik et al., 2022; Storm et al., 2020). For instance, He et al. (2023) used a combination of binary probit model and ordered probit model; Das et al. (2022) and Koirala and Acharya (2022) applied multinomial logit and multinomial probit models; Acosta et al. (2021) applied a quantile regression model; Park et al. (2023) applied multinomial logistic regression model while Sivonen (2023) and Sharna et al. (2024) applied ordinal logistic regression. Moreover, ordinal logistic regression is the common choice when the responses are categorical and can be ordered in a logical way related to people's opinions (Deisenroth et al., 2020; Sivonen, 2023; Storm et al., 2020).

The dependent/response variable in our research is ordinal. The lowest order (first category) of the preference variable has been assigned to the respondents who are either unaware of the available energy options or they are financially and technologically not capable to change their household energy choice or both. In (mostly urban) areas with access to grid electricity as well as the non-electrified (semi-urban and most rural) areas, the behaviour of the people to avoid transitioning to better alternatives is characterized by this class. The second category refers to the people's preference of being able to connect to grid electricity for household use, particularly in the non-electrified rural areas. In the case of already electrified urban areas, this category is indicative of people's desire of increasing their reliance on the grid electricity (for example by connecting to higher capacity lines) so that they can use more household electric appliances, without any contribution from other renewable sources. This category is indicative of complete dependency on the government with very limited initiatives for the energy transition from the users' side. The third category pertains to the people's preference to completely switch to other off-grid renewables for meeting their household energy demands. This indicates the households' desire to take the initiative from their side and decrease dependency on the state. Moreover, this category also denotes a condition in which the users have the ownership and more control over the energy generation and use in their houses. The fourth category is a condition which shows the households' access to both grid electricity and renewable energy sources such that the combination leads to an optimum use of energy for household purposes. Responses willing to opt for technological advancements (such as net metering) in the electricity sector of the electrified urban areas also come under this category. As a result, it was categorized as the highest ordinal (fourth) category.

Hence, an ordered logistic regression model has been used. The assumptions for application of this model such as proportional effect of independent variables on the outcome, independence of observations, linearity in log-odds of the response categories, no multicollinearity, homoscedasticity, sufficiently large sample size, no outliers and adoption of valid and meaningful categories have been satisfied (Deisenroth et al., 2020). Through model diagnostics, regression coefficients and marginal values of the explanatory variables, we explored how the people appraised the energy transition preferences using three models i) socio-economic parameters only (*SCE-model*), ii) climate change perception parameters only (*CCP-model*) and iii) combination of both parameters (*Composite-model*). In the first model, *ceteris paribus*, we assume that only the socio-economic variables affect people's energy preference. Likewise, in the second model, we assume that only the climate perception variables affect people's energy preference, holding all other socio-economic factors remain constant. However, in the third model, we consider the cumulative impact of both types of explanatory variables on the household energy preferences. The best performing model was chosen among these based on the above-mentioned metrics.

Mathematically, the energy transition preference behaviour can be represented as shown in Eq. 1 to Eq. 3.

$$\text{SCE} - \text{model}: Y_m(\textit{Preference}) = a_1 + \sum_{i=1}^{12} X_i\alpha + \varepsilon_i \tag{1}$$

$$\text{CCP} - \text{model}: Y_m(\textit{Preference}) = a_2 + \sum_{j=1}^{12} X_j\beta + \varepsilon_j \tag{2}$$

$$\text{Composite} - \text{model}: Y_m(\textit{Preference}) = a_3 + \sum_{i=1}^{12} X_i\alpha + \sum_{j=1}^{12} X_j\beta + \varepsilon_k \tag{3}$$

where, $Y_m(\textit{Preference})$ denotes the status of energy transition preference with four possible values of m (1 denoting Preference 1: no change from current energy conditions; 2 representing Preference 2: transitioning to grid electricity only; 3 denoting Preference 3: transitioning to other renewables only; and 4 representing Preference 4: transitioning to a combination of grid electricity and renewables). X is a vector of the explanatory variables with subscript i for the socio-economic variables while j for the climate change perception variables and a, α and β are the regression coefficients. ε denotes identically distributed error terms for the respective models with variance one and mean zero. The probability associated with people's preferences can be written as Eq. 4.

$$\pi\left(y_i \le \frac{j}{x_i}\right) = \Delta\left(\gamma_j - X\alpha\right) - \Delta\left(\gamma_{j-1} - X\alpha\right) \tag{4}$$

where, j is the observed variable and γ is the threshold parameter. Hence, the generic ordered logistic regression model is written as in Eq. (5).

$$Logit(Y_m) = Log_e\left(\frac{\pi}{1-\pi}\right) = a_0 + X_i\alpha_i + \varepsilon \tag{5}$$

The ordered logit model was implemented in STATA 16 and the descriptive analyses was carried out using Chi-square test to assess the statistically significant differences among the people's preference categories (StataCorp, 2023; Williams, 2006; Williams, 2018).

Results

Correlation

Fig. 3 depicts a correlation matrix of our dataset. The heatmap shows that the value of the Pearson correlation coefficient ($|r| < 0.3$) for majority of the variables. Only a few variables, for example *Occupation* and *Income*, *Literacy* and *Occupation* have r values in the range of 0.4 indicating weak correlation while only *Winter_rain* and *Summer_temp* demonstrate a moderate correlation of 0.68. Readers are referred to Annex Table A1 for details of the variables.

Descriptive statistics

Socio-economic variables

A considerable heterogeneity was seen among the four energy transition preference groups (Table 2). Out of the 323 respondents, 151 (47 %) were either unaware or chose no transition – preference 1; 74 (23 %) opted for transitioning to grid electricity only – preference 2; 47 (14 %) preferred changing to other renewables only – preference 3; and 51 (16 %) chose to transition to a combination of grid electricity and renewables – preference 4. The frequency (and percentage) of people's responses according to the classes of the explanatory variables are presented columnwise which add up to 323 (100 %) for each variable.

Results of the Chi-square test show that, among the 12 socio-economic variables, the differences were significant at 1 % ($p \le 0.01$) for four variables of urbanization status, level of education, living

Table 2
Descriptive statistics of the socio-economic variables with respect to the energy preferences.

Description of explanatory factors (*variables*) and classes	Energy transition preference								Chi-square (*p*-value)
	Preference 1: No change/ I do not know		Preference 2: To grid electricity only		Preference 3: To other renewables only		Preference 4: To electricity and renewables		
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	
Type of terrain									10.0368
(Physiography)									(0.123)
High hills (1)	51	34	19	26	8	17	17	33	
Mid hills (2)	65	43	41	55	23	49	26	51	
Terai Plains (3)	35	23	14	19	16	34	8	16	
Level of urbanization									25.150***
(Load_centre)									(0.000)
Kathmandu Valley (1)	23	15	28	38	14	30	22	43	
Other towns (2)	30	20	11	15	12	26	10	20	
Rural areas (3)	98	65	35	47	21	45	19	37	
Gender of the respondent									0.6897
(Gender)									(0.876)
Female (1)	34	23	15	20	8	17	11	22	
Male (2)	117	77	59	80	39	83	40	78	
Age of the respondent									9.2045
(Age)									(0.162)
≤ 35 years (1)	54	36	32	43	28	60	23	46	
35–50 years (2)	56	37	23	31	9	19	15	29	
> 50 years (3)	41	27	19	26	10	21	13	25	
Education level of the respondent									60.308***
(Literacy)									(0.000)
Illiterate (1)	34	23	4	5	1	2	4	8	
Primary school/informal education (2)	33	22	9	12	3	6	1	2	
Secondary/high school (3)	50	33	24	32	13	28	28	55	
University (4)	34	23	37	50	30	64	18	35	
Type of employment of the respondent									25.493**
(Occupation)									(0.013)
Unemployed/retired (1)	15	10	12	16	2	4	4	8	
Farming/livestock rearing (2)	51	34	14	19	10	21	8	16	
Self-employed (3)	43	28	17	23	10	21	15	29	
Academic/government service (4)	16	11	13	18	10	21	5	10	
Private organization (5)	26	17	18	24	15	33	19	37	
Annual household income in US$									11.9103
(Income)									(0.218)
< 692 (1)	51	34	14	19	9	19	11	22	
692–1154 (2)	16	11	9	12	6	13	6	12	
1154–1961 (3)	22	15	14	19	5	11	12	24	
> 1961 (4)	62	40	37	50	27	57	22	42	
Ethnic background of the household									15.875**
(Ethnicity)									(0.014)
Marginalized/underprivileged (1)	9	6	0	0	0	0	3	6	
Indigenous (2)	70	46	33	45	12	26	20	39	
Brahmin/Chhetri (3)	72	48	41	55	35	74	28	55	
Living standard of the household									32.276***
(House_type)									(0.000)
Mud hut/cottage (1)	18	12	3	4	1	2	2	4	
Bamboo/wood (2)	15	10	1	1	0	0	0	0	
Bricks and mud mortar (3)	20	13	8	11	2	4	3	6	
Bricks and cement (4)	98	65	62	84	44	94	46	90	
Household size and type of family									2.6390
(Family_size)									(0.853)
≤ 4: Nuclear (1)	62	41	34	46	25	53	23	45	
5–6: Extended (2)	65	43	29	39	15	32	19	37	
>6: Joint (3)	24	16	11	15	7	15	9	18	
Domestic energy options									27.360***
(Major_energy_source)									(0.007)
Agriculture residue (1)	21	14	6	8	4	9	8	16	
Petroleum (2)	11	7	6	8	7	15	1	2	
LPG (3)	90	60	34	46	30	64	27	53	
Grid-electricity (4)	25	17	28	38	5	11	15	29	
Renewables (5)	4	3	0	0	1	2	0	0	
Alternate household energy options									20.648**
(Second_major_energy)									(0.014)
Petroleum (1)	13	9	4	5	6	13	1	2	
LPG (2)	35	23	32	44	11	23	19	37	
Grid-electricity (3)	91	60	34	46	30	64	30	59	
Renewables (4)	12	8	4	5	0	0	1	2	
Total	**151**	**100**	**74**	**100**	**47**	**100**	**51**	**100**	

Note: Numbers in parenthesis alongside the variable classes in the first column indicate the numeric classes used for modelling. ** and *** in the last column refer to significance level of 5 % (p ≤ 0.05) and 1 % (p ≤ 0.01), respectively.

standard, and the availability of household energy options (Table 2). A majority (65 %) of the respondents not aware of the energy transition or reluctant to make any changes were from the rural areas. However, most respondents preferring to transition to grid-electricity and renewables (43 %) were from Kathmandu Valley, the capital city of the country. A considerable number of people preferring transitioning to renewables had university education (64 %), while those preferring to change to electricity and renewables were mostly (55 %) secondary or high school educated. Additionally, people living in houses made of bricks and cement were dominant in the response categories (no change in energy: 65 % and transition to renewables only: 94 %). People using LPG as their major source of household energy were sizable in number across all the preference categories ranging from 46 % (to grid electricity only) to 64 % (to other renewables only).

Similarly, the differences were significant at 5 % ($p \leq 0.05$) for three other variables: type of employment, ethnic background, and the availability of alternate sources of energy (Table 2). A large faction of the people working in private organizations (37 %) preferred to transition to grid electricity and renewables, whereas those unaware of the transition or choosing no change were mostly farmers (34 %). Similarly, 74 % of the respondents from the Brahmin/Chhetri (the privileged group in Nepal's context) ethnic group preferred transitioning to grid electricity only. Additionally, most of the people with grid electricity as their second major energy source opted either no change from the current conditions (60 %), use more electricity (64 %) or transition to grid electricity and renewables (59 %). Hence, a distinct pattern of people's energy transition preferences depending on the different socio-economic determinants was not observed.

Climate change perception variables

Results of the Chi-square test for the climate change perception variables showed four significant parameters: change in the average summer temperature, withdrawal of monsoon season, impact of climate change on energy availability, and the importance of community level subsidies at 1 % ($p \leq 0.01$) (Table 3). Most of the people (70 %) preferring to change to electricity and renewables and 64 % of the respondents preferring to change to grid electricity only perceived summer being hotter compared to twenty years ago. Similarly, a majority of the people who are not willing to make any energy transition (76 %) and choosing to change to grid electricity only (73 %) perceived no change in monsoon withdrawal. People perceiving high (45 %) and very high (39 %) impacts of climate change on energy availability respectively prefer transitioning to grid electricity only and a combination of grid electricity and renewables. Provision of community-level subsidies in energy efficient devices was considered highly effective measures for reduction of climate change impacts on household energy by people who chose transitioning to grid electricity and renewables (76 %) and those (65 %) who chose changing to grid electricity only.

Likewise, significant differences at 5 % ($p < 0.05$) were observed for four variables pertaining to the perceptions of change in the amount of summer rainfall, timing of monsoon start, impact of climate change on energy demand and energy consumption behaviour for space heating to reduce the impact of climate change on household energy (Table 3). A sizeable percentage of the respondents (47 to 74 %) choosing to transition to either of the four preference options did not perceive any change in the summer rainfall amount compared to two decades ago. Similarly, a major share of the people (77 to 86 %) did not perceive any change in the starting time of monsoon compared to the last twenty years. Additionally, people perceiving very high impacts of climate change on household energy demand preferred transitioning to grid electricity only (43 %) and grid electricity and renewables (37 %). Moreover, a considerable percentage of the respondents willing to make no changes in energy behaviour (44 %) perceived interventions in household heating could be beneficial for reduction of climate change impacts on the energy sector. As with socio-economic variables, no distinct pattern of people's preferences can be deduced with the climate change perception variables.

Socio-economic and climate change perception factors impacting people's energy transition preferences

Results of the ordinal logistic regression models show that the log likelihood values are comparable across the three models with the *Composite-model* having a relatively higher value (−365.56) (Table 4). The *p*-values are very close for all the three models. In addition, 10.5 % of the variance in the outcome is explained by the predictors in the *Composite-model* as shown by the McFadden's R2 which implies a reasonable fit of the model to the socio-economic and cross-section data (Hensher & Johnson, 2018; Ozili, 2023; Salam et al., 2023). Hence, the *Composite-model* is more representative of the data in explaining the response based on the explanatory variables.

For the *SCE-model*, variables related to the urbanization status, level of education, living standard, and the availability of alternate household energy sources are statistically significant predictors of the responses at 5 % level of significance (Table 4). In the case of *CCP-model*, variables linked to the perceptions regarding changes in winter rainfall, withdrawal of monsoon season, household energy demand, notably cooking and space heating, and the importance of community level subsidies for minimizing the climate change-induced effects on household energy patterns were found to be statistically significant (Table 4).

Similarly, for the *Composite-model*, variables associated to the urbanization status, level of education, living standard, the role of changing the energy consumption behaviour for cooking, and the importance of community level subsidies for minimizing the climate change-induced effects on household energy patterns were found to be statistically significant at 5 % (Table 4). The values of the coefficients within this model closely resemble those of the corresponding predictor variables within the *SCE-* and *CCP-models* (with some exceptions such as timing of start of monsoon, *Onset_monsoon*).

Table 5 presents the marginal effect estimates (coefficients) for the predictor variables for the four energy transition preferences (labelled as preference 1 (P1) to preference 4 (P4)) across three models: *SCE*, *CCP* and *Composite*. In the *SCE-model*, urbanization status, level of education, living standard and alternate household energy source were significant across all the response categories. For example, the marginal estimate is 0.080 for the first preference (no change to existing household energy behaviour) when considering the urbanization status variable (*Load_centre*). This indicates that as the value of this variable increases by one category (say, urban to semi-urban areas), the odds of preferring to transition to better energy technologies also increases by 8 %. On the other hand, the level of education (*Literacy*) depicts that it has a marginal coefficient of −0.118 for not preferring to make any energy changes. This shows that as the education level increases, people are more likely to prefer transitioning to better energy technologies. Interestingly, the probabilities continuously increase as we progress up the preference level from P1 to P4. Likewise, the marginal estimate of the respondents for their living standard (*House_type* variable) for being in the no change category (P1) is −0.103 indicating the probability of transitioning to higher options continuously increases with better living standards.

In the case of *CCP-model*, the marginal effects of people's perception of changes in winter rainfall, withdrawal of monsoon season, household energy demand, including cooking and space heating energy behaviour, and community level subsidies were found to be significant across all the response preferences (Table 5). For example, as the value of the winter rainfall perception variable (*Winter_rain*) increases by one category (say, from 'increased' to 'no change'), the odds of preferring to transition to better energy technologies also increases by 10 %. Conversely, marginal estimate (−0.110) in the 'no change' category in energy transition preference category (P1) for the community level subsidies (*Comm_interv_subsidy*) indicates that more the people start realizing the importance of community subsidies for energy efficiency, the odds of moving

Table 3
Descriptive statistics of the climate change perception variables with respect to the four energy transition preferences.

Description of perception based explanatory factors (*variables*) and classes	Energy transition preference								Chi-square (p-value)
	Preference 1: No change/ I do not know		Preference 2: To grid electricity only		Preference 3: To other renewables only		Preference 4: To electricity and renewables		
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	
Change in the summer temperature on an average *(Summer_temp)*									17.827*** (0.007)
Increased (1)	93	62	47	64	18	38	36	70	
No change (2)	47	31	18	24	26	56	11	22	
Decreased (3)	11	7	9	12	3	6	4	8	
Change in the winter temperature on an average *(Winter_temp)*									2.7493 (0.840)
Increased (1)	72	48	39	53	25	53	27	53	
No change (2)	68	45	30	41	17	36	22	43	
Decreased (3)	11	7	5	7	5	11	2	4	
Change in the amount of rainfall during summer *(Summer_rain)*									16.414** (0.012)
Increased (1)	33	22	23	31	20	43	16	31	
No change (2)	112	74	50	68	22	47	31	61	
Decreased (3)	6	4	1	1	5	11	4	8	
Change in the amount of rainfall during winter *(Winter_rain)*									5.8477 (0.440)
Increased (1)	35	23	22	30	16	34	16	31	
No change (2)	78	52	38	51	25	53	27	53	
Decreased (3)	38	25	14	19	6	13	8	16	
Change in the timing of monsoon start *(Onset_monsoon)*									13.976** (0.030)
Delayed (1)	19	13	17	23	6	13	6	12	
No change (2)	130	86	57	77	39	83	41	80	
Ahead (3)	2	1	0	0	2	4	4	8	
Change in the timing of monsoon end *(Withdrawal_monsoon)*									23.752*** (0.001)
Delayed (1)	33	22	18	24	18	38	24	47	
No change (2)	115	76	54	73	25	53	23	45	
Ahead (3)	3	2	2	3	4	9	4	8	
Impact of climate change on household energy availability *(climate change_energy_availability)*									26.375*** (0.009)
Very Low (1)	2	1	4	5	0	0	0	0	
Low (2)	13	9	3	4	5	11	3	6	
Moderate (3)	56	37	13	18	17	36	10	20	
High (4)	40	26	33	45	15	32	18	35	
Very high (5)	40	26	21	28	10	21	20	39	
Impact of climate change on household energy demand *(climate change_energy_demand)*									24.411** (0.018)
Very Low (1)	8	5	0	0	0	0	0	0	
Low (2)	15	10	6	8	4	9	1	2	
Moderate (3)	45	30	11	15	17	36	14	27	
High (4)	44	29	25	34	11	23	17	33	
Very high (5)	39	26	32	43	15	32	19	37	
Impact of change in cooking behaviour for reduction of climate change impacts on the household energy sector *(HH_intervention_cooking)*									9.4470 (0.664)
Very Low (1)	22	15	9	12	7	15	1	2	
Low (2)	13	9	4	5	3	6	3	6	
Moderate (3)	17	11	12	16	7	15	6	12	
High (4)	39	26	21	28	13	28	15	29	
Very high (5)	60	40	28	38	17	36	26	51	
Impact of change in space heating behaviour for reduction of climate change impacts on the household energy sector *(HH_intervention_heating)*									20.468** (0.059)
Very Low (1)	2	1	5	7	3	6	2	4	
Low (2)	7	5	4	5	2	4	2	4	
Moderate (3)	35	23	16	22	17	36	9	18	
High (4)	41	27	25	34	18	38	20	39	
Very high (5)	66	44	24	32	7	15	18	35	
Effectiveness of raising community level awareness for reduction of climate change impacts on household energy *(Community_awareness)*									18.9755* (0.089)
Very Low (1)	1	1	1	1	0	0	0	0	
Low (2)	2	1	0	0	1	2	0	0	
Moderate (3)	6	4	1	1	7	15	3	6	
High (4)	40	26	14	19	11	23	8	16	
Very high (5)	102	68	58	78	28	60	40	78	
Effectiveness of providing community level subsidies in energy efficient devices for reduction of climate change impacts on household energy *(Community_subsidy)*									36.737*** (0.000)

(*continued on next page*)

Table 3 (*continued*)

Description of perception based explanatory factors (*variables*) and classes	Energy transition preference								Chi-square (p-value)
	Preference 1: No change/ I do not know		Preference 2: To grid electricity only		Preference 3: To other renewables only		Preference 4: To electricity and renewables		
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	
Very Low (1)	1	1	1	1	2	4	0	0	
Low (2)	2	1	0	0	2	4	0	0	
Moderate (3)	20	13	1	1	6	13	2	4	
High (4)	59	39	24	32	7	15	10	20	
Very high (5)	69	46	48	65	30	64	39	76	
Total	**151**	**100**	**74**	**100**	**47**	**100**	**51**	**100**	

Note: Numbers in parenthesis alongside the variable classes in the first column indicate the numeric classes used for modelling. *, ** and *** in the last column refer to significance level of 10 % ($p \leq 0.1$), 5 % ($p \leq 0.05$) and 1 % ($p \leq 0.01$), respectively.

Table 4
Estimation of the impact that explanatory variables have on the response (preference) variable obtained by a) socio-economic (SCE) model ; b) climate change perception (CCP) model and c) combined socio-economic and climate change perception (Composite) model.

Variables	a) SCE-model			b) CCP-model			c) Composite-model		
	Coefficient	Std. Error	p-Value	Coefficient	Std. Error	p-Value	Coefficient	Std. Error	p-Value
Physiography	0.077	0.156	0.621				−0.037	0.165	0.822
Load Centre	−0.319**	0.142	0.025				−0.319**	0.156	0.041
Gender	0.130	0.287	0.650				0.124	0.297	0.675
Age	0.016	0.158	0.921				0.017	0.163	0.917
Literacy	0.474***	0.155	0.002				0.432***	0.165	0.009
Occupation	0.097	0.098	0.321				0.108	0.103	0.292
Income	−0.071	0.101	0.481				0.010	0.108	0.929
Ethnicity	−0.063	0.212	0.767				−0.095	0.219	0.663
House_type	0.413**	0.173	0.017				0.342**	0.175	0.050
Family_size	0.098	0.154	0.522				0.068	0.158	0.667
Major_energy_source	−0.118	0.130	0.365				−0.101	0.138	0.463
Second_major_energy	−0.309**	0.160	0.050				−0.317*	0.167	0.058
Summer_temp				−0.105	0.207	0.612	−0.235	0.219	0.283
Winter_temp				−0.083	0.183	0.651	−0.053	0.191	0.782
Summer_rain				−0.173	0.206	0.401	−0.013	0.219	0.954
Winter_rain				−0.411**	0.191	0.032	−0.271	0.202	0.181
Onset_monsoon				0.284	0.276	0.303	0.504*	0.288	0.080
Withdrawal_monsoon				−0.393*	0.212	0.063	−0.372*	0.219	0.090
CC_energy_availability				0.047	0.138	0.732	−0.001	0.146	0.995
CC_energy_demand				0.245*	0.128	0.056	0.184	0.132	0.164
HH_interv_cooking				0.176**	0.087	0.044	0.164*	0.093	0.077
HH_interv_heating				−0.278**	0.115	0.016	−0.273**	0.124	0.028
Comm_interv_awareness				−0.215	0.196	0.273	−0.127	0.211	0.548
Comm_interv_subsidy				0.442***	0.169	0.009	0.403**	0.179	0.024
Model diagnostics									
Log likelihood	−379.08			−388.94			−365.56		
LR chi2(12)	59.02			39.30			86.05		
Prob > chi2	0.000			0.0001			0.000		
McFadden's R2	0.0722			0.0481			0.105		
Number of obs.	323			323			323		

Note: Ordinal logistic regression was carried out separately for the three cases *a* , b, and c. *, ** and *** in the "Coefficeint" columns refer to significance level of 10 % ($p \leq 0.1$), 5 % ($p \leq 0.05$) and 1 % ($p \leq 0.01$), respectively.

up the preference category increases substantially. The same set of variables as in the individual *SCE-model* and *CCP-model* were found to be significant for the *Composite-model* except people's perception of changes in winter rainfall and influence of CC on household energy demand.

Discussion

Socio-economic data

Our choice of the socio-economic variables was based on literature review. As suggested by Butchers et al. (2020), careful attention has been given to capture the local energy context of Nepal. Most of the household energy is used for cooking in Nepal followed by lighting and other uses (MoF/GoN, 2023). People mostly use traditional fuels such as firewood, hay and dung cakes in the rural areas with very limited use of LPG and electric stoves whereas people in the urban areas mostly use LPG stoves with some electric appliances (CBS, 2021).

One of our respondents explained that 'guitha' (dried cow/buffalo dung cakes for direct combustion) is the only available option to her family for cooking and heating. Although her village is connected to the national electricity grid, but her family cannot afford to use electricity because of their poor financial condition. She reported a similar reluctance in the use of LPG stoves due to the same reason. Her family rears cows and buffalos and they prepare 'guitha' for free. She was not aware of the health issues that would arise due to extended use of 'guitha' for household use and did not believe that it would be harmful because she has seen the same thing in her kitchen from generations without anyone complaining (a mid-aged housewife from Laxminiya Rural Municipality of Dhanusha district in the Terai plains).

Unlike the developed countries, refrigerators and modern room heating/cooling technologies such as air conditioners, coolers and heaters are mostly limited to the upper-class people of urban areas only.

Table 5
Marginal effect estimates across the four preference values derived from a) socio-economic (*SCE*) model ; b) climate change perception (*CCP*) model and c) combined socio-economic and climate change perception (*Composite*) model.

Variables	a) SCE-Model				b) CCP-Model				c) Composite-Model			
	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
Physiograpy	−0.019	0.004	0.006	0.008					0.009	−0.002	−0.003	−0.004
Load_centre	0.080*	−0.018**	−0.027**	−0.035**					0.080**	−0.020*	−0.028**	−0.032**
Gender	−0.033	0.007	0.011	0.014					−0.031	0.008	0.011	0.013
Age	−0.004	0.001	0.001	0.002					−0.004	0.001	0.001	0.002
Literacy	−0.118***	0.026**	0.040***	0.052***					−0.108***	0.027**	0.038**	0.043***
Occupation	−0.024	0.005	0.008	0.011					−0.027	0.007	0.009	0.011
Income	0.018	−0.004	−0.006	−0.008					−0.002	0.001	0.001	0.001
Ethnicity	0.016	−0.004	−0.005	−0.007					0.024	−0.006	−0.008	−0.010
House_type	−0.103**	0.023**	0.035**	0.045**					−0.085*	0.021*	0.030*	0.034**
Family_size	−0.025	0.005	0.008	0.011					−0.017	0.004	0.006	0.007
Major_energy_source	0.029	−0.007	−0.010	−0.013					0.025	−0.006	−0.009	−0.010
Second_major_energy	0.077**	−0.017*	−0.026*	−0.034**					0.079*	−0.020*	−0.028*	−0.032*
Summer_temp					0.026	−0.005	−0.009	−0.012	0.059	−0.015	−0.021	−0.024
Winter_temp					0.021	−0.004	−0.007	−0.010	0.013	−0.003	−0.005	−0.005
Summer_rain					0.043	−0.008	−0.014	−0.021	0.003	−0.001	−0.001	−0.001
Winter_rain					0.102**	−0.019*	−0.034**	−0.049**	0.068	−0.017	−0.024	−0.027
Onset_monsoon					−0.071	0.013	0.024	0.034	−0.126*	0.031	0.044*	0.051*
Withdrawal_monsoon					0.098*	−0.018*	−0.033*	−0.047*	0.093*	−0.023	−0.032	−0.037*
CC_energy_availability					−0.012	0.002	0.004	0.006	0.000	0.000	0.000	0.000
CC_energy_demand					−0.061**	0.011	0.021*	0.029*	−0.046	0.011	0.016	0.018
HH_interv_cooking					−0.044**	0.008*	0.015**	0.021**	−0.041*	0.010*	0.014*	0.016*
HH_interv_heating					0.069**	−0.013**	−0.023	−0.033**	0.068**	−0.017*	−0.024**	−0.027**
Comm_interv_awareness					0.053	−0.010	−0.018	−0.026	0.032	−0.008	−0.011	−0.013
Comm_interv_subsidy					−0.110***	0.020**	0.037**	0.053***	−0.100**	0.025*	0.035**	0.040**

Note: *P1* denotes people's first preference responses “I don't know” or “No change”; *P2* denotes people's second preference responses “Transition to grid electricity only”; *P3* denotes people's third preference response “Transition to other renewables only”; *P4* denotes people's fourth preference responses “Transition to electricity and renewables”. *, ** and *** refer to significance level of 10 % ($p \leq 0.1$), 5 % ($p \leq 0.05$) and 1 % ($p \leq 0.01$), respectively.

The hilly regions are mostly cooler compared to the southern plains. Hence, cooling devices are generally not necessary. Traditional room heating (bonfires, charcoal fire in pans, *etc.*) are common in these areas. These days, some people with a strong financial status in the hilly areas have started using electric or LPG heaters. Hybrid solar water heating systems have also been piloted in some areas of Nepal recently (Thapa et al., 2022) but their sustainability is a big issue. On the other hand, the Terai plains are mostly hot throughout the year but only those households that can afford use table/ceiling fans mostly during summer.

It can be seen from Table 2 that the spread of the data across the different categories as well as across the different response classes is relatively well distributed. It is also evident that variables related to urbanization status, level of education, employment condition, ethnicity, living standards and availability of household energy sources are statistically significant as depicted by the *p*-values of Chi-square test. These results are as expected because the preferences of the local people are mostly governed by their level of awareness (which is explained by education), and financial capacity to move to better energy alternatives (which is explained by the level of urbanization, employment and living standards). Moreover, the underprivileged ethic groups do not have access to multiple energy options in Nepal as compared to the privileged classes (Lin & Kaewkhunok, 2021). As a result, the use of household energy, availability of modern and efficient energy technologies and willingness to adopt better options are rather limited in such underprivileged groups. These results are concurrent with other recent studies on household energy behaviour of Nepal such as Das et al. (2022) and Koirala and Acharya (2022). Moreover, Bhattarai et al. (2018) show doubt over whether the government subsidies and donations targeted at the rural poor and marginalized people are actually reaching them.

Climate change perception data

Similar to the socio-economic variables, the climate change perception variables have also been carefully chosen so that they depict the true context of Nepal encompassing the perceived changes in temperature, magnitude and timing of rainfall, impacts on the household energy use and the role of possible interventions at the household and community levels. It is to be noted that the climate of Nepal varies from subtropical to arctic over a short north-south span of <200 km (DHM/CCAFS, 2013). Because of the rugged terrain and hilly and mountainous topography, rainfall is largely influenced by factors such as orography, aspect (windward/leeward) and other micro-climatic conditions. Therefore, people living in such diverse climatic conditions have different perceptions of climate change and its impact on the household energy behaviour.

From a climate change perspective, change in summer temperature, timing and volume of monsoon, effectiveness of household interventions and community level interventions for reducing the climate-related impacts on household energy demand and availability have been identified as statistically significant variables across the classes (Table 3). Most people are aware that almost 100 % of Nepal's domestic electricity production is from hydropower which relies on the monsoon. As a result, people perceive the change in timing and volume of monsoon to have a considerable impact on the availability of energy (mostly electricity) in grid connected areas. The rural remote areas are also supplied with electricity generated by micro-hydropower supplied though local grids (AEPC/GoN, 2023). Hence, these smaller rivers are even more sensitive to the changes in monsoon. In addition, increased monsoon causes cloud cover for a longer period of time which could possibly impact the local rooftop solar power generation mainly for lighting the rural households.

One respondent during our field survey mentioned that his family has been cooking in LPG stoves since a long time. They find LPG stoves convenient because it does not produce smoke, the food is cooked relatively faster, the gas cylinders are conveniently available for refilling and they can easily afford one cylinder per month. Although being in an urban area with access to grid electricity, his family is hesitant to switch to electric stoves due to frequent power cuts. Interestingly, he is not aware of the impacts that climate change could have on (hydro) electricity generation and felt that the government is intentionally not generating enough electricity in the dry season despite the availability of tremendous volume of water in the rivers of Nepal (a mid-aged university graduate from Lalitpur Metropolitan in Kathmandu Valley).

People's energy transition preferences

Our results show that the same set of explanatory variables are statistically significant for the individual models as well as the combined model. Moreover, the model diagnostics show that the *Composite-model* is more appropriate in explaining people's energy transition preferences at the household level in Nepal.

Table 4 and Table 5 show that the statistically significant socio-economic variables related to urbanization status, level of education, living standard, availability of household energy sources, and employment status are indicative of two key points: the level of awareness and financial condition for transitioning to better energy forms (similar to the findings of Matavel et al. (2023) in Mozambique). People living in the urban areas (for instance, Kathmandu City of Nepal and other towns) have a general tendency to prefer switching to better renewable forms of energy. This is because, in most of the cases, these households are already connected to the national electricity grid. Additionally, they are in a relatively better financial condition and are used to fuel stacking as a result of the chaotic and disintegrated energy landscape of energy that Nepal had to go through (Das et al., 2022; Movik & Allouche, 2020).

However, people in the semi-urban and rural areas of the country have a lower level of literacy. Rural households are still largely dependent on conventional fuels (CBS, 2021). Additionally, they are either already reliant on off-grid energy technologies such as rooftop solar PVs (Gautam et al., 2015) or micro-hydropower projects (Yadoo & Cruickshank, 2012) or they are not in a financially stable position to make these changes. Moreover, studies have demonstrated that off-grid electricity systems in South Asia typically lack systematic distribution models and are mostly reliant on community-centred projects without proper linkage to income generating opportunities, sustainable market and poor technological management (Palit & Bandyopadhyay, 2016). National electricity grid has a limited reach in the remote areas of Nepal which are difficult to access (AEPC/GoN, 2023). Some studies have recommended increasing electricity tariffs to increase the efficiency of Nepal's electricity sector (Sovacool et al., 2013). However, such an intervention could prove counter-productive especially among the rural poor who are already in a difficult financial situation to afford electricity at the current price. A similar finding has been reported by Navarro-Espinosa and Thomas-Galán (2023) considering people in the lowest socio-economic category of Chile. Besides, people refrain from diverting their existing energy beliefs and practices and do not want to step out of their comfort zones (Chung & Kim, 2018; Nshimiyimana et al., 2024).

One of our survey respondents mentioned that he is unaware of the available renewable energy technologies applicable for daily household use. He also expressed his happiness that he took part in the survey with our team because he got to learn many new things about renewable energy. He further seemed willing to progress to clean renewable technologies at the household level that he could afford to build a better and sustainable energy future for Nepal (a resident from Banepa Municipality in Kavrepalanchowk district in mid hills region).

On the climate change end, the timing and volume of monsoon have been identified as statistically significant variables for people's energy transition preference (Table 4 and Table 5). Hence, people perceive hydropower to be the most impacted due to climate change in the future. Studies in the Hindu Kush Himalayan (HKH) region have shown that the performance of hydropower projects are likely to be adversely impacted by climate change (Shrestha et al., 2021). Conversely, some studies such as Bhattarai et al. (2022), Marahatta, Devkota, and Aryal (2021) and Marahatta et al. (2022) have projected increased hydropower generation possibilities as a result of climate change in the future addressing due challenges. Moreover, a recent study has shown that two-thirds of the untapped hydropower potential lies in the HKH region (Xu et al., 2023) among which Nepal has a possibility to contribute significantly. Nepal has a unique Himalayan climate with a massive economically feasible hydropower potential of 50,000 MW (Jha, 2010; Sharma & Awal, 2013). But the country has been able to harness only a miniscule fraction of the potential because of its poor economic condition (MoF/GoN, 2023; NEA/GoN, 2023). Recent studies have even quantified energy security of Nepal to find that it is in a 'pseudo energy-secure' condition (Bhattarai et al., 2024b). Such a resource-underutilized situation is common across many developing countries of Africa, Latin America and Asia (Hamududu & Killingtveit, 2016; Mtilatila et al., 2020; Uamusse et al., 2020).

Additionally, climate change studies such as Devkota and Bhattarai (2018) and (Lutz et al., 2022) have reported increasing extremes in temperature in Nepal and the entire HKH region. Identification of summer temperature as a significant variable in determining people's energy preferences could be linked to people's perception of summers becoming hotter (Marahatta, Aryal, et al., 2021). Because of the apprehension of changing monsoon and temperature, people also consider that climate change is likely to impact the household energy demand which can be addressed by regulated subsidies. Many instances of past failures of subsidies in the renewable energy sector have been reported in Nepal (Balachandra, 2015; Bhandari et al., 2017; Dhital et al., 2016). However, the effectiveness can be considerably enhanced by investing in awareness building on the benefits of using renewable energy at the community level.

Another survey respondent admitted not knowing about the household sector being the largest energy consuming sector of Nepal. She was aware of the health and environmental impacts of cooking using traditional fuels and LPG. She also showed concern about their impacts on climate change in the long run. But, to our surprise, she denied her willingness to completely switch to renewables for household energy because they were expensive and there were not enough and convincing awareness campaigns conducted at the community level (a university student from Lalitpur Metropolitan of Lalitpur District in the mid hills region).

Studies have shown that the energy policy trajectory of Nepal has been progressive over the last few decades (Bhattarai et al., 2024a). The rural energy policies of Nepal are more inclined towards increasing the penetration of off-grid renewable energy technologies in rural and remote areas whereas the other policies and strategies are centerd towards increasing access to quality grid hydroelectricity in Nepal. The rural energy policies of Nepal have undergone many revisions (2006, 2009, 2013 , 2016 and 2022) over the last couple of decades (AEPC/GoN, 2023; MoPE/GoN, 2016). The Seventh National Plan 1985 and Eight National Plan 1992 envisioned hydropower development and alternative renewable energy while the Hydropower Development Policy 1992 and 2001 and Water Resources Strategy 2002 promoted (large and small) hydropower development for meeting industrial, domestic and transportation demands (AEPC/GoN, 2023; HMG/N, 1992a; HMG/N, 1992b; HMG/N, 2001; HMG/N, 2002; Sanjel & Baral, 2020). Furthermore, the Second and Third Nationally Determined Contribution to UNFCC (MoFE/GoN, 2021) and the Nepal's Long-term Strategy for Net Zero Emissions (GoN, 2021) have strongly focused on the increment of renewables in the energy generation mix in the future. However, the effectiveness of such policies has been limited in Nepal, mainly due to administrative hassles in the implementation side and lack of proper 'energy ecosystem' development in the generation and use of renewables (Bhattarai, Maraseni, Apan, & Devkota, 2023). Moreover, we agree with the recommendations set out by Bhattarai et al. (2024a) on improving supply-side management, demand-side management, multi-sector collaboration, and political stability and good governance for a sustainable energy future of Nepal.

A well-educated self-employed businessman (one of the survey respondents) from Kathmandu Metropolitan city felt great pride in mentioning that he had installed two sets of electric wiring in his house: one for the use of grid electricity (alternating current) while the second for the use of solar electricity from his rooftop solar PV panel (direct current). He further mentioned that it was quite expensive from his end and did not get any rebates for the installation. Nevertheless, he felt a great deal of satisfaction in being able to generate electricity at his house through solar energy and rely less on the state-supplied grid electricity. However, he showed his frustration over the government of Nepal in not supporting him to install net metering systems in his house despite a lot of effort from his side. But he is hopeful that the state will soon implement supportive policies for such technological advancements to increase the share of renewables in the household energy sector of Nepal.

García-Gusano et al. (2017) highlights that energy transition comes with structural changes – rearrangement in policies, economies and societies leading to redistribution of power, resources and risks. Zhou et al. (2023) recommend strengthening renewable energy outputs, green technological innovation and financial development for reducing sectoral risks to a sustainable carbon-neutral society in Asia. Taking the case of South Korea, Cho et al. (2024) show that only technological advancements might not be adequate to attain future carbon-neutrality targets. The current trend of reduction in the use of traditional fuels for cooking at the cost of increased use of imported LPG at high prices in Nepal (MoF/GoN, 2023) should be discouraged at the policy and implementation levels. In addition, scholars have stressed regular revisions of the policies following a bottom-up pathway incorporating conflict sensitivity assessment to minimize disproportionate impacts on the stakeholders (Lomax et al., 2023; Pandey et al., 2021; Wu, 2020). Hence, Nepal needs to learn from the past mistakes and focus more on strengthening the energy policies to create a conducive environment encouraging generation of domestic renewable energy. The Government of Nepal has identified hydropower as the lead renewable energy technology in Nepal (WECS/GoN, 2013) which needs to be supplemented by other off-grid alternative renewables. Extension of the national electricity grid to the rural remote areas need to be the prime focus of the government to provide impetus to the renewable energy transition in Nepal. Moreover, proper check and balance mechanisms need to be in place to ensure that community level energy subsidies reach the actual needy. Likewise, effective energy credit measures and mass interventions of energy efficient devices not only for lighting but also for cooking to completely displace the usage of traditional fuels is seen as an utmost necessity for achieving economic as well as environmental well-being of the country sustainably.

There were some limitations in our study. Firstly, increasing the sample size could provide a more comprehensive coverage of the study area. Additionally, utmost care has been taken to collect data from different locations occupying diverse socio-economic respondents and implemented randomization to avoid sample bias. Moreover, perception and preferences are qualitative data which are relative in nature. Therefore, respondents belonging to similar socio-economic categories and climatic contexts can also have different perceptions and preferences. Furthermore, the perceptions and preferences of the same respondent can vary over time. We consider this as the measurement error that we might have in this study which could be overcome by longitudinal survey across different times. Additionally, we acknowledge that considering confounding variables could provide a more nuanced understanding of the relationships between the predictor-response variables. However, assessing the impacts of potential confounding variables (such as specific local environmental conditions, in−/out-migration, regional economic policies, and other socio-demographic factors, among others) on the household energy behaviour is beyond the scope of this work. They could be plausible areas of future research.

Conclusion

Realizing the need for research into the assessment of the combined effects of socio-economic factors and climate change perception on energy preferences in developing nations, we carried out this study taking the case of a South Asian developing country – Nepal – focusing on household level energy use behaviour.

Results show that 151 (47 %) respondents preferred no change from their existing conditions; 74 (23 %) opted solely to rely on grid electricity; 47 (14 %) chose transitioning to renewables only while 51 (16 %) preferred changing to a mix of grid-electricity and renewables. Moreover, the *Composite-model* outperformed the others two (socio-economic, *SCE* and climate change perception, *CCP*) models with relatively better model diagnostics. Most of the identified influencing parameters were common across the three models. The socio-economic factors pertaining mainly to urbanization status, education level, and availability of energy choices for households were found to be statistically significant with relatively higher marginal estimates. This indicated that creating awareness among the people and building economic motivation play key roles in energy transition preference of Nepalese households. Similarly, climate change perception determinants related to timing of monsoon, amount of winter rainfall, alterations in cooking and space heating energy demands, and community level energy subsidies were found to be statistically significant.

Hence, we infer that the socio-economic and climate change perception parameters need to be dealt with holistically to drive the renewable energy transition of Nepal effectively. Moreover, our research suggests that the combination of socioeconomic and climate perception factors yields comprehensive, meaningful, and adoptable outcomes for decision makers at all levels. The current energy prices are still unaffordable to a major share of the national population. Current fossil-fuel based technologies are not sustainable leading to increased trade deficits and have long-term environmental implications. The renewable energy potential of Nepal needs to be harnessed to help the country transition to a cleaner and sustainable energy future. However, the country does not possess adequate technical and financial capacity to adapt to changing energy conditions. Furthermore, there are high chances that subsidies for renewable energy may increase the disparity among the rich and poor. These issues act as barriers to the renewable energy transition of Nepal.

We conclude that, at the state level, Nepal should continuously update its energy policies to create a conducive environment for sustainable renewable energy transition. Promotion of domestic hydropower generation should lead the way with the addition of other renewable technologies in the generation mix. Relying on off-grid smaller energy technologies could be a temporary measure but the country should focus on extending the national electricity grid to the rural remote areas to penetrate the rural household energy sector of Nepal. In addition, it is seen that Nepal needs to focus on providing impetus to building community awareness and maximizing effectiveness of subsidies and other financial incentives. Hence, our contribution lies in this important policy-science-society interface which will be insightful to the decision makers in the energy sector of developing countries in general and Nepal in particular.

Longitudinal survey could be an extension of this research to examine the time-varying parameters and their likely influence on people's energy use behaviour. In addition, there are a number of unanswered questions in our study, such as those related to energy democracy and justice, bottom-up approaches in policy formulation, stakeholder involvement in development of energy generation projects, public concerns related to good governance and their impacts on the household energy sector. Furthermore, assessing the influence of other confounding variables could provide a better understanding of the predictor-response relationship. Addressing these concerns could serve as future research avenues.

CRediT authorship contribution statement

Utsav Bhattarai: Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Tek Maraseni:** Writing – review & editing, Supervision, Resources, Methodology, Conceptualization. **Laxmi Prasad Devkota:** Writing – review & editing, Validation, Supervision, Methodology. **Armando Apan:** Writing – review & editing, Validation, Supervision.

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Declaration of competing interest

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

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Appendix A

Table A1
Independent explanatory and response variables and their classification adopted in this study.

S·N	Description	Variables	Classes	Code	Justification
a) Explanatory socio-economic variables					
1	Type of terrain	*Physiography*	High hills	1	We excluded High Mountains among the four physiographic zones of Nepal as it is almost inhabited. Each of these regions showcases distinct patterns of energy generation and consumption. Therefore, this classification has been adopted
			Mid hills	2	
			Terai (plains)	3	

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Table A1 (*continued*)

S·N	Description	Variables	Classes	Code	Justification
					to encompass the diverse energy dynamics across the country.
2	Level of urbanization	*Load_centre*	Kathmandu Other towns Others	1 2 3	This variable primarily represents the accessibility and utilization of grid electricity in Nepal. Kathmandu (the capital city) is characterized by a significantly high population density, extensive electricity infrastructure and large energy consumption. In contrast, other towns have lower population densities and smaller electricity consumption rates. The remaining areas (Others) are considered less significant for electricity use.
3	Gender of the respondent	*Gender*	Female Male	1 2	These are obvious natural categories.
4	Age of the respondent	*Age*	20–35 years 35–50 years > 50 years	1 2 3	This variable pertains not to the age of the household head, but to the age of the individuals who possess greater awareness of energy-related matters within the household. Category '1' encompasses young individuals, including students and those in the early stages of their careers. Likewise, the second category '2' represents middle-aged people who have established careers and exhibit maturity in household decision-making. The third category '3' pertains to retirees or those who work less in comparison to the other two groups.
5	Education level of the respondent	*Literacy*	Illiterate Primary school/ informal education Secondary / high school University	1 2 3 4	These categories are selected to examine people's awareness level based on their education.
6	Type of employment of the respondent	*Occupation*	Unemployed/ retired Farming/ livestock rearing Self-employed Academic/ government service Private organization	1 2 3 4 5	Socioeconomic circumstances and occupation shape individual's perspectives, lifestyles and household behaviours. People with stable occupations are more likely to make deliberate and sustainable household choices whereas those unemployed or engaging in unstable professions are more inclined towards to temporary decisions. Our classification scheme for this variable aims to capture the responses of these distinct groups.
7	Annual household income (US$)	*Income*	< 692 692–1154 1154–1961 > 1961	1 2 3 4	We have considered the income thresholds aligning them with the World Bank's categorization of: (category 1) the international poverty line (US$ 1.90 per day), and the income brackets of (category 2) lower middle-income (US$ 3.20 per day) and (category 3) upper-middle income countries (US$ 5.50 per day). Considering the foreign exchange rate of US$ 1 ≈ NRs 130 during the time this research was conducted for Nepal, an annual income of NRs 90,000 which is equivalent to US$ 692 per year corresponds to category 1; NRs 150,000 which is equivalent to US$1154 per year corresponds to category 2; and NRs 255,000 is equivalent to US$ 1961 per year corresponds to category 3.
8	Ethnic background of the household	*Ethnicity*	Marginalized/ Underprivileged Indigenous Brahmin/ Chhetri	1 2 3	These categories correspond to the caste/ethnicity structure prevalent in Nepal in which the distinction is made between the privileged, indigenous and underprivileged communities of the society. Such a segregation have led to disparities in access to amenities, services, information and household behaviours between these groups which we aim to consider in our analysis.
9	Living standard of the household	*House_type*	Mud hut/ cottage Bamboo/ wood Bricks and mud mortar Bricks and cement	1 2 3 4	The type of house reflects the overall economic condition of the family. A well-to-do family generally have their houses made of bricks and cement while the extremely poor ones live in temporary structures such as mud huts and cottages. Moreover, the energy use pattern is also highly dependent on the type of houses people have. The bricks and cement houses are generally located in the urban areas which are electrified whereas the poor people rely on traditional fuels for meeting their domestic energy needs.
10	Household size and type of family	*Family_size*	Nuclear (≤4 members) Extended (4–6 members) Joint (> 6 members)	1 2 3	The extended family structure (including grandparents) is prevalent in most semi-urban and rural areas of Nepal whereas the nuclear family model has lately become predominant in urban settings. Nevertheless, joint family setups, including grandparents, uncles, aunts, nephews, and nieces living together are still very common in the rural and remote areas of the country. Size of the family is likely to impact the household energy behaviour and we aim to incorporate this phenomenon into our analysis through this classification.
11	Availability of household energy options	*Major_energy_source*	Firewood/ dung/ agriculture residue	1	These categories have been devised based on the most common types of household fuels in Nepal. The accessibility,

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Table A1 (*continued*)

S·N	Description	Variables	Classes	Code	Justification
			Petroleum (kerosene)	2	cost, health impacts, environmental implications and individual preferences considerably differ among the households utilizing various energy sources. We aim to consider such a variation into our analysis through information segregated for these classes.
			Liquified petroleum gas (LPG)	3	
			Grid-electricity	4	
			Renewables	5	
12	Availability of alternate household energy options	*Second_major_energy*	Petroleum (kerosene)	1	These categories have been devised based on the most common types of household fuels in Nepal. The accessibility, cost, health impacts, environmental implications and individual preferences considerably differ among the households utilizing various energy sources. We aim to consider such a variation into our analysis through information segregated for these classes.
			Liquified petroleum gas (LPG)	2	
			Grid-electricity	3	
			Renewables	4	
b) Explanatory climate change perception variables					
1	Change in the summer temperature on an average	*Summer_temp*	Increased	1	Temperature and rainfall are two of the most important climatic variables that are used for climate change assessments. Moreover, Nepal has a diverse climate ranging from sub-tropical to alpine. There are distinct summers (which are mostly hot) and winters (which are mostly cold). High temperatures during the summer and low temperatures during the winter are of special importance in Nepal's climatic system. Moreover, temperature has a great contribution mostly in agriculture and in the overall availability of natural resources. Hence, people's perception of whether they have felt any change in the summer and winter temperatures lately compared to twenty years ago is an important factor for this study which is expected to largely influence the people's preferences of energy transition.
			No change	2	
			Decreased	3	
2	Change in the winter temperature on an average	*Winter_temp*	Increased	1	
			No change	2	
			Decreased	3	
3	Change in the amount of rainfall during summer	*Summer_rain*	Increased	1	Similarly, the rainfall pattern is also quite distinct in Nepal with very wet monsoons (June to September) and dry during the rest of the year. As Nepal's electricity is completely reliant on hydropower, the amount of monsoon and its timing is very important. Most of the hydropower projects of Nepal are run-of-river types which are completely reliant on the monsoon water. Therefore, people's perception of whether they have felt any change in the rainfall compared to twenty years ago is an important factor for this study which is expected to largely influence the people's preferences of energy transition.
			No change	2	
			Decreased	3	
4	Change in the amount of rainfall during winter	*Winter_rain*	Increased	1	
			No change	2	
			Decreased	3	
5	Change in the timing of monsoon start	*Onset_monsoon*	Increased	1	
			No change	2	
			Decreased	3	
6	Change in the timing of monsoon end	*Withdrawal_monsoon*	Increased	1	
			No change	2	
			Decreased	3	
7	Impact of climate change on household energy availability	*CC_energy_availability*	Very Low	1	These variables are important because there is a large variation in how people perceive climate change across the different socio-economic categories in Nepal. Moreover, most people are aware of the country's dependency of electricity on hydropower, which in turn is impacted by the change in the overall hydrology. Additionally, change in climatic conditions could lead to altered availabilities of traditional fuels such as firewood and agricultural residue which form the major energy source for the rural domestic sector. Furthermore, impact of climate change on the energy requirement for different domestic purposes is an important aspect for this study.
			Low	2	
			Moderate	3	
			High	4	
			Very high	5	
8	Impact of climate change on energy demand	*CC_energy_demand*	Very Low	1	
			Low	2	
			Moderate	3	
			High	4	
			Very high	5	
9	Effectiveness of household level intervention in cooking to reduce the impact of climate change	*HH_interv_cooking*	Very Low	1	People's perceptions of their existing energy behaviour in cooking is a major factor in deciding their household energy transition preferences. Additionally, it is also interesting to understand how people have related their energy sources and technologies for cooking and whether making any interventions at the household level will make any contribution to reduce the impact of climate change.
			Low	2	
			Moderate	3	
			High	4	
			Very high	5	
10	Effectiveness of household level intervention in space heating to reduce the impact of climate change	*HH_interv_heating*	Very Low	1	People's perception of their existing energy behaviour in space heating is another major factor in deciding their household energy transition preferences. In addition, a better understanding of the relation between energy sources and technologies for space heating will help identify the necessary interventions required to contribute in reduction of the impact of climate change.
			Low	2	
			Moderate	3	
			High	4	
			Very high	5	
11	Effectiveness of increasing energy awareness at the community level to reduce the impact of climate change on household energy	*Comm_interv_awareness*	Very Low	1	In addition to household level energy technologies, off-grid systems at the community level also play a major role in people's energy transition preference. Raising awareness at the community level has high impacts on promoting such locally gridded technologies which reduce the reliance on the central (electricity) grid as well as motivate people to use clean and renewable energy. Community level efforts have
			Low	2	
			Moderate	3	
			High	4	
			Very high	5	

(*continued on next page*)

Table A1 (*continued*)

S·N	Description	Variables	Classes	Code	Justification
					been lagging behind in Nepal despite tremendous government efforts. Therefore, raising awareness has been considered an important intervention which direct impacts on the reduction of the impacts of climate change.
12	Effectiveness of increasing subsidy for energy efficiency at the community level to reduce the impact of climate change on household energy	*Comm_interv_subsidy*	Very Low	1	Additionally, many studies in the past have shown that subsidies for the household and community level energy systems have not been as effective as anticipated. Various
			Low	2	reasons have been identified for this ineffectiveness.
			Moderate	3	Moreover, if such subsidies can be effectively implemented,
			High	4	they would contribute largely towards the development of
			Very high	5	efficient clean energy systems which leads to mitigation of the climate change impacts. This perspective of the local people has been addressed by this variable which would govern their energy transition preference.
	Response variable				This is the dependent variable which has been
1	People's preference of transitioning to improved household energy options	*Preference*	Not aware/no change	1	conceptualized to be determined by a number of explanatory
			To grid-electricity only	2	variables discussed above. The people's responses indicate the variation in choice of transitioning to better energy
			To other renewables only	3	alternatives for domestic consumption. Moreover, such a categorization is able to capture people's willingness to
			To grid-electricity and other renewables	4	choose the best option for their socio-economic condition as well as future energy scenario due to climate change. In addition, segregation of the responses by different socio-economic categories provides insight into which areas need to be attended to by the state for a sustainable energy transition in Nepal. As studies have shown that large hydropower (grid-electricity) and other renewables (micro-hydro, solar, wind and hybrid systems) are the possible feasible energy options in Nepal, these have been selected as the response categories of this variable.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esd.2024.101505.

References

Abbas, K., Butt, K. M., Xu, D., Ali, M., Baz, K., Kharl, S. H., & Ahmed, M. (2022). Measurements and determinants of extreme multidimensional energy poverty using machine learning. *Energy, 251*, Article 123977. https://doi.org/10.1016/j.energy.2022.123977

Acharya, R., Maraseni, T. N., & Cockfield, G. (2019). Local users and other stakeholders' perceptions on the identification and prioritization of ecosystem services in fragile mountains: A case study of Chure region of Nepal. *Forests, 10*, 421. https://doi.org/10.3390/f10050421

Acosta, A., Nicolli, F., & Karfakis, P. (2021). Coping with climate shocks: The complex role of livestock portfolios. *World Development, 146*. https://doi.org/10.1016/j.worlddev.2021.105546

Adedoyin, F. F., Bekun, F. V., & Alola, A. A. (2020). Growth impact of transition from non-renewable to renewable energy in the EU: The role of research and development expenditure. *Renewable Energy, 159*, 1139–1145. https://doi.org/10.1016/j.renene.2020.06.015

Adha, R., Hong, C., Yang, S., & Muzayyanah, S. (2024). Re-Unveiling the energy efficiency impact: Paving the way for sustainable growth in ASEAN countries. *Sustainable Development. Portico*. https://doi.org/10.1002/sd.3005

AEPC/GoN. (2023). *Progress at a Glance: Year in Review FY 2079/80 (2022/23)*. Kathmandu, Nepal: Alternative Energy Promotion Centre. www.aepc.gov.np.

Amrutha, A. A., Balachandra, P., & Mathirajan, M. (2018). Model-based approach for planning renewable energy transition in a resource-constrained electricity system—A case study from India. *International Journal of Energy Research, 42*(3), 1023–1039. https://doi.org/10.1002/er.3892

Andreas, J. J., Burns, C., & Touza, J. (2018). Overcoming energy injustice? Bulgaria's renewable energy transition in times of crisis. *Energy Research & Social Science, 42*, 44–52. https://doi.org/10.1016/j.erss.2018.02.020

Anik, A. R., Begho, T., Sharna, S. C., Eory, V., & Rahman, M. M. (2022). Toward improving nitrogen use efficiency in rice production: The socio-economic, climatic and technological determinants of briquette urea adoption. *Renewable Agriculture and Food Systems, 37*(5), 417–428.

Bahn, O., De Bruin, K., & Fertel, C. (2019). Will adaptation delay the transition to clean energy systems? An analysis with ad-merge. *Energy Journal, 40*(4), 235–253. https://doi.org/10.5547/01956574.40.4.obah

Balachandra, P. (2015). Review of energy access, poverty, and development: The governance of small-scale renewable energy in developing Asia. *The Energy Journal, 360*.

Ballantyne, A. G., Wibeck, V., & Neset, T. S. (2016). Images of climate change – A pilot study of young people's perceptions of ICT-based climate visualization. *Climatic Change, 134*(1–2), 73–85. https://doi.org/10.1007/s10584-015-1533-9

Baniya, R., Talchabhadel, R., Panthi, J., Ghimire, G. R., Sharma, S., Khadka, P. D., Shin, S., Pokhrel, Y., Bhattarai, U., Prajapati, R., & Thapa, B. R. (2023). Nepal Himalaya offers considerable potential for pumped storage hydropower. *Sustainable Energy Technologies and Assessments, 60*, Article 103423. https://doi.org/10.1016/j.seta.2023.103423

Bhandari, B., Lee, K. T., Chu, W. S., Lee, C. S., Song, C. K., Bhandari, P., & Ahn, S. H. (2017). Socio-economic impact of renewable energy-based power system in mountainous villages of Nepal. *International Journal of Precision Engineering and Manufacturing - Green Technology, 4*(1), 37–44. https://doi.org/10.1007/s40684-017-0005-2

Bhandari, R., Saptalena, L. G., & Kusch, W. (2018). Sustainability assessment of a micro hydropower plant in Nepal. *Energy, Sustainability and Society, 8*(3). https://doi.org/10.1186/s13705-018-0147-2

Bhat, K. S., Bachhiesl, U., Feichtinger, G., & Stigler, H. (2019). A techno-economic model-based analysis of the renewable energy transition in the Indian subcontinent region. *Elektrotechnik und Informationstechnik, 136*(8), 361–367. https://doi.org/10.1007/s00502-019-00773-w

Bhattarai, D., Somanathan, E., & Nepal, M. (2018). Are renewable energy subsidies in Nepal reaching the poor? *Energy for Sustainable Development, 43*, 114–122. https://doi.org/10.1016/j.esd.2018.01.001

Bhattarai, U., Devkota, L. P., Marahatta, S., Shrestha, D., & Maraseni, T. (2022). How will hydro-energy generation of the Nepalese Himalaya vary in the future? A climate change perspective. *Environmental Research, 214*, Article 113746. https://doi.org/10.1016/j.envres.2022.113746

Bhattarai, U., Devkota, R., Maraseni, T., Devkota, L., & Marahatta, S. (2023). Attaining multiple sustainable development goals through storage hydropower development amidst community vulnerabilities. *Sustainable Development*. https://doi.org/10.1002/sd.2634

Bhattarai, U., Maraseni, T., Apan, A., & Devkota, L. P. (2023). Rationalizing donations and subsidies: Energy ecosystem development for sustainable renewable energy transition in Nepal. *Energy Policy, 177*, Article 113570. https://doi.org/10.1016/j.enpol.2023.113570

Bhattarai, U., Maraseni, T., Devkota, L., & Apan, A. (2024b). A Composite Indicator-based Method to Assess the Energy Security of Nepal and prospects of Cross-border Electricity sharing in South Asia. *Environment and Development*. https://doi.org/10.1016/j.envdev.2024.101002

Bhattarai, U., Maraseni, T., Devkota, L. P., & Apan, A. (2023). Application of machine learning to assess people's perception of household energy in the developing world: A case of Nepal. *Energy and AI, 14*, Article 100303. https://doi.org/10.1016/j.egyai.2023.100303
Bhattarai, U., Maraseni, T., Devkota, L. P., & Apan, A. (2024a). Evaluating four decades of energy policy evolution of a south asian country – Nepal: a comprehensive review. *Sustainable Development*. https://doi.org/10.1002/SD.3053
Bigerna, S., Bollino, C. A., & Polinori, P. (2021). Convergence in renewable energy sources diffusion worldwide. *Journal of Environmental Management, 292*. https://doi.org/10.1016/j.jenvman.2021.112784
Borozan, D. (2022). Asymmetric effects of policy uncertainty on renewable energy consumption in G7 countries. *Renewable Energy, 189*, 412–420. https://doi.org/10.1016/j.renene.2022.02.055
Braito, M., Flint, C., Muhar, A., Penker, M., & Vogel, S. (2017). Individual and collective socio-psychological patterns of photovoltaic investment under diverging policy regimes of Austria and Italy. *Energy Policy, 109*, 141–153. https://doi.org/10.1016/j.enpol.2017.06.063
Bremer, J., & Linnenluecke, M. K. (2017). Determinants of the perceived importance of organisational adaptation to climate change in the Australian energy industry. *Australian Journal of Management, 42*(3), 502–521. https://doi.org/10.1177/0312896216672273
Butchers, J., Williamson, S., Booker, J., Tran, A., Karki, B., & Gautam, B. (2020). *Understanding sustainable operation of micro-hydropower: A field study in Nepal*. https://doi.org/10.5523/bris.1k9cigxbcdiye22kuay4wbt5yu
CBS. (2021). *Nepal in figures 2021*. Kathmandu, Nepal: Central Bureau of Statistics. www.cbs.gov.np.
Chhogyel, N., Kumar, L., Bajgai, Y., & Hasan, M. K. (2020). Perception of farmers on climate change and its impacts on agriculture across various altitudinal zones of Bhutan Himalayas. *International journal of Environmental Science and Technology, 17* (8), 3607–3620. https://doi.org/10.1007/s13762-020-02662-8
Cho, S., Jeong, Y. S., & Huh, J. H. (2024). Is South Korea's 2050 Carbon-Neutral scenario sufficient for meeting greenhouse gas emissions reduction goal? *Energy for Sustainable Development, 80*, Article 101447. https://doi.org/10.1016/j.esd.2024.101447
Chung, J. B., & Kim, E. S. (2018). Public perception of energy transition in Korea: Nuclear power, climate change, and party preference. *Energy Policy, 116*, 137–144. https://doi.org/10.1016/j.enpol.2018.02.007
Cloke, J., Mohr, A., & Brown, E. (2017). Imagining renewable energy: Towards a Social Energy Systems approach to community renewable energy projects in the Global South. *Energy Research and Social Science, 31*, 263–272. https://doi.org/10.1016/j.erss.2017.06.023
Das, I., Rogers, B., Nepal, M., & Jeuland, M. (2022). Fuel stacking implications for willingness to pay for cooking fuels in peri-urban Kathmandu Valley, Nepal. *Energy for Sustainable Development, 70*, 482–496. https://doi.org/10.1016/j.esd.2022.08.017
Debnath, K. B., & Mourshed, M. (2024). Although feasible, falling renewables costs might not benefit Bangladesh's energy sector's decarbonisation: Is this another 'debt-fossil fuel production trap'? *Energy for Sustainable Development, 79*, Article 101416. https://doi.org/10.1016/j.esd.2024.101416
Deisenroth, M. P., Faisal, A. A., Ong, C., & Soon.. (2020). *Mathematics for machine learning* (1st ed.) (1st ed., Vol. 1). Cambridge University Press https://mml-book.com.
Devkota, R., Bhattarai, U., Devkota, L., & Maraseni, T. N. (2020). Assessing the past and adapting to future floods: A hydro-social analysis. *Climatic Change, 163*(2), 1065–1082. https://doi.org/10.1007/s10584-020-02909-w
Devkota, R. P., & Bhattarai, U. (2018). Assessment of climate change impact on floods from a techno-social perspective. *Journal of Flood Risk Management, 11*, S186–S196. https://doi.org/10.1111/jfr3.12192
Dhital, R. P., Ito, Y., Kaneko, S., Komatsu, S., Mihara, R., & Yoshida, Y. (2016). Does institutional failure undermine the physical design performance of solar water pumping systems in rural Nepal? *Sustainability (Switzerland), 8*(8). https://doi.org/10.3390/su8080770
DHM/CCAFS. (2013). Agroclimatic atlas of Nepal. In *Department of Hydrology and Meteorology (DHM), Ministry of Science, Technology and Environment, Government of Nepal and Climate Change Agriculture and Food Security CGIAR-CCAFS Regional (IGP) Program Unit*.
Dhungana, N., Silwal, N., Upadhaya, S., Khadka, C., Regmi, S. K., Joshi, D., & Adhikari, S. (2020). Rural coping and adaptation strategies for climate change by Himalayan communities in Nepal. *Journal of Mountain Science, 17*(6), 1462–1474. https://doi.org/10.1007/s11629-019-5616-3
Dominguez, C., Orehounig, K., & Carmeliet, J. (2021). Understanding the path towards a clean energy transition and post-electrification patterns of rural households. *Energy for Sustainable Development, 61*, 46–64. https://doi.org/10.1016/j.esd.2021.01.002
EC. (2014). 2030 climate and energy policy framework – Conclusions. *European Council, Brussels*, (24 October 2014).
Evensen, D., & Brown-Steiner, B. (2018). Public perception of the relationship between climate change and unconventional gas development ('fracking') in the US. *Climate Policy, 18*(5), 556–567. https://doi.org/10.1080/14693062.2017.1389686
Franco, M. A. J. Q., & Taeighagh, A. (2024). Sustainable energy adoption in poor rural areas: A comparative case perspective from the Philippines. *Energy for Sustainable Development, 79*, Article 101389. https://doi.org/10.1016/j.esd.2024.101389
García-Gusano, D., Iribarren, D., & Garraín, D. (2017). Prospective analysis of energy security: A practical life-cycle approach focused on renewable power generation and oriented towards policy-makers. *Applied Energy, 190*, 891–901. https://doi.org/10.1016/j.apenergy.2017.01.011
Gautam, B. R., Li, F., & Ru, G. (2015). Assessment of urban roof top solar photovoltaic potential to solve power shortage problem in Nepal. *Energy and Buildings, 86*, 735–744. https://doi.org/10.1016/j.enbuild.2014.10.038
Gautam, D., & Bolia, N. (2024). Understanding consumer choices and attitudes toward electric vehicles: A study of purchasing behavior and policy implications. *Sustainable Development, 1–21*. https://doi.org/10.1002/sd.2939
Ghimire, L. P., & Kim, Y. (2018). An analysis on barriers to renewable energy development in the context of Nepal using AHP. *Renewable Energy, 129*, 446–456. https://doi.org/10.1016/j.renene.2018.06.011
Ghosh, M., & Ghosal, S. (2020). Determinants of household livelihood vulnerabilities to climate change in the himalayan foothills of West Bengal, India. *International Journal of Disaster Risk Reduction, 50*. https://doi.org/10.1016/j.ijdrr.2020.101706
GoN. (2021). *Nepal's Long-term Strategy for Net-zero Emissions*. Government of Nepal.
Gümüş, Y. K. (2015). How secure is the EU energy policy after the Ukraine crisis? *International Journal of Energy Economics and Policy, 5*(4), 1016–1021.
Haldar, A., Sethi, N., Jena, P. K., & Pradhan, P. C. (2023). Towards achieving sustainable development goal 7 in sub-Saharan Africa: Role of governance and renewable energy. *Sustainable Development, 31*, 2446–2463. https://doi.org/10.1002/sd.2521
Hamilton, L. C. (2012). *Statistics with Stata: Version 12*. Cengage Learning.
Hamududu, B. H., & Killingtveit, Å. (2016). Hydropower production in future climate scenarios; the case for the Zambezi River. *Energies, 9*(7). https://doi.org/10.3390/en9070502
Han, P., Tong, Z., Sun, Y., & Chen, X. (2022). Impact of climate Change Beliefs on Youths' Engagement in Energy-Conservation Behavior: The Mediating Mechanism of Environmental concerns. *International Journal of Environmental Research and Public Health, 19*(12). https://doi.org/10.3390/ijerph19127222
He, R., Jin, J., Qiu, X., Zhang, C., & Yan, J. (2023). Rural residents' climate change perceptions, personal experiences, and purchase intention–behavior gap in energy-saving refrigeration appliances in Southwest China. *Environmental Impact Assessment Review, 98*. https://doi.org/10.1016/j.eiar.2022.106967
Hensher, D. A., & Johnson, L. W. (2018). *Applied discrete-choice modelling*. Routledge.
Hess, D. J., & Mai, Q. D. (2014). Renewable electricity policy in Asia: A qualitative comparative analysis of factors affecting sustainability transitions. *Environmental Innovation and Societal Transitions, 12*, 31–46. https://doi.org/10.1016/j.eist.2014.04.001
HMG/N. (1992a). *Water Resources Act, 2049 (1992). His Majesty's Government of Nepal*.
HMG/N. (1992b). *Hydropower Development Policy, 1992. His Majesty's Government of Nepal*.
HMG/N. (2001). *Hydropower Development Policy, 2058 (2001). His Majesty's Government of Nepal*.
HMG/N. (2002). *Water Resources Strategy Nepal. Water and Energy Commission Secretariat, his Majesty's Government of Nepal. Singha Durbar, Kathmandu, Nepal*.
Huda, M. S., & McDonald, M. (2016). Regional cooperation on energy in South Asia: Unraveling the political challenges in implementing transnational pipelines and electricity grids. *Energy Policy, 98*, 73–83. https://doi.org/10.1016/j.enpol.2016.07.046
Hurlbert, M., Osazuwa-Peters, M., McNutt, K., & Rayner, J. (2020). Transitioning from coal: Toward a renewables-based socio-technical regime in Saskatchewan. *Environmental Innovation and Societal Transitions, 36*, 321–330. https://doi.org/10.1016/j.eist.2019.11.005
Hussain, A., Sarangi, G. K., Pandit, A., Ishaq, S., Mamnun, N., Ahmad, B., & Jamil, M. K. (2019). Hydropower development in the Hindu Kush Himalayan region: Issues, policies and opportunities. *Renewable and Sustainable Energy Reviews, 107*, 446–461. https://doi.org/10.1016/j.rser.2019.03.010
Israel, A., & Jehling, M. (2019). How modern are renewables? The misrecognition of traditional solar thermal energy in Peru's energy transition. *Energy Policy, 133*. https://doi.org/10.1016/j.enpol.2019.110905
Jacksohn, A., Grösche, P., Rehdanz, K., & Schröder, C. (2019). Drivers of renewable technology adoption in the household sector. *Energy Economics, 81*, 216–226. https://doi.org/10.1016/j.eneco.2019.04.001
Jha, R. (2010). Total Run-of-river type hydropower potential of Nepal. *Hydro Nepal: Journal of Water, Energy and Environment, 7*, 8–13. https://doi.org/10.3126/hn.v7i0.4226
Johnstone, P., Rogge, K. S., Kivimaa, P., Fratini, C. F., Primmer, E., & Stirling, A. (2020). Waves of disruption in clean energy transitions: Sociotechnical dimensions of system disruption in Germany and the United Kingdom. *Energy Research and Social Science, 59*. https://doi.org/10.1016/j.erss.2019.101287
Kapoor, M., & Garg, R. D. (2021). Solar potential assessment over canal-top using geospatial techniques. *Arabian Journal of Geosciences, 14*(254), 1–13. https://doi.org/10.1007/s12517-021-06674-7/Published
Karatayev, M., Hall, S., Kalyuzhnova, Y., & Clarke, M. L. (2016). Renewable energy technology uptake in Kazakhstan: Policy drivers and barriers in a transitional economy. *Renewable and Sustainable Energy Reviews, 66*, 120–136. https://doi.org/10.1016/j.rser.2016.07.057
Karlstrøm, H., & Ryghaug, M. (2014). Public attitudes towards renewable energy technologies in Norway. The role of party preferences. *Energy Policy, 67*, 656–663. https://doi.org/10.1016/j.enpol.2013.11.049
Koirala, D. P., & Acharya, B. (2022). Households' fuel choices in the context of a decade-long load-shedding problem in Nepal. *Energy Policy, 162*. https://doi.org/10.1016/j.enpol.2022.112795
Lacroix, K., & Gifford, R. (2018). Psychological Barriers to Energy Conservation Behavior: The Role of Worldviews and climate Change Risk perception. *Environment and Behavior, 50*(7), 749–780. https://doi.org/10.1177/0013916517715296
Li, Y., Wang, G., Shen, B., Zhang, Q., Liu, B., & Xu, R. (2021). Conception and policy implications of photovoltaic modules end-of-life management in China. *Wiley*

Interdisciplinary Reviews. Energy and Environment, 10(1). https://doi.org/10.1002/wene.387
Liao, C., Erbaugh, J. T., Kelly, A. C., & Agrawal, A. (2021). Clean energy transitions and human well-being outcomes in lower and Middle Income Countries: A systematic review. In *, 145*. *Renewable and Sustainable Energy Reviews*. Elsevier Ltd. https://doi.org/10.1016/j.rser.2021.111063.
Lin, B., & Kaewkhunok, S. (2021). The role of socio-culture in the solar power adoption: The inability to reach government policies of marginalized groups. *Renewable and Sustainable Energy Reviews, 144*, Article 111035. https://doi.org/10.1016/j.rser.2021.111035
Lin, B., & Omoju, O. E. (2017). Focusing on the right targets: Economic factors driving non-hydro renewable energy transition. *Renewable Energy, 113*, 52–63. https://doi.org/10.1016/j.renene.2017.05.067
Lomax, J., Mirumachi, N., & Hautsch, M. (2023). Does renewable energy affect violent conflict? Exploring social opposition and injustice in the struggle over the Lake Turkana Wind Farm, Kenya. *Energy Research and Social Science, 100*. https://doi.org/10.1016/j.erss.2023.103089
Lutz, A. F., Immerzeel, W. W., Siderius, C., et al. (2022). South Asian agriculture increasingly dependent on meltwater and groundwater. *Nat. Clim. Chang., 12*, 566–573. https://doi.org/10.1038/s41558-022-01355-z
Manasi, B., & Mukhopadhyay, J. P. (2024). Definition, measurement and determinants of energy poverty: Empirical evidence from Indian households. *Energy for Sustainable Development, 79*, Article 101383. https://doi.org/10.1016/j.esd.2024.101383
Marahatta, S., Aryal, D., Devkota, L. P., Bhattarai, U., & Shrestha, D. (2021). Application of swat in hydrological simulation of complex mountainous river basin (part ii: Climate change impact assessment). *Water (Switzerland), 13*(11). https://doi.org/10.3390/w13111548
Marahatta, S., Bhattarai, U., Devkota, L. P., & Aryal, D. (2022). Unravelling the water-energy-economics-continuum of hydroelectricity in the face of climate change. *International Journal of Energy and Water Resources*. https://doi.org/10.1007/s42108-021-00174-w
Marahatta, S., Devkota, L. P., & Aryal, D. (2021). Application of swat in hydrological simulation of complex mountainous river basin (Part i: Model development). *Water (Switzerland), 13*(11). https://doi.org/10.3390/w13111546
Martinez, N., & Komendantova, N. (2020). The effectiveness of the social impact assessment (SIA) in energy transition management: Stakeholders' insights from renewable energy projects in Mexico. *Energy Policy, 145*. https://doi.org/10.1016/j.enpol.2020.111744
Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M., & Waterfield, T. (2019). Global warming of 1.5°C An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty Edited by Science Officer Science Assistant Graphics Officer Working Group I Technical Support Unit. www.environmentalgraphiti.org.
Matavel, C. E., Kächele, H., Hafner, J. M., Rybak, C., Uckert, G., Hoffmann, H., … Sieber, S. (2023). How to increase cookstove adoption? Exploring cost-effective dissemination techniques in Central Mozambique. *Energy Research and Social Science, 100*. https://doi.org/10.1016/j.erss.2023.103082
McGreevy, D. M., MacDougall, C., Fisher, D. M., Henley, M., & Baum, F. (2021). Expediting a renewable energy transition in a privatised market via public policy: the case of south Australia 2004-18. *Energy Policy, 148*. https://doi.org/10.1016/j.enpol. 2020.111940
Millot, A., Krook-Riekkola, A., & Maïzi, N. (2020). Guiding the future energy transition to net-zero emissions: Lessons from exploring the differences between France and Sweden. *Energy Policy, 139*. https://doi.org/10.1016/j.enpol.2020.111358
MoF/GoN. (2023). *Economic survey 2022/23*. Government of Nepal: Ministry of Finance.
MoFE/GoN. (2021). *Nepal's Third National Communication to the United Nations Framework Convention on climate Change (UNFCC)*. Singha Durbar, Kathmandu, Nepal: Ministry of Forests and Environment, Government of Nepal.
Mohsin, M., Kamran, H. W., Atif Nawaz, M., Sajjad Hussain, M., & Dahri, A. S. (2021). Assessing the impact of transition from nonrenewable to renewable energy consumption on economic growth-environmental nexus from developing Asian economies. *Journal of Environmental Management, 284*, Article 111999. https://doi.org/10.1016/j.jenvman.2021.111999
MoPE/GoN. (2016). *Renewable Energy Subsidy Policy, 2073 BS*. Singha Durbar, Government of Nepal: Ministry of Population and Environment.
Movik, S., & Allouche, J. (2020). States of Power: Energy Imaginaries and Transnational Assemblages in Norway, Nepal and Tanzania. *Energy Research and Social Science, 67*. https://doi.org/10.1016/j.erss.2020.101548
Mtilatila, L., Bronstert, A., Shrestha, P., Kadewere, P., & Vormoor, K. (2020). Susceptibility of water resources and hydropower production to climate change in the tropics: The case of Lake Malawi and Shire River Basins, SE Africa. *Hydrology, 7*(3). https://doi.org/10.3390/HYDROLOGY7030054
Mukhtarov, S., Mikayilov, J. I., Humbatova, S., & Muradov, V. (2020). Do high oil prices obstruct the transition to renewable energy consumption? *Sustainability (Switzerland), 12*(11). https://doi.org/10.3390/su12114689
Munro, F. R. (2019). Renewable energy and transition-periphery dynamics in Scotland. *Environmental Innovation and Societal Transitions, 31*, 273–281. https://doi.org/10.1016/j.eist.2018.09.001
Navarro-Espinosa, A., & Thomas-Galán, M. (2023). Firewood electrification in Chile: Effects on household expenditure and energy poverty. *Energy Policy, 173*, Article 113337. https://doi.org/10.1016/j.enpol.2022.113337
NEA/GoN. (2023). *A year in review fiscal year 2022/23*. Government of Nepal: Nepal Electricity Authority.
Nepal, R., Jamasb, T., & Sen, A. (2018). Small systems, big targets: Power sector reforms and renewable energy in small systems. *Energy Policy, 116*, 19–29. https://doi.org/10.1016/j.enpol.2018.01.013
Nshimiyimana, J. P., Mukeshimana, M. C., & Nshimyimana, E. (2024). Tracking the progress towards adopting LPG as a clean cooking fuel in Rwanda: User's perspective. *Energy for Sustainable Development, 80*, Article 101441. https://doi.org/10.1016/j.esd.2024.101441
Ozili, P. K. (2023). The acceptable R-square in empirical modelling for social science research. In *Social research methodology and publishing results: A guide to non-native English speakers* (pp. 134–143). IGI global.
Palit, D., & Bandyopadhyay, K. R. (2016). Rural electricity access in South Asia: Is grid extension the remedy? A critical review. In *, 60*. *Renewable and Sustainable Energy Reviews* (pp. 1505–1515). Elsevier Ltd. https://doi.org/10.1016/j.rser.2016.03.034.
Pandey, A., Prakash, A., & Werners, S. E. (2021). Matches, mismatches and priorities of pathways from a climate-resilient development perspective in the mountains of Nepal. *Environmental Science and Policy, 125*, 135–145. https://doi.org/10.1016/j.envsci.2021.08.013
Paravantis, J. A., Stigka, E., Mihalakakou, G., Michalena, E., Hills, J. M., & Dourmas, V. (2018). Social acceptance of renewable energy projects: A contingent valuation investigation in Western Greece. *Renewable Energy, 123*, 639–651. https://doi.org/10.1016/j.renene.2018.02.068
Park, J., Namkung, O. S., & Ko, J. (2023). Changes in public bike usage after the COVID-19 outbreak: A survey of Seoul public bike sharing users. *Sustainable Cities and Society, 96*, 104716.
Paudel, B., Zhang, Y., Yan, J., Rai, R., Li, L., Wu, X., … Khanal, N. R. (2020). Farmers' understanding of climate change in Nepal Himalayas: Important determinants and implications for developing adaptation strategies. *Climatic Change, 158*(3–4), 485–502. https://doi.org/10.1007/s10584-019-02607-2
Poortinga, W., Aoyagi, M., & Pidgeon, N. F. (2013). Public perceptions of climate change and energy futures before and after the Fukushima accident: A comparison between Britain and Japan. *Energy Policy, 62*, 1204–1211. https://doi.org/10.1016/j.enpol.2013.08.015
Proka, A., Hisschemöller, M., & Loorbach, D. (2018). Transition without conflict? Renewable energy initiatives in the dutch energy transition. *Sustainability (Switzerland), 10*(6). https://doi.org/10.3390/su10061721
Ramagoma, J., & Adendorff, C. (2016). Managing a transition to green energy sources: The perspectives of energy practitioners in the Southern African Development Community region. *Journal of Energy in Southern Africa, 27*(4), 77–90. https://doi.org/10.17159/2413-3051/2016/v27i4a1638
Raza, M. A., Khatri, K. L., & Hussain, A. (2022). Transition from fossilized to defossilized energy system in Pakistan. *Renewable Energy, 190*, 19–29. https://doi.org/10.1016/j.renene.2022.03.059
Ritchie, H., Roser, M., & Rosado, P. (2022). Energy. https://ourworldindata.org/energy.
Roberts, J. (2020). Power to the people? Implications of the Clean Energy Package for the role of community ownership in Europe's energy transition. *Review of European, Comparative & International Environmental Law, 29*(2), 232–244. https://doi.org/10.1111/reel.12346
Saha, P., & Idsø, J. (2016). New hydropower development in Norway: Municipalities' attitude, involvement and perceived barriers. In *, 61*. *Renewable and Sustainable Energy Reviews* (pp. 235–244). Elsevier Ltd. https://doi.org/10.1016/j.rser.2016.03.050.
Salam, M. A., Rahman, S., Anik, A. R., & Sharna, S. C. (2023). Exploring competitiveness of surface water versus ground water irrigation and their impacts on rice productivity and efficiency: An empirical analysis from Bangladesh. *Agricultural Water Management, 283*, Article 108298.
Salari, M., Javid, R. J., & Noghanibehambari, H. (2021). The nexus between CO2 emissions, energy consumption, and economic growth in the U.S. *Economic Analysis and Policy, 69*, 182–194. https://doi.org/10.1016/j.eap.2020.12.007
Sanjel, N., & Baral, B. (2020). Technical investigation of Nepalese electricity market-a review. *Journal of Physics: Conference Series, 1608*(1). https://doi.org/10.1088/1742-6596/1608/1/012005
Shahzadi, I., Yaseen, M. R., Khan, M. T. I., Makhdum, M. S. A., & Ali, Q. (2022). The nexus between research and development, renewable energy and environmental quality: Evidence from developed and developing countries. *Renewable Energy, 190*, 1089–1099. https://doi.org/10.1016/j.renene.2021.10.050
Shakya, S. R., Bajracharya, I., Vaidya, R. A., Bhave, P., Sharma, A., Rupakheti, M., & Bajracharya, T. R. (2022). Estimation of air pollutant emissions from captive diesel generators and its mitigation potential through microgrid and solar energy. *Energy Reports, 8*, 3251–3262. https://doi.org/10.1016/j.egyr.2022.02.084
Sharma, R. H., & Awal, R. (2013). Hydropower development in Nepal. *Renewable and Sustainable Energy Reviews, 21*, 684–693. https://doi.org/10.1016/j.rser.2013.01.013
Sharna, S. C., Maraseni, T., & Radanielson, A. M. (2024). Determinants of organic soil fertilization methods use over time and in the face of climate vulnerability. *Soil and Tillage Research, 240*, Article 106066.
Shrestha, A., Shrestha, S., Tingsanchali, T., Budhathoki, A., & Ninsawat, S. (2021). Adapting hydropower production to climate change: A case study of Kulekhani Hydropower Project in Nepal. *Journal of Cleaner Production, 279*, Article 123483. https://doi.org/10.1016/J.JCLEPRO.2020.123483
Shrestha, U. B., Shrestha, A. M., Aryal, S., Shrestha, S., Gautam, M. S., & Ojha, H. (2019). Climate change in Nepal: A comprehensive analysis of instrumental data and people's perceptions. *Climatic Change*. https://doi.org/10.1007/s10584-019-02418-5

Sivonen, J. (2023). Attitudes toward global and national climate policies in Finland – The significance of climate change risk perception and urban/rural-domicile. *GeoJournal, 88*(2), 2247–2262. https://doi.org/10.1007/s10708-022-10750-0

Sovacool, B. K. (2014). Energy studies need social science. *Nature, 511*, 529–530.

Sovacool, B. K., Dhakal, S., Gippner, O., & Jain Bambawale, M. (2013). Peeling the energy pickle: Expert perceptions on overcoming Nepal's electricity crisis. *South Asia: Journal of South Asia Studies, 36*(4), 496–519. https://doi.org/10.1080/00856401.2013.788469

StataCorp. (2023). *Stata: Release 18. Statistical Software*. College Station, TX: StataCorp LLC.

Storm, H., Baylis, K., & Heckelei, T. (2020). Machine learning in agricultural and applied economics. *European Review of Agricultural Economics, 47*(3), 849–892. https://doi.org/10.1093/erae/jbz033

Strazzera, E., & Statzu, V. (2017). Fostering photovoltaic technologies in Mediterranean cities: Consumers' demand and social acceptance. *Renewable Energy, 102*, 361–371. https://doi.org/10.1016/j.renene.2016.10.056

Tanti, P. C., & Jena, P. R. (2023). Perception on climate change, access to extension service and energy sources determining adoption of climate-smart practices: A multivariate approach. *Journal of Arid Environments, 212*. https://doi.org/10.1016/j.jaridenv.2023.104961

Thapa, B., Wang, W., & Williams, W. (2022). Life-cycle cost optimization of a solar combisystem for residential buildings in Nepal. *Journal of Asian Architecture and Building Engineering, 21*(3), 1137–1148. https://doi.org/10.1080/13467581.2021.1928502

Tsvetanov, T. (2019). When the carrot goes bad: The effect of solar rebate uncertainty. *Energy Economics, 81*, 886–898. https://doi.org/10.1016/j.eneco.2019.05.028

Uamusse, M. M., Tussupova, K., & Persson, K. M. (2020). Climate change effects on hydropower in Mozambique. *Applied Sciences (Switzerland), 10*(14). https://doi.org/10.3390/app10144842

UN. (2015). *Transforming our world: The 2030 agenda for Sustainable Development, Resolution Adopted by the General Assembly on 21 October 2015, a/RES/70/1*. United Nations General Assembly.

van Valkengoed, A. M., Steg, L., & Perlaviciute, G. (2021). Development and validation of a climate change perceptions scale. *Journal of Environmental Psychology, 76*. https://doi.org/10.1016/j.jenvp.2021.101652

Verma, P., Chodkowska-Miszczuk, J., & Raghubanshi, A. S. (2024). Are cities ready for low-carbon inclusive strategies? Household energy management under heterogeneous socioeconomic conditions. *Sustainable Development*, 1–17. https://doi.org/10.1002/sd.2922

WB. (2024). World Bank national accounts data, and OECD National Accounts data files. Webpage. https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=NP&msclkid=c583c33ad00811ec9a96c3a8dce184bf accessed on 29 March, 2024.

WECS/GoN. (2013). Nepal's energy sector vision 2050 A.D. In *Water and Energy Commission Secretariat*. Singhadurbar, Kathmandu, Nepal: Government of Nepal.

WECS/GoN. (2023). *Nepal energy sector synopsis report-2023. Water and Energy Commission Secretariat*. Singhadurbar, Kathmandu, Nepal: Government of Nepal.

Weko, S., & Goldthau, A. (2022). Bridging the low-carbon technology gap? Assessing energy initiatives for the Global South. *Energy Policy, 169*. https://doi.org/10.1016/j.enpol.2022.113192

Wiehe, J., Thiele, J., Walter, A., Hashemifarzad, A., Zum Hingst, J., & von Haaren, C. (2021). Nothing to regret: Reconciling renewable energies with human wellbeing and nature in the German Energy transition. *International Journal of Energy Research, 45*(1), 745–758. https://doi.org/10.1002/er.5870

Williams, R. (2006). Generalized ordered logit/partial proportional odds models for ordinal dependent variables. *The Stata Journal, 6*(1), 58–82.

Williams, R. (2018). *Ordered logit models–basic & intermediate topics*. University of Notre Dame.

Windemer, R. (2023). Acceptance should not be assumed. How the dynamics of social acceptance changes over time, impacting onshore wind repowering. *Energy Policy, 173*. https://doi.org/10.1016/j.enpol.2022.113363

Winkler, B., Lewandowski, I., Voss, A., & Lemke, S. (2018). Transition towards renewable energy production? Potential in smallholder agricultural systems in West Bengal, India. *Sustainability (Switzerland), 10*(3). https://doi.org/10.3390/su10030801

Wu, S. (2020). The evolution of rural energy policies in China: A review. In *, 119*. *Renewable and Sustainable Energy Reviews*. Elsevier Ltd. https://doi.org/10.1016/j.rser.2019.109584.

Xu, R., Zeng, Z., Pan, M., Ziegler, A. D., Holden, J., Spracklen, D. V., … F.. (2023). A global-scale framework for hydropower development incorporating strict environmental constraints. *Nature Water, 1*(1), 113–122. https://doi.org/10.1038/s44221-022-00004-1

Yadoo, A., & Cruickshank, H. (2012). The role for low carbon electrification technologies in poverty reduction and climate change strategies: A focus on renewable energy mini-grids with case studies in Nepal, Peru and Kenya. *Energy Policy, 42*, 591–602. https://doi.org/10.1016/j.enpol.2011.12.029

Yaghoubi, J., Yazdanpanah, M., & Komendantova, N. (2019). Iranian agriculture advisors' perception and intention toward biofuel: Green way toward energy security, rural development and climate change mitigation. *Renewable Energy, 130*, 452–459. https://doi.org/10.1016/j.renene.2018.06.081

York, R., & Bell, S. E. (2019). Energy transitions or additions? Why a transition from fossil fuels requires more than the growth of renewable energy. *Energy Research and Social Science, 51*, 40–43. https://doi.org/10.1016/j.erss.2019.01.008

Zhou, P., Abbas, J., Najam, H., & Alvarez-Otero, S. (2023). Nexus of renewable energy output, green technological innovation, and financial development for carbon neutrality of Asian emerging economies. *Sustainable Energy Technologies and Assessments, 58*, Article 103371. https://doi.org/10.1016/j.seta.2023.103371