Journal of Engineering and Applied Sciences 15 (7): 1844-1850, 2020
ISSN: 1816-949X
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Identification, Classification and Prioritization of Rural Electrification Barriers of Nepal using AHP

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Abstract: Electricity is one of the major forms of energy and a pre-requisite for the socioeconomic development of a nation. However, 12% of Nepalese households still lack access to electricity. Standalone renewable energy systems such as micro hydro, solar home lighting and wind energy are considered as ways to accelerate rural electrification. Approximately, 10% of Nepal's population receives electricity through such standalone systems. This study analyzes the barriers to rural electrification in Nepal. Barriers are identified, analyzed and ranked based on expert's perceptions using analytical hierarchy process. The experts are classified based on three characteristics: specific expertise, type of organization and years of experience. Areas of expertise include: policy, implementation, user, academic, technical and finance. The selection criteria ensure that opinions from a wide variety of stakeholders are represented. Experts are asked to rank barriers in terms of the cost to remove them, the impact of their removal and the time to remove them. These three factors are ranked by their relative importance. The impact of their removal is adjudged the most important criteria for prioritizing barriers, followed by the cost of removal while the time needed to remove barriers was ranked third. Analysis of the overall ranking of barriers to rural electrification revealed six barriers. In order of their importance, they are: financial, geographical, policy, legal and administrative, social and technological.

Key words: Energy, rural electrification, AHP, barrier, Nepal

INTRODUCTION

Electricity has become indispensable for improving living conditions. Convenient end-use devices for lighting and thermal applications have replaced traditional energy sources. Besides lighting and heating, electrically powered modern technological devices have enhanced everyday activities and the quality of life. Today, electricity generation and its access is an indicator of a country's economic development.

Rural electrification is one of the most challenging and pressing issues in Nepal. More than 80% of Nepalese populations live in rural areas (WB., 2019). However, more than one-fourth of the rural Nepalese do not have access to electricity (MPE., 2016). Rural electrification in Nepal is mainly driven by standalone small energy systems. The financial viability of the installed system in rural areas is an issue of concern. Based on the quality and quantity of electricity available from standalone systems, one can argue they are a short-term electrification solution before a national electricity grid can be implemented (Anonymous, 2015). Considering long-run sustainability and to solve the energy deficit in rural Nepal, rural electrification needs renewed policy attention and extensive planning (Ghimire and Kim, 2018). Nepal has a huge reserve of natural resources for electricity generation but there are many obstacles that need to be overcome in order to accelerate electrification. With rural electrification in particular, the challenges are considerable. Barriers must be identified, prioritized and a way forward identified to enhance energy access and security in rural areas. Economic conditions and the political instability are among the major barriers to renewable energy system development in Nepal (Ghimire and Kim, 2018).

The identification of barriers to rural electrification is of foremost importance, followed by prioritization and removal. Research in this field is not new. However, to the best of our knowledge, there are no studies that specifically attempt to identify the barriers to rural electrification in Nepal and to rank them. Analysis on barriers to rural electrification through renewable energy technologies in rural areas of Nepal can, thus, be a significant contribution to the research (Adhikari *et al*., 2019).

Thus, this study aims to identify and rank barriers to rural electrification of Nepal through renewable energy technologies. While we consider factors identified in previous studies, we also consider other barriers, specifically within the context of Nepal, that are affecting rural electrification development. Barriers are identified from a literature review, questionnaire

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feedback, interviews, field visits and interactions with stakeholders. The barriers are classified mainly into policy, geographical, financial, technical, legal and administrative and social. Experts are surveyed for their opinions on the identified barriers. This study adopted the Analytical Hierarchy Process (AHP) in order to rank barriers.

Rural electrification in Nepal: Rural electrification initiatives in Nepal have a long history but consolidated effort is a recent phenomenon. Rural electrification efforts have increased renewable energy share in the energy mix from almost zero in 2004 to 2.6% in 2014. The share of traditional energy accounted for 87.8% of total energy used in 2004 and 80.0% in 2015 while the share of commercial energy increased from 11.7-17.4% (AEPC., 2019). Traditional energy sources consist of fuel wood, agricultural waste and animal waste. Commercial energy sources consist of petroleum products, coal and electricity. Rural electrification in Nepal is mainly through renewable energy systems such as micro and mini hydro, solar photovoltaic home lighting systems and solar and wind mini-grids. These systems are clean and climate friendly, providing energy without the emission of Carbon Dioxide (CO_2). The 2.6% share of rural electrification results from consideration of energy development as an integral part of national economic development, since, 1985 (AEPC., 2014). In the early '90s, the government of Nepal dedicated itself to the promotion of rural electricity and brought forth a policy to allow the private sector to become an integral part of electricity development. In addition to that, the rural electrification sector is aided by various development partners through technical and financial support. Rural electrification is expensive compared to conventional energy sources, however, it became popular in rural and remote areas of Nepal to provide modern energy access to rural communities. Today, the government of Nepal is encouraging rural electrification development through the subsidies for off-grid renewable energy technologies (AEPC., 2014).

MATERIALS AND METHODS

Identification of rural electrification barriers in Nepal: The literature shows that rural electrification barriers are mainly identified through extensive review of previously published studies and policy documents, site visits, review of policy documents in person interviews, survey questionnaires and interactions with stakeholders (Abdullah and Markandya, 2009). Another study (Schwan, 2011) on overcoming barriers to rural electrification used an example of solar home systems in Bangladesh with barriers identified from an extensive literature study. Furthermore, Painuly (2001) and other researchers argued that literature review, site visit and interaction with stakeholders are suitable approaches to identify barriers. Similar procedures were also considered in this study. Besides extensive study reviews, identification of barriers was cross-validated by interviewing rural electrification experts from different organizations with varying years of experience and different types of expertise to ensure that a wide variety of opinion were considered. This study classified experts based on three categories: specific expertise, type of organization and years of experience. Barriers to rural electrification in Nepal were classified into six groups: geographical, policy, social, financial, legal and administrative and technical.

The literature review concluded that these same major barriers were found in most of the other studies. The literature review finding was also validated through a survey of expert's opinions from multiple fields in the area of rural electrification during the primary data collection using a survey questionnaire.

Analytical Hierarchy Process (AHP) framework for barrier ranking: Analytical Hierarchy Process (AHP) is found to be a widely used approach in ranking or prioritizing multiple alternatives based on Multi-Criteria Decisions Analysis (MCDA). Wangused the AHP approach for multi-criteria analysis for sustainable decision making (Wang *et al*., 2009). Similarly, Lee *et al*. (2008) worked with a fuzzy AHP Model to determine factors for a renewable energy dissemination program. Ghimire and Kim (2018) used AHP for analyzing barriers to renewable energy systems in Nepal. Likewise, Luthra worked and explored barriers of renewable energy systems in India using AHP (Luthra *et al*., 2015). Works above in similar field reveals AHP is the best and most widely used approach for analyzing barriers where multi-factor criteria and decisions are involved.

This study similarly employed the AHP method, based on a Multi-Criteria Decision Making (MCDM) framework. AHP is a popular tool for assigning weights to compare certain criteria or alternatives. It provides flexibility in developing models for decision-making as well as ranking and prioritizing problems. It helps to simplify complex subjective problems, allowing researchers to manage and formulate the hierarchy model accordingly (Saaty, 1987). It is used to quantify subjective measurement problems into coefficients for comparison. AHP utilizes four basic steps to derive its model (Qureshi and Harrison, 2003).

First step-AHP Model: In the first step, a hierarchical structure is formed using research goals and

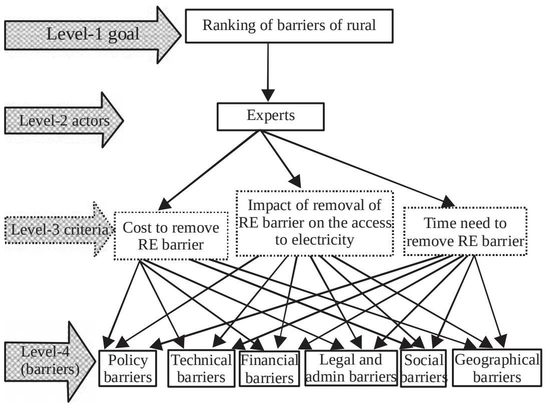

Fig. 1: Hierarchical structure for rural electrification barriers in Nepal

decision criteria. The hierarchical structure of this research has four levels and their categories are shown in Fig. 1.

Level one: The first level, the goal of this this research is to rank the rural electrification barriers of Nepal. The goal can also be called the main objective this study.

Level two: The second level is defined as experts related to rural electrification in Nepal. This study classified experts based on three categories: specific expertise skills, type of organization and years of experience. The specific expertise skills include: policymaker, implementation expert, developer/promoter (manufacturer, supplier and installer), user, academician, technician and finance expert. Likewise, we also applied organization categories: central government, local government, private sector, donor, finance and academia. Experience categories group experts based on those with over 15 years of experience, those with 5-15 years of experience and those with <5 years. This extensive categorization effort was designed to involve all kinds of experts in ranking the barriers to rural electrification in Nepal.

Level three: At level 3 are the criteria that form the basis for comparing rural electrification barriers. Through an extensive survey of literature and in-person interviews with eminent experts having experience using AHP for ranking of alternatives, three criteria are identified and considered for this study: cost to remove rural electrification barriers, impact of removal of rural electrification barriers and time to remove rural electrification barriers in Nepal.

Level four: Six groups of barriers to rural electrification of Nepal are identified in level 4: policy, technical, financial, legal and administrative, social and geographical. These barriers are ranked and prioritized from analysis of the opinions of experts.

Second step-survey questionnaire development: The second step of the AHP Model is to develop a questionnaire for the experts with pair-wise comparisons of criteria and barriers. The questionnaire consists of two sections. The first section is for the pair-wise comparison of criteria and barriers using a nine-point scale. The second section gathers demographic information on the respondent, i.e., specific expertise skill, type of organization and years of experience. The responses are analyzed using a computer software program called Expert Choice. Each category and subcategory of response is analyzed to produce the overall ranking and specific factor or actor-based rankings.

Third step-analysis and computing weight: A comparison matrix is constructed with the data gathered in the survey. All categories and subcategories of expert's views are collected in this step and each barrier's corresponding weight coefficient value is calculated. The weights of criteria and barriers can be calculated from Eq. 1:

$$A\omega = \lambda_{max} X\omega \quad (1)$$

where, X is a comparison matrix of size n×n. For n criteria, also called the priority matrix and ω is an eigen vector of size n×1, also called the priority vector in which the weight. λ_{max} is the maximum eigen value (Satty, 1987).

Fourth step-validation: The final stage is the calculation of a Consistency Index (CI) and Consistency Ratio (CR) as shown by Eq. 2 and 3. The validation of expert's opinions in AHP is carried out by degree of consistency.

$$CI = (\lambda\, max - n)/(n-1) \quad (2)$$

$$CI = CI/RI \quad (3)$$

where, RI is a random variable that varies depending on the order of the matrix. If CR value is ≤0.1, it is in the acceptable range (Satty, 1987). The standard values of RI for up to 10 criteria are obtained by approximating random indices using a sample size of 500 as shown in Table 1 (Satty, 1987).

Data surveying and validation: Validation of results is an important element of any study. For a reliable AHP analysis, data should be sufficient and reliable. While we are unable to identify the total number of respondents

Table 1: Values of Random Index (RI)

Parameters	Values									
N	1	2	3	4	5	6	7	8	9	10
RI	0.0	0.0	0.9	1.1	1.2	1.3	1.4	1.4	1.5	1.5

required for a reliable AHP analysis from previous studies, reliability and sufficiency of data was carefully considered in this study. From 187 experts who participated in the survey, 131 valid responses were used to rank the barriers to the rural electrification of Nepal. Of the 131 valid responses, there were 34 technologists, 22 implementation experts, 21 user/beneficiary experts, 14 academicians, 34 policy experts and 6 finance experts. Classified by organization, there were 36 from central government, 9 from local governments, 18 donor/INGOs, 14 academics, 48 from the private sector and 6 from banking and finance. Similarly, according to years of experience, 44 had more than 15 years of experience, 38 had 5-15 years of experience and 36 had <5 years of experience. Thirteen respondents had an unknown level of experience.

Sufficient numbers of respondents from different organizations and years of experience were chosen to assure reliability of the data. Before giving their opinion on ranking barriers, all respondents were informed about rural electrification development in Nepal, the purpose of this study and given a list of barriers to rural electrification. They were then asked to compare the importance of each criteria and barrier on a nine-point scale in the survey questionnaire. Surveys were conducted via. direct meeting, a Google questionnaire, email, video-conference and Skype.

RESULTS AND DISCUSSION

Analysis of the primary data, collected from a survey of experts was carried out using the AHP framework developed, to rank rural electrification barriers in Nepal. The outcomes are presented based on the opinions of experts. Overall and category-level analysis is carried out to cover a broader spectrum of opinions and understanding among different groups of experts on rural electrification in Nepal.

Ranking of criteria: A ranking of criteria associated with the removal of barriers to rural electrification is one of the products of this research. This analysis helps us understand the relative importance of the three criteria. The respondent's ranking data are fitted using the AHP model. Table 2 shows the rankings with priority indices from respondent's perspectives. "Impact of Removal of RE Barrier to Increase Access to Electricity" is ranked as the most important criteria for the removal of rural electrification barriers with a weighting coefficient of

Table 2: Priority of factors/criteria as a basis to remove rural electrification barrier

Rank	Factor/Criteria	Priority index
1	Impact of removal of RE barrier in the fast access of electricity	0.38
2	Cost to remove barrier	0.33
3	Time to remove RE barrier	0.29

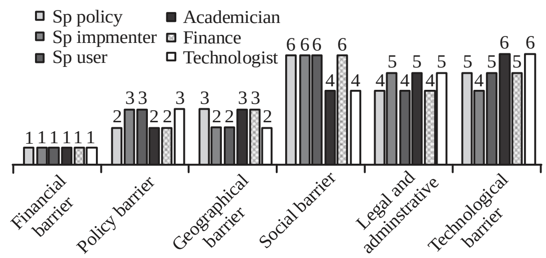

Fig. 2: Ranking of RE-B based on specific expertise skills

0.38. This is followed by "Cost to Remove RE Barrier" with a weighting coefficient of 0.33. Finally, "Time to Remove RE Barrier" is the least important with a weighting of 0.29. Repetitive validation of the AHP Model for these criteria showed 0.01 inconsistencies. Thus, the results are found to be reliable with only 1% of error, i.e., 99% accurate.

Individual special expertise sub-category results: The respondent categories are split into sub-categories of experts based on their specific expertise. The opinions of academicians, technologists, finance experts, specific policy experts, specific implementation experts and specific user experts are used to rank barriers to RE in Nepal. In general, the ranking results in two groups of barriers with the first group viewed as having significantly more important barriers to rural electrification than the second group. The more important barriers are financial, policy and geographical. The second, less important, group includes legal and administrative, social and technical barriers. In Fig. 2, "Financial Barrier" is ranked as the most important by all experts. "Policy Barrier" and "Geographical Barrier" tied for second most important with both barriers receiving 50% of the vote. In the second group of barriers, everyone except academicians and technologists agree that "Social Barrier" is sixth in rank (least important) while "Legal and Administrative" and "Technological Barrier" are fourth and fifth in rank, respectively.

Differences in ranking alternative barriers are found when analyzing individual expert's views, however, their overall weight value results are the same as the main category. Some interesting findings can be observed in the rankings. For example, according to specific implementation experts, "Geographical Barrier" with its priority weight of 0.2 was the second most important barrier among the six. Similarly, technical expert's opinion revealed "Geographical Barrier" as second in importance and "Technological Barrier" as sixth. Finance experts and specific policy experts vote "Financial Barrier" as number one and "Policy Barrier" as number two. Moreover, specific user expert opinions were also found to deviate from the overall expert category rankings. They ranked "Geographical Barrier" second with a priority weight of 0.19 and "Technological Barrier" fourth with a priority weight of 0.15.

The overall individual expert category group results still found "Financial Barrier" to be the most important with "Policy Barrier" and "Geographical Barrier" tied for second, "Legal and Administrative Barrier" as fourth and "Social Barrier" and "Technological Barrier" as the fifth and sixth ranked barriers to RE in Nepal.

Organization type sub-categories results: It was also important to choose experts working in different organizations to represent different perceptions in ranking of barriers to rural electrification. The 131 valid responses are associated with six different types of organizations: central government, local government, private sector, developmental partner/donor, university/academic institute and financing organization.

Types of organizations to which the experts are affiliated are analyzed in this sub-section including the individual organization sub-category as well as the overall rankings from all organizations. Figure 3 shows the results where 1 represents the most important rank and 6 represent the least important rank. As with the specific expertise analysis, the overall organization sub-category priority weight also produces two distinct ranking groups. Priority weights according to different organizational experts are also found to deviate slightly from the overall finding. Specially, academic institute experts fully agree with the overall rankings, seeing "Financial Barrier" as the most important issue while private sector respondents strongly view "Geographical Barrier" as the most important. One may surmise that providers of technology always think of difficult geography and poor infrastructure as the number one hindrance to a faster pace of electrification. This view is also supported by central government experts who voted "Geographical Barrier" number two in importance, after "Financial Barrier." Local government voted "Policy" first, "Financial" second and "Legal and Administrative" third in a deviation from the overall ranking. "Social" and "Technological" barriers were ranked fifth and sixth by the experts overall, implying that these two barriers are less important than the other four.

Years of experience sub-category results: All the valid respondents are sub-divided by their level of RE experience into three sub-categories and a separate analysis is done on the ranking of rural electrification barriers. The experience sub-categories are: more than 15 years, 5-15 years and <5 years of experience. We can assume those experts with long experience in the RE sector will have wiser and more realistic rankings. The outcome of the separate analysis is presented in Table 3. Barrier rankings from experts with more than 15 years of experience are identical to the rankings from experts with 5-15 year's experience and match the overall rankings. Experts with <5 years of experience agreed with the other two experience groups in ranking "Financial" and "Technological" barriers as the most and least important, respectively. However, the barriers they ranked second, third, fourth and fifth differed from the more experienced experts. Overall, "Financial Barrier" is found to be most important in the experience sub-category analysis with a priority weight of 0.23 and "Technological Barrier" is least important with a 0.11 priority weight.

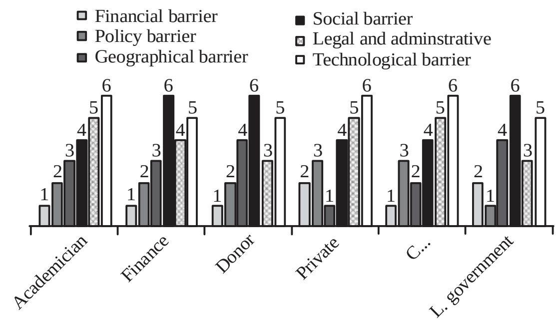

Fig. 3: RE-B ranking based on type of organization

Table 3: RE-B ranking based on years of experience of respondent

RE-B, alternatives	>15 years	5-15 years	<5 years
Financial barrier	1	1	1
Policy barrier	2	2	3
Geographical barrier	3	3	2
Social barrier	4	4	5
Legal and administrative	5	5	4
Technological barrier	6	6	6

Overall ranking and prioritization results: The overall ranking results are presented in Table 4. The overall barrier ranking corresponds to the prioritization of barriers, considering the effect of criteria and alternative opinions. The overall opinions of all 131 expert's valid responses are included in the analysis.

Results revealed the "Financial Barrier" as the most important barrier to the rural electrification development of Nepal with a priority weight of 0.22. "Policy Barrier" with its priority weight of 0.20 is second ranked, followed by "Geographical Barrier" as the third most important with a 0.19 priority weight. The other barriers with their priority weights are: "Legal and Administrative" 0.14, "Social" 0.13 and "Technological" 0.12.

Table 4: Overall ranking of barriers to rural electrification in Nepal

Alternative barriers	Priority weight	Rank
Financial barrier	0.22	1
Policy barrier	0.20	2
Geographical barrier	0.19	3
Legal and administrative barrier	0.14	4
Social barrier	0.13	5
Technological barrier	0.12	6

Main and individual analysis showed the same or similar rankings for barriers to rural electrification in Nepal. Priority weights of all barriers are also found to be similar. Comparing results from both the overall category and sub-categories, it is established that removal of the financial barrier is the most important and removal of the technological barrier is least important to accelerating rural electrification development in Nepal.

Financial, policy and geographical barriers are consistently ranked as the more important group of barriers while the legal and administrative, social and technological barrier group is less important. The difference in priority weight within either of the two groups is not very significant but there is some difference in weight between the two groups, meaning that the three lower ranked barriers have similar impact but are less important than those in the first group.

CONCLUSION

An analysis of the ranking of criteria which are taken as the basis to rank RE barriers, concluded that the impact of removal of a barrier is the most important factor while cost and time to remove a barrier are the second and third-ranked factors, respectively.

Overall, the financial, policy and geographical barriers are ranked as the first, second and third most important barriers to RE development in Nepal. A comparison of the coefficients of weight among these three barriers reveals no significant difference. This is also the case in many sub-category analyses indicating that these three barriers should be targeted first. Legal and administrative, social and technological barriers are ranked as the fourth, fifth and sixth, respectively, in terms of priority, placing them in a second group. In the second group of barriers, there is little difference in the priority weights. Small differences in priority weights imply that none of these second-group barriers is more important than another, when considering them for removal to speed up the RE development of Nepal.

The study also tried to bring in different perspectives for a wider spectrum of analysis of RE barriers in Nepal. Opinions of RE experts from different expertise areas, organizations and levels of experience showed some differences in priority ranking, however, the differences are nominal. However, the results from different categories and sub-categories indicate clearly that all six barriers are important.

Besides this research, other similar studies, in Nepal and other countries have come to similar conclusions. Nepal is one of the least developed countries; it has a poor economy and lacks adequate infrastructure. Consequently, there are many barriers to overcome for faster development. The Gross Domestic Product (GDP) per capita in Nepal was 812.20 USD in 2018. GDP growth was just 6.7% of the world’s average (Trading Economics, 2019). This situation is exacerbated by political instability, low investment resources and difficult terrain. With other national priorities like heath, education, transportation and so on, competing for limited public funds, electricity generation may not be able to increase its share of development funding. This general situation can be correlated with the financial barrier as the most important barrier to rural electrification in Nepal. In the past, rural electrification in Nepal mostly depended upon standalone off-grid energy systems, due to the difficult geography and scattered rural settlements. These systems are difficult to develop and maintain at the village level. In most rural areas of Nepal, households are in clusters a few kilometers in diameter and separated by difficult terrain. Community-based micro-hydro and household-based solar home systems were the maintechnologies promoted. These two technological solutions have served to fill the gap until the mainstream national grid reaches these areas. Therefore, the experts opined that technology is not a relatively large hurdle and thus, it was consistently voted as a less important challenge or barrier to RE in Nepal.

When this study started between 2011 and 2019, the socio-economic conditions and fund flows to rural areas from remittance has changed. Overall, incomes of individuals in rural Nepal have gone up and the cost of solar PV technology has fallen, reducing the financial barrier to some extent. Major policy changes such as increases in subsidies to rural communities for technologies like solar and micro-hydro have further reduced the pressure on local people to make upfront investments in rural energy systems. The Nepal Electricity Authority introduced a 90% subsidy policy through community co-operative distribution management as a large incentive to semi-remote areas (Rana, 2012).

A rapid increase in the number of all-weather roads in remote areas has greatly reduced the cost of transportation for off-grid systems and that of the development of big hydro projects, thus, lessening the severity of geographical barriers and supporting RE development. In the last decade, RE coverage has increased from 40.0-77.8% of rural households (Pun, 2016). Transmission line extension, grid connectivity, up-scaling of standalone power plants and so on are still needed for development of RE in Nepal. A few positive developments also took place in the social barrier sector, after the settlement of long-standing social conflicts, resulting in a softening of attitudes toward development projects. Political instability in the government has also abated to a certain extent, after a newly elected majority single-party government came into power. Government stability ensures reliability in policy which attracts private and foreign investment, thus, helping to reduce important barriers to RE. After implementation of the new constitution, Nepal became a federal state with 761 elected governments, bringing government to the people. Local levels of government can make their own policies for energy generation and distribution to suit their specific needs and lessen the legal and administrative barriers.

In conclusion, there are a number of barriers hindering electrification This study concluded that financial barriers, policy barriers and geographical barriers are most important barriers in the rural electrification of Nepal. In addition to these barriers, legal and administrative barriers, social barriers and technology barriers are second-level barriers as ranked by RE experts representing a wide group of stakeholders. In recent years, socio-economic and policy changes have addressed many of these barriers to some extent, resulting in a faster pace of rural electrification.

Though the situation of rural electrification is improving, more consolidated and integrated efforts are required to overcome identified barriers to faster and higher-quality rural electrification development. We hope this study will guide decision makers and rural electrification stakeholders to improve and further develop the RE sector.

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