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Sustainability Status of Solar PV Projects in Nepal

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Original Research Article

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Abstract: Harsh topographic conditions are a huge challenge for rural electrification in Nepal through national grid extension. Hence off-grid electrification has a huge potential and is gaining huge popularity in Nepal. Recognizing the significance of renewable energy in rural areas, with the support of various development partners, Government of Nepal considers rural electrification through renewable energy technologies as an appropriate means to enhance rural livelihoods and conserve environment in rural areas. As the intention of the installation is to increase access to solar energy services for livelihood enhancement, it has been realized to assess whether these systems installed and/being installed across different parts of Nepal is sustainable and contributing for socio-economic growth of society. The overall objective of this study is to measure and eventually assess the sustainability of solar energy projects in Nepal that have been installed for a year through a developed framework. The sustainability frame work has been developed which measures sustainability in general and technical, economic, social, and institutional and environment sustainability in particular for renewable projects implemented. Testing with framework, 74 percentages system is weakly sustainable, 10 percentages are not sustainable and only 16 percentage system is sustained which raises a question on sustainability of renewable energy projects in rural Nepal. At 70 percentages subsidy policy from Government of Nepal, there are no much changes in sustainability status of solar PV projects. 21 percentages system are sustainable, 70 percentages are weakly sustainable whereas 9 percentage system are still not sustainable. Decreasing trend on PV panel cost and increasing the electricity tariff rate might increase the sustainable status of renewable systems installed.
Keywords: Renewable energy, Rural Nepal, Subsidy Criteria, Sustainability Metric.

INTRODUCTION

Sustainability is an important term used in modern development practices and is understood in many ways according to its application in various fields. Sustainability assessment is a complex appraisal method. It is conducted for supporting decision-making and policy in a broad environmental, economic and social context, and transcends a purely technical/scientific evaluation applied to almost every system on earth[1]. In fact, the earth's resources are limited and all human activity should emphasize the sustainable use of it. According to the International Union for Conservation of Nature, the United Nations Environment Programmed and the World Wildlife Fund, sustainability consists of improving the quality of human life while living within the carrying capacity of supporting eco-systems. Talking about the sustainability of any energy project for instance, it is a necessary requirement for achieving the sustainability of other human undertakings as well. Sustainability is also directly associated with the value for money of the investment made in the development sector [2].

As energy plays a vital role in the modern lifestyle of any country, understanding how sustainable the energy system of a country remains an important policy issue [3]. Nepal, being located in favorable latitude, receives ample solar radiation. The average solar radiation varies from 3.6–6.2 kWh/m^2/day, and the sun shines for about 300 days a year. The national average sunshine hours and solar energy are 6.8/day and 4.7 kWh/m^2/day respectively Adhikari *et al*. [4]. The development of solar energy technology is thus reasonably favorable in many parts of the country. The commercial potential of solar power for grid connection is 2,100 MW [5]. With National average sunshine hours of 6.8/day and solar insolation intensity of about 4.7 kWh/m^2/day, there is a huge potential for solar thermal devices such as Solar Water Heaters (SWH), Solar Dryers (SD), Solar Cookers (SC). Presently SWH have been fully commercialized and till 2009 more than 185,000 SWH have been installed in the country. SD and SC are still in the phase of dissemination and commercialization. Stand-alone Solar Home System (SHS) constitute above 5000 kWp with 185017 numbers as of until 2008/09. Till December 2004, 51 solar PV pumping systems have been installed, of which 28 were installed after 2000 with subsidy provided from AEPC. This shows quite significant improvement in SWH installations in recent years[6].

For a large part of the rural population consuming low electrical energy, there is no viable alternative to solar electricity for rural electrification. The operation and maintenance cost of diesel generators is too high, biogas technology does not work satisfactorily on the fairly cold high altitudes or in the mountains and would be difficult to achieve with roving herds of cattle [7]. Small Hydro turbines need specific topographical conditions that are only found near a small percentage of users' dwellings. Solar electricity generating systems, which do not need fuel or extensive infrastructure, are easy and quick to install and thus could be very attractive option in many locations of the country[8]. After installation of those systems, it is the responsibility of the participating community or the users to operate maintain and manage the system. The sustainability of renewable energy projects considered largely depends on how much revenue it can generate from its users for operation, maintenance and management. Revenue from users depends upon multiple factors categorized as technical, financial/economic, social, institutional and environmental [9-11]. As such, sustainability of the projects needs to be evaluated based on the multiple criterions in a holistic manner. Sustainability of the photovoltaic water pumping systems installed across different parts of Nepal is one of the main concerns for those who are involved in renewable energy sector [12].

The issue of sustainability pertains more to poor countries like Nepal, where most of the infrastructure is constructed through one-time donors' support or government investments. The infrastructure, after it is constructed and handed over to the concerned authority is either never looked after or poorly managed by the concerned authority until it reaches a totally defunct stage. Based on objectives set by the stakeholders of the project, there may be different views on the sustainability aspect of the project. The objective of this research paper is to find viability of solar PV systems installed in rural Nepal using sustainability tools.

MATERIALS AND METHODS

Preparation of questionnaires for field survey

The first step of the field research was to prepare questionnaires. Two different sets of questionnaires were prepared for two different levels of respondents.

First Group of Respondents

The selected renewable energy (RE) owners, operators and managers (by considering physiographic region) are treated on the first level where primary data regarding the technical, social, financial, environmental and institutional aspects of the renewable energy systems were collected. The real picture of the selected areas with actual perception of renewable energy owners, operators and managers in terms of their needs, desires, potential and feedbacks on existing renewable energy systems was explored and analyzed in view of sustainability.

Semi-structured questionnaires were prepared and were put into pre-testing at ten sites. The results of the pre-testing exercise were further discussed and the questionnaires were finalized after making appropriate adjustments. In order to collect primary data, few enumerators were deployed to conduct the field survey. The purpose of orientation was to develop a common understanding about the objective, technology and outcomes of the proposed study. This orientation also involved a pre-testing of the questionnaires at the agreed site.

Second Group of Respondents

The questionnaire/checklist for the second group of audience was basically developed to identify the core issues and challenges of the sector. Renewable energy experts, academicians, policy makers, private sector representatives were interviewed to find ways and means to remove problems/barriers related to the sustainable operation of renewable energy projects in Nepal. The Delphi method was applied to validate the criteria and indicators selected and to evaluate energy systems. In this method, experts' opinion is screened at every step of interaction. The process was continued until the correct and common criteria. The principal investigator conducted the second level surveys with direct interaction cum discussion on the basis of structured questionnaires and checklists.

Selection of study areas/sites and conduction of field research

In order to collect primary data from the sites/field, the study adopted the following procedures for the selection the sample size for solar energy systems:

Determination of population

The correct number of sample size needed for the research was identified when the population size was known. Following norms were set in order to determine the population size of the energy systems:

- The RE systems should be AEPC supported,
- The systems should be in operation for at least two years,

- The system should either serve the community or institution. Here in case of solar, only institutional solar photovoltaic system (ISPS) and photovoltaic pumping (PVPS) system have been considered for the study.

However, database for these systems at Alternative Energy Promotion Centre are not well organized. The inconsistency in the number of each system mostly of those systems that were installed before 2007 compelled this research to consider only those systems that fulfill the above criteria and were installed in the period of 2007-2010. The population size of solar projects is summarized in Table 1.

Table-1: Population size of AEPC supported Solar (ISPS and PVPS) Projects

RE Systems	Ecological Region	Development Region					NA	Grand Total
		Eastern	Central	Mid-western	Far-western	Western		
Solar	Mountain	99	46	29	178	168		520
	Hill	146	111	74	76	133		540
	Terai		11		1	3		15
	NA						2	2
	Grand Total	245	168	103	255	304	2	1077

Source: NRREP Baseline Report 2013; unpublished database, Solar Sub-component 2015

Sampling

The areas and RE sites have been selected based on random sampling which represents all physiographic region of Nepal i.e. mountain, hills and Terai. Since all three ecological belts should be included proportionately, PPS (Probability Proportional to Size) samplings design was adopted. For this current study, Stratified Random Sampling technique has been used.

Minimum required sample size in estimating the population proportion $_\pi$ is

$$n=\frac{Z^2\pi(1-\pi)}{e^2}$$

Since the estimate of true population proportion (π) was unknown, 0.5 was taken to maximize the variance and hence demand larger sample size. Likewise, the margin of error (i.e. tolerable maximum limit of sampling error) was set at 0.10 (i.e. 10%). An error margin of 10% is an acceptable level in sampling design of social science and other research studies. Similarly, a 90% confidence level is adopted which implies a Z-value of 1.645 [13].

Substituting these values in the above sample size computing formula, a sample size of 68 is required for the study. Therefore a minimum of sample size 68 solar projects were selected.

In order to determine the sample size of 68, the researcher has adopted an internationally accepted Microsoft Excel's 'Sample Size Determination' Template. This template provided flexibility to change input parameters like the value of π (estimate of true proportion), e (sampling error) and confidence level (e.g. 90%).

The same template was then used to determine the samples for the finite populations. Here, the population of the solar systems (both ISPS and PVPS) is 1077. The sample size needed for this finite population is only 64.

It was also borne in mind that in case, if there is a non-response rate of a maximum of 20%, it needs to inflate the above sample size of 64. The working of the inflation is delineated as: inflated sample size = 64 ÷ (1-0.20) = 80. These numbers are divided into three parts proportional to the population size of three ecological belt viz., Mountains, Hills, and Terai. These three belts are the strata of the population. The rounding should be done properly so that the sum the sample size of the three belts becomes 80.

Further, the sample sizes in each belt are readjusted so as to consider sufficient samples to carry out geological region-wise generalization of the findings of the survey.

Using Microsoft Excel PH-Stat Adds-in program, the sample size is computed as below:

Table-2: Sample size calculation method for solar projects

Sampling for Finite Populations	
Population Size	1,077
Calculated Sample Size	63.6974
Sample Size Needed	64
Sample Size Needed @ 20% non-response rate	80

Ecological Region-wise Sampling	Population	Proportion	Sample size	Readjusted Size
Mountain	520	0.48	38.63	37
Hill	540	0.5	40.11	38
Terai	15	0.01	1.11	5
NA	2	0	0.15	0
Total	1077	1	80	80

The solar energy project sites to be surveyed in each ecological region are mentioned in Table 3.

Table-3: Sample size needed for the field research for Solar systems

RE Systems	Ecological Region-wise Sampling	Population	Sample size	Readjusted Sample Size
Solar	Mountain	520	38.63	37
	Hill	540	40.11	38
	Terai	15	1.11	5
	NA	2	0.15	0
		1077	80.00	80

Development of framework to measure sustainability

Sustainability Metric (SM) has been developed to measure sustainability of rural energy projects by assigning numerical values [14]. The SM allows objective measurement of sustainability and rank projects according to their SM value. The SM has been developed by following method:

- Factors affecting technical, economic, environmental and social sustainability criteria of rural energy projects are identified [15],
- To quantify the identified factors, either equations are developed or numerical values are assigned by using AHP to the responses from the expert in renewable energy system in Nepal,
- Metric that considers each of the sustainability criterion, namely, technical, economic, environmental and social is developed to obtain numerical values that measure sustainability [16].

SUSTAINABILITY ANALYSIS

In order to check the sustainability of the solar energy projects being operated in rural Nepal, a sample of 80 solar sites was taken. Prudent site survey and questionnaires were carried out so as to provide the score to the involving factors in each of the sustainability metric and finally via proper evaluation, total sustainability metric was calculated.

Technical Sustainability metric (SM_1) is calculated as [14]:

$$SM_1 = 16.918\eta - 22\beta + 20.3 \quad [\text{For } 0 \le \text{SM}_1 \le 33]$$

Economic Sustainability metric (SM_1) is calculated as:

$$SM_2 = 27BC - 13.5 \qquad [\text{For } 0 \le \text{SM}_2 \le 27]$$

The value of Environmental Sustainability Metric (SM_3) is obtained by the summation of individual obtained score considering each of the three environmental factors.

$$SM_3 = 11R_I + 6R_C + 5R_L \qquad [\text{For } 0 \le \text{SM}_3 \le 22]$$

Where, $R_{I,}$ R_C and R_L are the respondents' weightage given to sub-factors impact on ecosystem, CO_2 emission and land requirement respectively. The value of each weightage ranges from 0 to 1.

The value of Social Sustainability Metric (SM_4) is obtained by the summation of individual obtained score considering each of the three social factors

$$SM_4 = 4R_S + 7R_p + 7R_E \qquad [\mathrm{For}\ 0 \leq \mathrm{SM}_3 \leq 18]$$

Where, $D_{S,}$ D_P and D_E are the respondents' weightage given to sub-factors social acceptability, project contribution in economic productivity/income generation and community equity/stake in the project respectively. The value of each weightage ranges from 0 to 1.

Total Sustainability

The Total Sustainability Metric is given by:

$$SM_{TOT} = SM_1 + SM_2 + SM_3 + SM_4 \ [\mathrm{For}\ 0 \leq \mathrm{SM}_{\mathrm{TOT}} \leq 100]$$

Then, as per the conditions of sustainability, the rural energy projects can be classified as unsustainable, weakly sustainable, sustainable or highly sustainable projects[17].

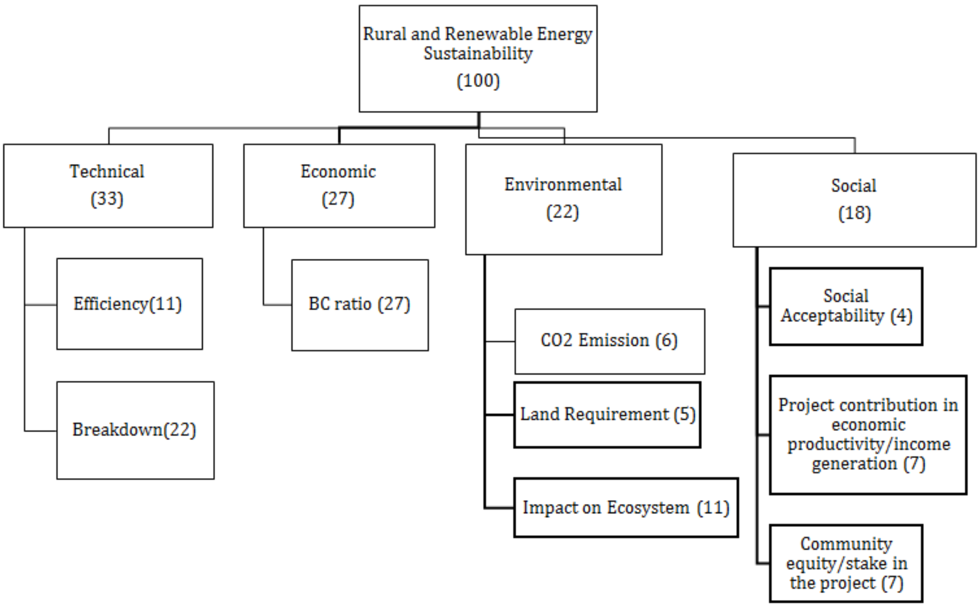

Fig-1: Hierarchical structure with their weights

RESULTS

It has been observed that in the taken sample of 80; 59 of the sites (74%) are weakly sustainable and only 13 (16%) sites are sustainable. Total of 8 sampled PV projects are not sustainable. None of the sites are sustainable or highly sustainable. Almost all of the projects are seen to have SM_2 failure which means the projects are unsustainable due to B/C ratio less than one. Almost for all the cases the benefits are less than the costs of the projects which shows that the investment in rural solar projects is high due to many reasons. Some of them being materials cost, labour cost, transportation cost, high interest rate, etc.

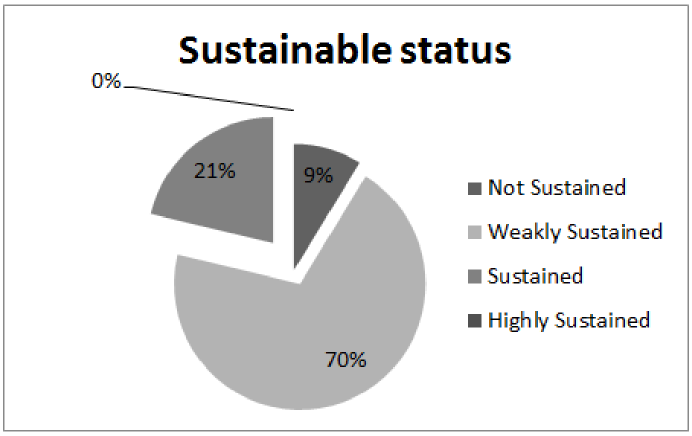

Fig-2: Sustainable status of the solar energy project

Sustainability according to the ecological regions

Despite the difference in the ecological regions, most of the projects are unsustainable. However, most of the projects are weakly sustained in case of Terai (Plain) region being 40%. The main reason behind is the easy access of transportation and material availability.

Table-4: Ecological region wise sustainability status

Ecological region	Weakly sustained	Not sustained	Sustained
Terai	2	2	1
Mountain	30	2	5
Hilly	27	4	7
Total	59	8	13

Sustainability according to development regions

Most of the installed projects seem to be unsustainable in each of the development regions. The proportion of the weakly sustained projects are almost same as all the development regions are proportionately divided consisting all the three ecological regions in each development region.

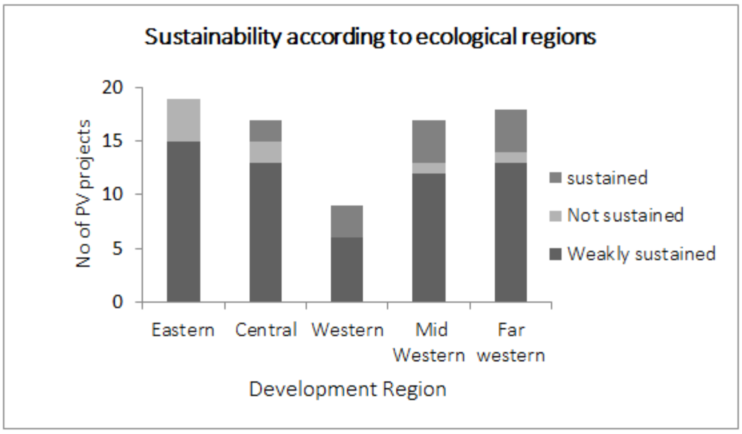

Fig-3: Sustainability status according to development regions

DISCUSSION

Sustainability Metric (SM) has been developed to measure sustainability of solar energy projects by assigning numerical values. The SM allows objective measurement of sustainability and rank projects according to their SM value. The total sustainability metric is the summation of five different sustainability metrics namely, technical, economic, environmental and social. As per the conditions of sustainability, the rural energy projects can be classified as unsustainable, weakly sustainable, sustainable or highly sustainable projects.

As majority of sites are seen to be weakly sustainable projects after this analysis, an attempt has been made to find a way on enhancing the sustainability of those sites. Few cases have been examined here which proved to be helpful to augment the sustainability of the energy projects. The research shows most of the solar sites seem to fail economically. They aren't earning enough revenue to address the investment made and the running costs. In this paper, an attempt has been made to enhance the overall sustainability by increasing the economic sustainability.

Case I: Removing the subsidy on analysis

Most of the solar energy projects operating in the rural Nepal (under consideration here in this research) have been subsidized either by AEPC or from the international donors. Excluding the subsidy part, that is taken to be around 70% of the initial investment, and then proceeding for the sustainability metric calculation, overall sustainability of the projects is explicitly augmented. 17 of the sites are found to be sustained while just 7 of them are seen to be not sustained. Most of them (70%) are still weakly sustained.

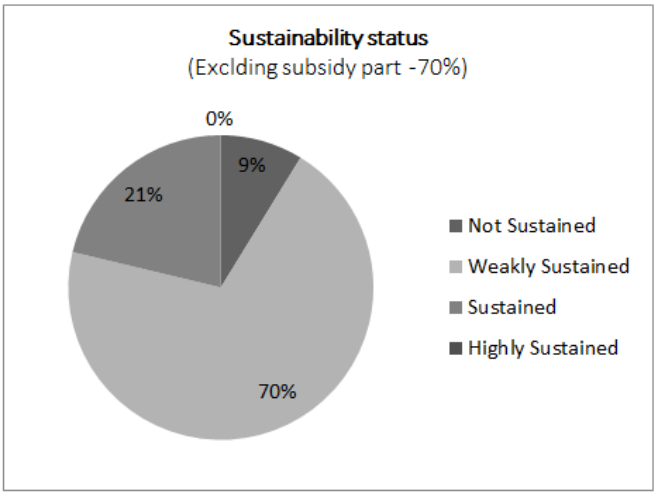

Fig-4: Sustainability status analysis excluding subsidy part

But the main concern is although the subsidy part is removed in the analysis; the investment has already been made by the government. Removing it in just the analysis part won't minimize the problem. Some other way needs to be sought that can justify the sustainability of whole investment, even this subsidy.

Case II: Increasing the Tariff Rate

As most of the projects fail in terms of financial sustainability, enhancing the tariff rate can surely add up to the financial sustenance of the projects and will enhance the overall sustainability of the projects. To verify this, tariff rate has been increased to 250 from 150 and the results obtained seems to be more sustainable.

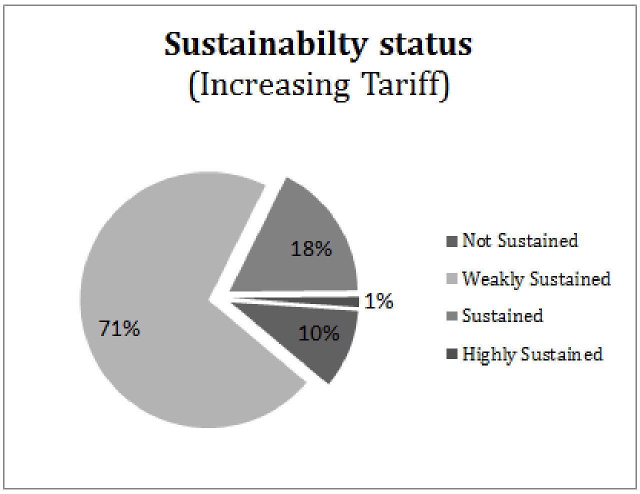

Fig-5: Sustainability status analysis increasing tariff rate

On increasing the tariff, 14 of the sites becomes sustained while 8 sites remains not sustained. The PV projects can also be made sustainable by increasing the tariff more but the question will arise whether the local villagers can pay such increased tariff.

The sustainability analysis is done for a sample of 80 solar projects in Nepal. Among which most of the projects are unsustainable and none of them are highly sustainable. The main reason behind this is due to economic factors (SM_2 failure). Thus steps must be carried on to increase the benefits from the projects which can be done by increasing the tariff rate. Also subsidy policy should be revisited and has to be increased for economical poor zone sand geographically backward so as to make the project sustainable. Cost of Solar PV systems are in decreasing pattern and hence this will decrease the cost of the projects so that a project can be sustainable.

CONCLUSIONS

The 74 percentage solar PV systems have been found weakly sustainable whereas 10 percentage solar PV systems have been not sustainable. Only 16 percentage PV projects are sustainable. Provision of subsidy policy made the 21 percentage solar PV systems sustainable. It was noted 70 percentage systems were still weakly sustainable. Decreasing trend on PV panel cost and increasing the electricity tariff rate might increase the sustainable status of renewable systems in Nepal.

REFERENCES

1. Sala S, Ciuffo B, Nijkamp P. A systemic framework for sustainability assessment. Ecological Economics. 2015 Nov 1;119:314-25.
2. Terrapon-Pfaff J, Dienst C, König J, Ortiz W. A cross-sectional review: Impacts and sustainability of small-scale renewable energy projects in developing countries. Renewable and Sustainable Energy Reviews. 2014 Dec 31;40:1-0.
3. Iddrisu I, Bhattacharyya SC. Sustainable Energy Development Index: A multi-dimensional indicator for measuring sustainable energy development. Renewable and Sustainable Energy Reviews. 2015 Oct 1;50:513-30.
4. Adhikari KR, Bhattarai BK, Gurung S. Estimation of Global Solar Radiation for Four Selected Sites in Nepal Using Sunshine Hours, Temperature and Relative Humidity. Journal of Power and Energy Engineering. 2013 Aug 30;1(03):1.
5. Proietti S, Sdringola P, Castellani F, Garinei A, Astolfi D, Piccioni E, Desideri U, Vuillermoz E. On the possible wind energy contribution for feeding a high altitude smart mini grid. Energy Procedia. 2015 Aug 1;75:1072-9.
6. Shrestha RM, Rajbhandari S. Energy and environmental implications of carbon emission reduction targets: Case of Kathmandu Valley, Nepal. Energy Policy. 2010 Sep 1;38(9):4818-27.
7. Smith KR, Samet JM, Romieu I, Bruce N. Indoor air pollution in developing countries and acute lower respiratory infections in children. Thorax. 2000 Jun 1;55(6):518-32.
8. Prakash G, Garg HP. Solar energy: fundamentals and applications.
9. Santoyo-Castelazo E, Azapagic A. Sustainability assessment of energy systems: integrating environmental, economic and social aspects. Journal of Cleaner Production. 2014 Oct 1;80:119-38.
10. Wang JJ, Jing YY, Zhang CF, Zhao JH. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renewable and Sustainable Energy Reviews. 2009 Dec 1;13(9):2263-78.
11. Wang Y, Lam KC, Harder MK, Ma WC, Yu Q. Developing an indicator system to foster sustainability in strategic planning in China: A case study of Pudong New Area, Shanghai. Ecological indicators. 2013 Jun 1;29:376-89.
12. Panthi K, Bhattarai S. A framework to assess sustainability of community-based water projects using multi-criteria analysis. InFirst International Conference on Construction in Developing Countries (ICCIDC–I) 2008 Aug 4 (pp. 464-472).
13. Li B, Yang H, Wei Y, Su R, Wang C, Meng W, Wang Y, Shang L, Cai Z, Ji L, Wang Y. Is It Time to Change Our Reference Curve for Femur Length? Using the Z-Score to Select the Best Chart in a Chinese Population. PloS one. 2016 Jul 26;11(7):e0159733.
14. Alsharif MH, Kim J, Kim JH. Green and sustainable cellular base stations: an overview and future research directions. Energies. 2017 Apr 25;10(5):587.
15. Sipahi S, Timor M. The analytic hierarchy process and analytic network process: an overview of applications. Management Decision. 2010 Jun 1;48(5):775-808.
16. McBride AC, Dale VH, Baskaran LM, Downing ME, Eaton LM, Efroymson RA, Garten Jr CT, Kline KL, Jager HI, Mulholland PJ, Parish ES. Indicators to support environmental sustainability of bioenergy systems. Ecological Indicators. 2011 Sep 1;11(5):1277-89.
17. SWERA. kathmandu: Alternative Energy Promotion Center. 2008.