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Alternative pathways for providing access to electricity in developing countries

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ABSTRACT

The discussion on electrification pathways tends to dangle between the merits of centralized on-grid versus decentralized off-grid electrification, and most of the time, both routes are promoted in parallel. However, the basis for choosing pathways has neither been very clear nor rational. This study compares three pathways for rural electrification considering (i) off-grid renewable energy (RE) technologies for individual households (ii) mini grids (with micro hydro and diesel generators) and (iii) grid extension. Different technological pathways are analyzed considering various technical and socio-economic parameters in two country cases: Nepal and Afghanistan. Levelized cost of electricity (LCOE) is taken as the main basis for comparison of the various options, in which both environmental externalities and life cycle costs are considered. The analysis shows that the micro hydro based mini grid technology is the most competitive alternative for electrifying isolated and remote rural areas in both countries. Individual household technology should be promoted only in places with scattered households where there is no possibility of mini grid solution. The choice of technology and the pathway adopted in Nepal seems functional, though some flaws within the pathways need to be addressed. In Afghanistan, the technological pathways for rural electrification are not well-defined and the country lacks a clear cut national policy framework for rural electrification. Here, micro hydro based mini grid would be a more sustainable proposition rather than diesel generators as promoted in the transitional phase. Afghanistan can benefit from lessons learnt in Nepal not least in the formation of markets for renewable technologies.

1. Introduction

Rural areas in many developing countries are sparsely populated, geographically isolated and of difficult accessibility. The electricity market in poor rural areas is characterized by low access rate and low load factors [1,2]. This increases the unit cost of electricity delivery [3,4]. Off-grid and on-grid options are normally promoted in parallel when pursuing rural electrification in many developing countries, although the basis for choice is not very clear. Both options are often implemented in line with political interests or donors' priorities. The proper resource assessment or analysis of the cost-efficiency of different pathways is often overlooked. Given the major costs of providing electricity to large populations, and the potential impacts of this endeavor, there is need for a more rational comparison of the options at hand.

The most common pathway for rural electrification has been to provide access through grid extension. This comes from the conventional mindset that prevailed for a long time when electrification was seen as the responsibility of a government utility [5]. Experience and practice have shown that extension of the grid line will not be enough to meet the immediate needs of electricity access of billions of rural people in developing regions. In fact, innovation in off-grid technologies, especially those based on renewable resources, deregulation of energy markets, and increasing private investments in electrification have shown new pathways for rural electrification. These new pathways have already resulted in higher electrification rates in many countries [6].

A large body of literature analyses the role and relevance of various alternatives for rural electrification, their dissemination and costs [7–14]. Wamukonya and Davis [15] employed household questionnaire survey technique to analyze and compare socio economic benefits of off-grid technology and grid line extension in Namibia. Oparaku [16] compared a centralized photovoltaic (PV) generating system of various capacities with the grid line extension for meeting different load requirements in a remote rural location of Nigeria using life cycle costing. Branker et al. [17] and Bhattacharyya [18] reviewed several methodological options for analyzing the off-grid electricity supply. Nguyen [19] examined economic feasibility of two off-grid technologies i.e. solar photovoltaic (PV)

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and wind power in the context of rural Vietnam, looking at their levelized cost of electricity (LCOE). Thiam [20] analyzed alternative pathways (off-grid versus on-grid technologies) in the context of Senegal using a similar methodology as Nguyen [19] with additional consideration of environmental externalities.

In this study, we used the LCOE to compare alternative pathways for rural electrification in Nepal and Afghanistan, taking environmental externalities and other life cycle costs into account. The main objective was to analyze the least cost technological alternatives and pathways for electrifying rural households in the two countries under the prevailing market and policy context. The paper also looked at how subsidy policies affect the competitiveness of the technologies, and evaluated whether the technological choices and pathways being applied in these two countries are leading in the right direction. The study analyzed rural electrification pathways that are in practice in Nepal and Afghanistan considering (i) off-grid isolated renewable energy (RE) technologies for individual households (Path-A), (ii) mini grid with micro hydro or with conventional fossil-based technology (Path-B), and (iii) grid line extension (Path-C).

Following this introduction, the second section of the paper discusses the electrification situation in Nepal and Afghanistan. The third section highlights alternative pathways for rural electrification and discusses the LCOE methodology adopted in the study. Results and analysis are discussed in the fourth section. In the fifth section, pathways chosen by the two countries in the context of resource availability, socio-economic situations and demography are considered when cross-checking the effectiveness of present pathways. Final conclusions are drawn in the sixth section. This paper will help policy makers and planners in the studied countries to better appreciate the costs behind different technological pathways and to understand the influence of subsidy in alternative pathways. Thus, the study provides basic guidance for decisions on the most appropriate technology for electrification.

Nepal and Afghanistan are landlocked and among the poorest countries in the world. Politically, both countries have a long history of conflict and insurgency. Both countries have a huge rural population (66% in Nepal and 93% in Afghanistan) yet to be served with electricity services [6,21]. When it comes to resources, both countries have similar resource conditions. Neither of them has fossil fuel resources. There are many similarities when it comes to the needs and opportunities for electricity provision in Nepal and Afghanistan.

The annual average solar insolation in Nepal varies from 3.5 to 7.0 kWh/m^2/day [22] and the estimated amount of days with sunshine in a year is 300 days [23]. Wind energy technology has not been harnessed in Nepal so far. However, efforts have been made to collect data on wind velocity at a height of 10 m in some selective locations [24]. Among those places, we have explored the wind energy alternative in Ramechhap (represents locations with medium annual average wind speed of 3.4 m/s), and in Kagbeni (represents locations with high annual average wind speed of 6.5 m/s) [24]. Regarding hydro resources, there are about 6000 rivers in the country (including rivulets and tributaries) with a total river catchment of 145,723 km^2 and annual average rainfall of 1500 mm [25–27]. A hilly topography from east to west gives abundant potential for hydro power in Nepal. The estimated economic potential of micro hydro in Nepal is about 50 MW [28].

In the case of Afghanistan, the annual average solar insolation varies from 4 to 6.5 kWh/m^2/day spread over 300 days of sunshine per year [29]. Similar to Nepal, wind energy technology has not been harnessed in Afghanistan so far. The potential for wind power in Afghanistan has not been considered in this analysis due the limited information available on wind resources in the country. Afghanistan has significant hydro resources with the river catchment area of 677,900 km^2, annual average rainfall of 300 mm and wide spread hilly topography [27,30].

2. Electricity situation in Nepal and Afghanistan

2.1. Electricity situation in Nepal

Nepal is a landlocked country with an area of 147,181 square kilometers (4.4 times smaller than Afghanistan) and a total population of 26.6 million as of 2011 [31]. Government policies in Nepal promote both on-grid and off-grid solutions for rural electrification. Off-grid electrification is promoted by Alternative Energy Promotion Center (AEPC), the government body formed to promote alternative energy technologies. Micro hydro and solar technologies are the current choices in Nepal because of the provision of government subsidy under two major programmes: Renewable Energy for Rural Livelihood (RERL) previously known as Rural Energy Development Programme (REDP), and Energy Sector Assistance Programme (ESAP). RERL is supported by United Nation Development Programme (UNDP), and World Bank, whereas ESAP is supported by Danish International Development Agency (DANIDA) and Norwegian Agency for Development (NORAD). The government of Nepal is in the process of merging all rural energy programmes into a single national programme.

On-grid electrification is developed by Nepal Electricity Authority (NEA), the national utility accountable for generation, transmission and distribution of electricity. Community Rural Electrification Department (CRED) has been established under NEA to perform community based rural electrification. Besides, there are some independent power-producers (IPP) who are involved in power generation which is then sold to NEA. The development of both on-grid and off-grid electricity generation in Nepal over the past years (2000/01–2008/09) is presented in Table 1. In the recent year 2008/09, the majority of power is generated from hydro power (2765 GWh) and a very small portion (9 GWh) comes from thermal

Table 1
Electricity supply from on-grid and off-grid in Nepal, 2000/01–2008/09.

Technology/descriptions	Fiscal year								
	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09
On grid (including NEA's, IPP's and electricity imported from India – in GWh)									
NEA hydro	1113.4	1113.3	1478.4	1345.5	1522.9	1568.6	1747.4	1793.1	1839.5
NEA thermal	27.14	17.01	4.4	9.92	13.669	16.1	13.31	9.17	9.06
IPP (hydro)	501.38	698.02	628.81	838.84	864.80	930.04	962.26	958.42	925.74
From India	226.54	238.29	149.88	186.68	266.23	241.39	328.83	425.22	356.46
Off grid (including pico/micro hydro mini grid and individual solar PV system – in GWh)									
Micro hydro	10.58	11.42	13.11	14.50	15.81	18.08	25.06	31.30	37.77
Solar PV	0.083	0.25	0.472	0.611	0.750	0.806	0.861	1.139	1.556
Total (on-grid and off-grid)	1879.1	2078.3	2275.1	2396.1	2684.1	2775.0	3077.7	3218.4	3170.1

Note: NEA: Nepal Electricity Authority; IPP: Independent Power Producer. Source: WECS, 2010; NEA 2010, [23,32].

plant using fossil fuel. There is also a significant portion of electricity (about 356 GWh) being imported from India [32]. Nepal has not been able to meet the growing electricity demand in the country, and load shedding of more than 14 h a day has been practiced in the recent years in those areas supplied with grid lines.

The grid line has reached mainly in urban areas and also some accessible village development committees (VDCs). In fact, out of 3915 VDCs in Nepal, only 2100 VDCs are connected to the national electricity grid. Solar PV and micro hydro technologies are typically supplying off-grid electricity particularly in rural remote areas. The contribution of off-grid electricity is comparatively small (39 GWh as of 2008/09) but has increased significantly in the last ten years, and has been instrumental in increasing electricity access in rural areas [33]. Presently, 44% of the total population of Nepal has access to electricity, 90% in the urban areas and 34% in the rural areas. This is a comparatively better access rate than African countries with similar per capita income [6,34].

2.2. Electricity situation in Afghanistan

Afghanistan is also a landlocked country with an area of 647,500 square kilometers and a total population of 32.4 million as of 2011 [35]. Damage in the infrastructure of Afghanistan due to a decade long political insurgency, poor maintenance, lack of investment and poor technical and management capacity has hindered the country's development, pushing it several years back [36]. Before 1978 i.e. before the major insurgency, the total installed power capacity in the country amounted to 396 MW. By 2002, the country's functional installed capacity had decreased to 243 MW.

Huge international resources have been mobilized in the form of development assistance to support Afghanistan's rehabilitation after the downfall of the Taliban government in 2002, including massive infrastructure development. As a result, the country's electricity generation capacity increased to 464 MW by 2007 including 15 MW from off-grid micro/mini hydro. Additional power was imported from neighboring countries to meet increasing national demand [37]. At present, only 15.5% of the population has access to electricity, and only 7% of the rural areas are served [34,38]. The electricity contributions from various sources between 2006 and 2010 are shown in Table 2.

For the rural electrification, Ministry of Rural Rehabilitation and Development (MRRD) has implemented a program "Energy for Rural Development in Afghanistan" (ERDA) with the support of UNDP and other donors. Presently, ERDA is supporting the implementation of micro hydro schemes in different provinces of Afghanistan, and has also mandate to implement the use of other rural energy technologies such as solar and wind power. ERDA has installed 746 kW of micro hydro projects in the last 4 years [40]. National Solidarity Program (NSP) is another important programme implemented by the Ministry of Rural Rehabilitation and Development (MRRD), and supported by the World Bank. In this program, community development councils are being created which implement various projects including many rural energy projects. NSP has electrified 600 villages (i.e. about 72,000 households) with solar PV across Afghanistan [41]. In addition, the Afghanistan Clean Energy Programme, an USAID initiative, is also promoting clean energy. In line with these efforts and the challenges ahead, the pathways that Afghanistan is taking towards rural electrification are worth evaluating.

Table 2
Supply of electricity in Afghanistan 2006–2010, by source (in GWh).

Technology/descriptions	Year				
	2006	2007	2008	2009	2010
Hydro	644.0	674.7	605.6	741.7	910.1
Thermal	212.9	170.0	197.4	87.9	101.5
Imported	432.3	441.0	752.2	1013.1	1572.6
Total	1289.2	1285.7	1555.2	1842.7	2584.2

Source: AEIC, 2012 [39].

3. Methodology

Rural electrification is usually achieved through three distinct pathways i.e. isolated off-grid individual home system (Path-A), mini grid (Path-B) and national grid line extension (Path-C). Fig. 1 illustrates these three pathways. Reference technologies: solar home system (SHS), wind home system (WHS), micro hydro (MH), conventional diesel generators (DG) and the grid extensions are chosen as options for analysis in this study. These technologies were selected based on existing practices, policies, and technological developments observed in the studied countries. They are then compared using LCOE. LCOE is a comparative analysis tool which provides benchmarking to evaluate the cost effectiveness of electricity generation from various technologies [17,42]. This approach is used to quantify and compare the monetary value of electricity produced from various generation technologies. It uses life cycle costs instead of simple capital cost comparison [20]. Our analysis includes environmental costs, considering emissions factors from the different generation technologies and monetization of the burdens caused by these emissions to society. The methodology of LCOE used here is an elaboration of the methods applied by Nguyen [19] and Thiam [20].

LCOE can be highly sensitive to input assumptions. Thus, clear and transparent assumptions are important for understanding and accuracy. Rather than using a single value of a particular input parameter into the LCOE model and getting a single LCOE value as output, we looked at a data range for the particular input parameters based on the best available data. This increases the level of certainty in the results. We further carried out some sensitivity analysis to reflect the uncertainty associated with the various parameters viz. variation in the load factors, rise in the fuel price (in case of fossil based technology), and distance from the grid, load densities and availability of capital subsidy.

Assessment was done for Nepal and Afghanistan, and cost references were taken from local market prices as of 2011. In the case of Nepal, data were collected from several projects implemented under Alternative Energy Promotion Center/Ministry of Environment, Regional Renewable Energy Service Center (RRESC), and the private companies. In the case of Afghanistan, availability of systematic data was a major constraint. Data were collected from National Solidarity Programme (NSP) and National Area Based Development Programme (NABDP) under the Ministry of Rural Rehabilitation and Development.

Selection of technology, estimation of energy output and economic assessment of alternative technologies create a comparative basis for different pathways. The methods for estimating energy output from various technologies and their economic analysis considering the externalities are discussed in more detail in the following sections of this chapter.

3.1. Technology selection and energy estimation in Nepal and Afghanistan

Stand-alone technologies like solar home systems (SHS) and wind home systems (WHS) are promising off-grid technologies for remote rural electrification in Nepal. Wind technology is not much explored yet but a wind resource mapping has been done with the support of the United Nations Environment Programme (UNEP), and some small wind generators have been installed for demonstration

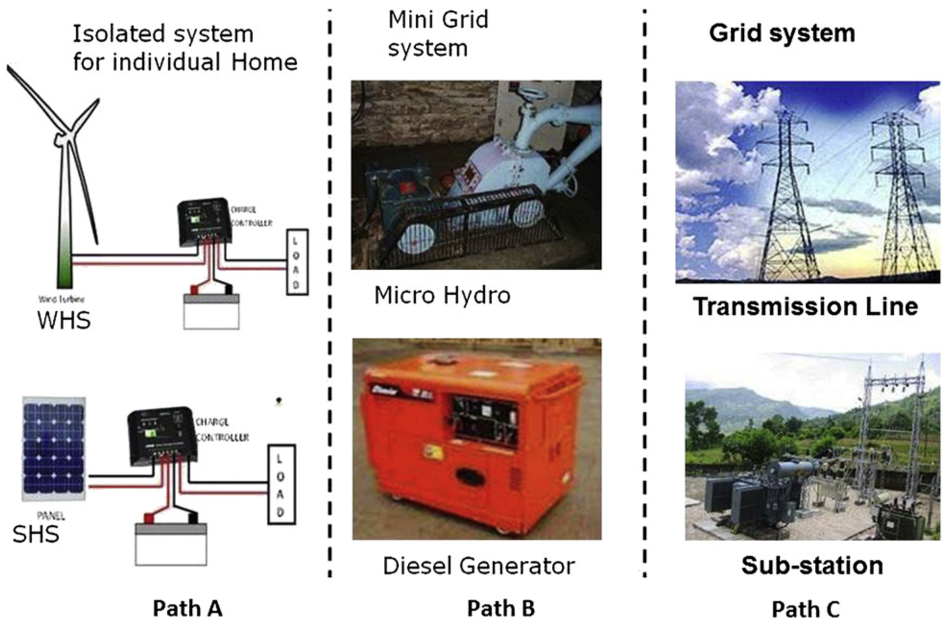

Fig. 1. Pathways for rural electrification in Nepal and Afghanistan. Note: Other generation sources than illustrated are possible in each pathway. Photo Source: MEC Consultancy (P) Ltd. and Him Hippo Company (P) Ltd, Nepal.

purposes. Micro hydro is very popular in rural electrification of Nepal in connection with mini grids, while diesel generator sets are only used in some places close to road heads but without access to grid lines. The subsidies in place only support the renewable based electrification in Nepal [43].

In this paper, we discuss three specific pathways for rural electrification in Nepal. Path-A includes the following technological options for off-grid electrification: (i) solar home system of 40 Wp, and (ii) wind generator set of 400 Wp. Path-B analyzes mini grid options using (i) micro hydro of 25 kW and 50 kW and (ii) diesel generator of 20 kW. Path-C analyzes the electrification option through grid line extension.

In the case of Afghanistan, the source of electricity is mainly solar home system, micro hydro power and diesel generators. No records on the exploitation of wind energy were found. We analyzed the levelized cost of solar home system (60 Wp), micro hydro (25 kW and 50 kW) and diesel generators (20 kW).

After choosing the reference technologies for the analysis, we estimated the availability of energy for the application of renewable energy technologies. Energy produced by these technologies is location specific and hence differs in the cases of Afghanistan and Nepal. The amount of energy generated depends on the meteorological conditions and is estimated based on the annual average data on the resources availability. The electricity generated by a solar PV system depends upon the surface area, daily solar insolation and the time of exposure to the sun. The annual energy produced (E_s) by a solar panel can be expressed by Equation (1)

$$E_s = \eta_s * I * A_{\text{surface}} * 365 \tag{1}$$

where, η_s is the system efficiency including battery charging and discharging, charge controller and wirings. "I" is the annual average solar insolation kWh/m^2/day and "A_{surface}" is the surface area. Further, the surface area can be expressed in terms of the nominal power of the module. In addition, the insolation depends on the surface orientation. With an assumption that the surface of the module is tilted at an angle equal to the latitude of the location, the relation can be further expressed as Equation (2).

$$E_s = \eta_s * (I) * \left(\frac{W_p}{I_0}\right) * 365 \tag{2}$$

where, W_p is the peak capacity of the module and "I_0" is the standard insolation (1000 W/m^2) chosen for defining watt peak of the solar modules by the manufacturers [44].

For the wind turbine, the power output varies with the cube of the average wind speed. So, wind velocity is central when determining the amount of power that can be generated. Thus, to estimate the quantity of energy produced by a wind turbine in a given site, sound knowledge on the wind distribution pattern at the location is necessary. Though the wind distribution varies from site to site, the distribution normally follows the Rayleigh distribution function, which is basically a probability density function. If we look at such distribution, the probability of winds occurring at low speeds and at high speeds are minimum and the probability of the middle speed are maximum [45].

The Weibull distribution further simplified the distribution function and represents the wind speed distribution. If V_a is the average wind speed, then the probability function $f(v)$ to have the wind speed of v can be expressed as in Equation (3)

$$f(v) = \pi * \left(\frac{v}{2}\right) * \left(\frac{1}{V_a}\right)^2 * \exp\left[\left(\frac{-\pi}{4}\right) * \left(\frac{v}{V_a}\right)^2\right] \tag{3}$$

The annual energy production from a wind turbine in a location with an annual average velocity of V_a can be estimated by the following Equation (4) [19].

$$E_w = \sum_{v=1}^{25} \eta_s * f(v) * P(v) * 8760 \tag{4}$$

where, $P(v)$ is the turbine power at speed v; $f(v)$ is the probability density function; η_s is the system efficiency. All the above equations have been used in estimating the potential annual energy production in this paper.

The available energy (E_M) from the micro hydro power plant depends upon the gross head from the pipeline intake to the powerhouse (H_g) and the design discharge through the pipeline (Q_d). The available energy can be estimated using Equation (5).

$$E_M = \eta_s * \rho * H_g * Q_d * 9.81 * 8760 \tag{5}$$

where, η_s is the system efficiency and ρ is the density of the water. Micro hydro projects are mostly run of river type and are normally designed with 11 month exceedance flow (i.e. design discharge should be available at least 11 months in a year) [46]. Micro hydro is a site specific technology and thus the available discharge and head vary significantly from site to site. In this study, the design power generation and the availability factor has been used to estimate the energy generation.

3.2. Economic analysis

Resource availability and the economic analysis of selected energy technologies help to select the least cost option among available alternatives. After the energy estimation, the financial and economic data were then analyzed to calculate the LCOE of various reference technologies.

3.2.1. Calculation of levelized cost of electricity (LCOE)

LCOE is a means to compare alternative technologies with different scales of operation, investment or operating periods. Levelized cost is the discounted average cost per kWh of useful electrical energy produced by the system over the life period of the technology which can be expressed as Equation (6).

$$\text{LCOE} = \frac{\text{Total life time cost of the project}}{\text{Total life time useful electricity produced}} \tag{6}$$

LCOE is the net present value of total life time costs of the project divided by the quantity of energy produced over the system life time. LCOE provides the information on the relative cost competitiveness of technologies and a transparent method to show the key factors affecting the costs of different technologies [47,48]. The composition of the levelized cost model used in this paper is represented in Fig. 2.

As shown in Fig. 2, meteorological information is important to evaluate the resource potential of the technology in a particular location. The parameters associated with the system reliability such as life spans of the components and system, and plant availability are another important input in estimating the LCOE. Similarly, the performance indicators such as system losses, efficiency and load factors, financial parameters such as system capital cost, installation cost, operation and maintenance cost, discount rate, price escalation rates are also important factors in determining the LCOE of technologies. The residual value of the plant after its life time, and the system degradation factor have not been taken into account for simplification. We now proceed describing the method for calculating the levelized cost of various technologies.

Further expanding the Equation (6), the life time costs of the project is basically the discounted costs incurred each year and summed over the life time. These costs include capital costs (C_c), operation and maintenance cost (C_{om}), replacement cost (C_r), fuel cost (C_f) and the environmental externalities cost (C_e), which are further discussed in this section. All these costs are calculated using the similar methodology used by Nguyen [19]. If the amount of useful electricity produced over the total life period of the system is (E_l) then LCOE is represented by Equation (7) as follows:

$$\text{LCOE} = \frac{C_c + C_{om} + C_r + C_f + C_e}{E_l} \tag{7}$$

Capital costs (C_c) are the initial investment for purchasing equipment and installing them before the system is put in operation i.e. in year zero. If initial investments have been made during

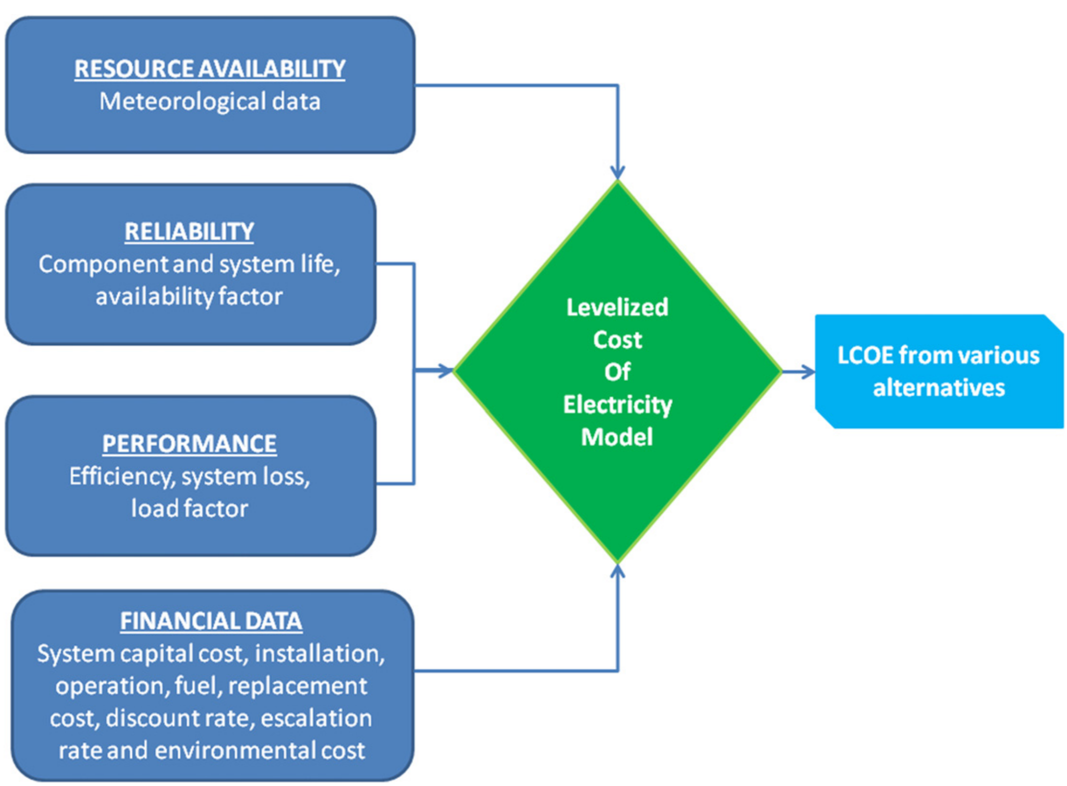

Fig. 2. LCOE model.

several years before the plant comes into operation, then all these investments should be discounted to the year zero (start year of plant operation). This is applicable in the case of micro hydro installations which may take a few years to be installed.

Operation and maintenance costs (C_{om}) are the costs incurred during the life-time operation of the system. This includes the recurring costs for staffing, and repairing and maintaining the components as per required. The operation and maintenance costs are low for renewable energy in comparison to the fossil based conventional technologies. If “AOMC” represents the annual operation and maintenance cost of the year one, “e_0” is the general escalation factor and “r” is the discount rate, “N” is the life span of the technical system then the life time operation and maintenance cost (C_{om}) can be expressed as in Equation (8).

$$C_{om} = \mathrm{AOMC}^*\left(\frac{1+e_0}{r-e_0}\right)\left(1-\left(\frac{1+e_0}{1+r}\right)^N\right) \tag{8}$$

Replacement Cost (C_r) is associated with the investment needed for replacing equipment or components in the system that have shorter life span than the overall project under evaluation. The replacement cost can be expressed as in Equation (9).

$$C_r = \sum_{i=1}^{v}\left\{\mathrm{Item\ Cost}_i^*\left(\frac{1+e_0}{1+r}\right)^{N_R}\right\} \tag{9}$$

where, “Item Cost$_i$” is the replacement cost for the item “i” with the life span of N_R; and “v” is the number of components to be replaced.

Fuel Cost (C_f) represents the cost invested in fuels during the life time of the project. In the case of diesel generators, it represents the total cost invested in the diesel needed for operation of the generator. If “AFC” is the annual fuel cost and “F_f” represents the yearly increment in the fossil fuel price, then annualized fuel cost over the project period is represented by Equation (10).

$$C_f = \mathrm{AFC}^*\left(\frac{1+F_f}{r-F_f}\right)^*\left[1-\left(\frac{1+F_f}{1+r}\right)^N\right] \tag{10}$$

Environmental Externalities Cost (C_e) is the external cost of energy use and this can be represented in monetary terms based on the value of the different impacts caused by the various technologies (see Section 3.3). Internalization of external costs into the cost of energy production is a smart way to pursue reduction of negative impacts of energy supply and use [49]. CO_2 emissions from the power generation are one of the major contributors of global warming, and emission of NO_x and SO_x have impact on health. We considered these impacts in this paper. If E is the annual energy generated and EF is the emission factor in (Kg/kWh) and D_{cost} is the marginal external/damage cost ($/Kg), then the environmental externalities cost over the project period is estimated by Equation (11).

$$C_e = C_{e\_\mathrm{marginal}}{}^*E^*\left(\frac{1+e_0}{r-e_0}\right)\left(1-\left(\frac{1+e_0}{1+r}\right)^N\right) \tag{11}$$

where,

$$C_{e\_\mathrm{marginal}} = (\mathrm{EF}^*D_{\mathrm{cost}})_{NO_x} + (\mathrm{EF}^*D_{\mathrm{cost}})_{SO_x} + (\mathrm{EF}^*D_{\mathrm{cost}})_{CO_2} \tag{12}$$

3.2.2. Discount rate

The role of discount rate is important in estimating the levelized cost. This is the real annual interest rate, also called the real interest rate, which is used to convert one-time costs into annualized costs. The annual real interest rate is related to the nominal interest rate of the bank and has relation with the inflation rate. This is represented by the Equation (13).

$$\mathrm{Discount\ Rate}(r) = \frac{(\mathrm{Nominal\ interest\ rate} - \mathrm{Inflation\ rate})}{(1+\mathrm{Inflation\ rate})} \tag{13}$$

In this study, we took the average of the projected inflation rate between 2011 and 2015 using the data of the International Monetary Fund (IMF). For the case of Nepal, it was 5% [50], and for the case of Afghanistan, it was 4% [51]. The bank's nominal interest rate in lending was 16% (Nepal) and 18% (Afghanistan). Thus, the discount rates adopted for the calculation were 10% and 13% respectively.

Life time electricity is the present worth of the total useful electricity (E_l) produced over a life span of N years and discounted at the rate “r”. The estimation of annual energy production from different resources has already been discussed in Section 3.1. If “E” is the energy produced annually, then

$$E_l = E^*\left[\frac{1-(1+r)^{-N}}{r}\right] \tag{14}$$

The LCOE from individual home system (Path-A), mini grid systems (Path-B) and extended grid line (Path-C) areas were then estimated using Equation (7) as mentioned earlier.

3.3. Internalizing environmental external costs

Consideration of externalities offers an indication of the cost of damages associated with different energy alternatives [52]. This helps in assessing trade-offs between different available energy options looking beyond the cost of technology [49]. A couple of studies have estimated the external cost based on the approach suggested by the European Commission's ExternE Project [20,49,53,54]. The methodology suggested by ExternE considered the life cycle impact of the technologies [55]. In our study, we considered impacts due to emissions at different stages along the life cycle activities (i.e. taking into account construction, operation and dismantling, and the fuel cycle of the technologies). The damage costs (specifically the damages related to health) are region specific [56]. In fact, no specific studies were available on this topic for Nepal and Afghanistan. In our calculations, we have used the marginal external/damage cost (i.e. 0.021 €/kg for CO_2, 4.4 €/kg for SO_x and 1.16 €/kg for NO_x) suggested by Zhu et al. [53] for the case of India, which was the closest proxy found in the literature for our cases. All these costs have been converted to US dollar 2011.

The emission factors (as seen in Table 3) for the renewable energy technologies are very small compared to diesel generators [20,57]. Since the grid power in Nepal is largely based on hydro power (particularly run of river type), the emission from grid line extension is also quite small.

4. Results and analysis

Having discussed the resource availability, methods for energy estimation, economic analysis and internalization of external costs, we now present the results and analysis of supplying electricity through the different technological pathways being followed in our two case studies: Nepal and Afghanistan.

4.1. Path-A: Providing access to electricity with off grid home systems – LCOE for SHS and WHS

In this section, we analyzed LCOE for SHS (solar home system) in Nepal and Afghanistan, and WHS (wind home system) in Nepal.

Table 3
Emission factors for various technologies (considering life cycle emission).

Emissions	Technologies				
	Solar PV[a]	Wind[a]	Micro/mini hydro[a]	Diesel[b]	Grid line extension[c]
CO_2 (g/kWh)	83.43	7.90	5.92	965	3.36
NO_x (g/kWh)	0.193	0.01	0.01	2.96	–
SO_x (g/kWh)	0.322	0.02	0.01	0.95	–

[a] The emission factors for Solar PV, Wind, Micro/mini hydro are adopted from the database of CASES [58].
[b] Emission factor (g/kWh) for diesel is derived from emission factor (g/GJ) × heat rate (GJ/kWh) referred from Kordy et al. [57].
[c] Emission factors for the electricity consumption through extended grid line is taken from Brander et al. [59] for Nepal.

Although WHS has not been explored in none of the two countries, some demonstration schemes have been launched in Nepal [60].

SHS basically comprises solar PV modules, a bank of battery, charge controller and supplies for the DC output. DC appliances like CFL lamps, TVs and small radios are the most common loads served by such system. WHS comprises the wind generator and its mounting accessories; the other components are similar to SHS. The details of technical and cost parameters for SHS and WHS, and assumptions are presented in Table 4.

LCOE from SHS ranged from 0.55 to 1.10 USD/kWh in Nepal, and from 0.99 to 1.61 USD/kWh in Afghanistan. The variable range of LCOE within the country is due to variations in insolation at different locations. The higher the insolation is, the lower the value of LCOE that can be achieved and vice versa. The LCOE for solar PV is high in Afghanistan when compared with Nepal. There is a high risk factor associated with the PV business in Afghanistan due to security problems and weak market structure. Meanwhile, the solar PV market already enjoys a well-defined structure in Nepal [13]. The cost of solar PV systems has gone down with learning-by-doing and economies of scale in the global market [61]. This will certainly help in bringing down the PV technologies cost in the developing countries as well. In the case of Afghanistan, the price for SHS has been going down at the rate of 3%–5% per annum [62].

The analysis showed that the LCOE for WHS varies from 0.44 to 3.1 USD/kWh in Nepal depending upon the wind speed. WHS could be more attractive than SHS in locations with high average wind speed. The wind energy market in Nepal is at very primitive level and there are very few local companies manufacturing the wind turbine. However, the development and involvement of local companies are important to disseminate the technologies across the country. The capability of building micro-wind turbines at local market helps to create a resilient energy system, making a strong supply chain for spare parts and training of local manpower needed for repair and maintenance, in addition to boosting the local economy [63]. Creating well-organized supply chains could also help to reduce the cost of technology significantly. The wind energy sector in Nepal is currently at the shallow start of the life cycle "S curve" of the business where only early adopters and niche markets are buying or investing on the technology. Therefore, some initial support in terms of technical and financial assistance is needed for the formation of market infrastructure. The Government of Nepal has introduced subsidy on WHS in 2009. At present, the national wind energy policy of Nepal is under preparation which may help to establish a supportive environment to exploit the wind resources in Nepal in the near future [60].

Table 4
Technical and cost parameters of SHS and WHS in Nepal and Afghanistan, 2011.

Country	Nepal		Afghanistan
Description/specification	SHS[a]	WHS[b]	SHS[c]
Module capacity in watt	40	400	60
System cost in USD	132	920	305
12 V-battery AH-capability	36 AH	4 × 100 AH	100 AH
Battery life time in years	3	3	3
Battery cost in USD	56	289	135
Charger controller life in years	10	10	10
Charge controller cost in USD	14	125	30
Installation/transportation cost in USD	25	174	34
System life time	20	20	20
Annual O&M cost in % of total system cost (0.5 for SHS and 2.5% WHS)	2.2	38	2.7
Solar insolation kWh/m^2/day	3.5–7.0	–	4.0–6.5
Average wind velocity (m/s)	–	3.4–6.5	–
Estimated levelized cost in USD/kWh[d]	**0.55–1.10**	**0.44–3.1**	**0.99–1.61**

[a] Data Source: Dibya Urja Pvt. Ltd, Nepal.
[b] Krishna Grill, Nepal.
[c] MRRD/UNDP, Afghanistan.
[d] The environmental external cost for providing electricity from solar and wind technologies is very low (less than 0.3% of LCOE).

4.2. Path-B: Providing access to electricity with mini grid technologies – LCOE for MH and DG

Mini-grid electrification from renewable resources like micro hydro or diesel generator sets are possible alternatives for supplying electricity in many remote rural areas of the developing countries. We analyzed the LCOE for these two technological options in mini-grids in Nepal and Afghanistan.

4.2.1. Micro hydro (MH) for the rural electrification

Micro hydro is a very site specific technology and cost will tend to vary in line with physical features of the site. These features determine the length and types of civil components like headrace structure, penstock, and type of electromechanical equipment such as turbine and also length of electrical transmission distribution system. Typical micro hydro projects of 25 kW and 50 kW were adopted for the analysis in both Nepal and Afghanistan. A previous study has shown that the cost of MH projects decreased with the increase in plant size in Nepal, indicating economies of scale [13]. Small and minor replacements might be needed in micro hydro power plants but, in general, these plants can operate without any major replacement cost during their full life span [64]. Here, small replacement costs were taken into account in the regular operational and maintenance costs. Normally, construction of a micro hydro takes 1.5–2.5 years. We assumed a construction period of 2 years with equal distribution of the investment along the two years. Technical and cost parameters, and assumptions used in this study are indicated in Table 5.

In Nepal, the estimated LCOE varies between 0.28 and 0.35 USD/kWh for the 25 kW plant, and between 0.25 and 0.30 USD/kWh for the 50 kW plant. The LCOE is relatively higher in Afghanistan, which is, between 0.50 and 0.67 USD/kWh for the 25 kW plant, and between 0.34 and 0.47 USD/kWh for the 50 kW plant. The higher LCOE in Afghanistan is due to higher installation costs and comparatively lower average load factors. The analysis further shows that the LCOE varies little with the size of the technology but largely depends on the initial capital investment.

A sensitivity analysis was done for a 25 kW micro hydro project with upper value of cost per kW. Fig. 3 shows that LCOE decreases with the increase in the load factor. The sensitivity of LCOE is high with the load factor up to 40%. Once the load factor crosses 40%, the variation in LCOE is less significant.

Normally, the rural electrification is characterized by low load factors resulting in high LCOE. So, promotion of the productive end

Table 5
Technical and cost parameters for MH projects in Nepal and Afghanistan, 2011.

Countries	Nepal		Afghanistan	
Description/plant size→	25 kW	50 kW	25 kW	50 kW
Installation cost per kW[c] in 000 USD	2.8–3.5[a]	2.5–3.0[a]	3.0–4.0[b]	2.5–3.5[b]
Yearly O & M cost in terms of total project cost	5%	5%	5%	5%
Availability factor	0.9	0.9	0.9	0.9
Load factor	0.3	0.3	0.2	0.25
Life span	20	20	20	20
Estimated levelized cost in USD/kWh[d]	**0.28–0.35**	**0.25–0.30**	**0.50–0.67**	**0.34–0.47**

[a] Data Source: RRESCs, ESAP, Nepal.
[b] MRRD/UNDP, Afghanistan.
[c] Installation cost including cost of generation and distribution.
[d] The environmental external cost for providing electricity with micro hydro technologies is very low (less than 0.1% of LCOE).

uses in the rural electrification projects is very important to increase the load factor and turn these projects into financially attractive investments.

4.2.2. Diesel generator (DG) for the rural electrification

Diesel generators have often been used in commercial and industrial sectors as back-up power. Diesel generators (DG) are also commonly used for rural electrification in developing countries not least because the initial installation of such generators is cheap compared to renewable energy technologies. For decentralized electrification, small size DG sets are commonly used where low load factors prevail [4]. DG sets have been extensively used in Afghanistan for rural electrification whereas they are not so common in Nepal. As per the National Solidarity Programme of Afghanistan, about 1310 diesel schemes have been installed in various provinces with the total installed capacity of 47.25 MW and each ranging from 4 kW to 280 kW [65]. In this section, we look at the LCOE of DGs.

A diesel generator (brushless AC, 3 phase, 400 V, power factor 1.0 with revolving field, and directly coupled) has been taken as the reference for cost analysis. The technical and cost information of DG sets in Nepal and Afghanistan is given in Table 6. The estimated LCOE considering environmental externalities is USD 0.599/kWh (Nepal) and USD 0.769/kWh (Afghanistan). The LCOE for DG increases by 6% when environmental externalities are considered.

The LCOE for DG was estimated assuming 4% fuel price escalation factor. However, the cost of fossil fuel is volatile in nature and it may keep on fluctuating between high and low values. Sensitivity analysis was performed to look at the impact of fuel price escalation on the LCOE. This is shown in Fig. 4.

The analysis revealed that fuel cost had a significant impact on the LCOE. With 25% escalation in the fuel price, the LCOE increased with 60%. Further, in remote areas, the fuel needs to be transported by porters and mules. Thus, the price of the fuel in the remote location is high because of additional transportation cost. The transportation cost increases with the remoteness and in some remote hilly areas, they are as significant as the cost of the fuel itself. Although remoteness ultimately impacts the fuel price, a separate sensitivity analysis for remoteness had not been made. In any case, the increased fuel price due to remoteness further make this option financially unattractive and also reliability of fuel supply in such remote areas tends to be uncertain.

Table 6
Parameters for analysis of LCOE of DG sets in Nepal and Afghanistan, 2011.

Country	Nepal	Afghanistan
Description/specification	DG	DG
Diesel generator capacity in kW	20	20
Generator, accessories, installation cost in USD	12,500[b]	14,100[a]
Cabling, distribution cost in USD (with 200 HH/Km^2 and 200 HH and 4 km/km^2)	8345	10,014
System life time in operational hours	20,000	20,000
Fuel tank cost in USD	700	780
Fuel tank life in years	3	3
Annual operational and maintenance cost in USD (5% for total cost of DG installation)	1081	1245
Diesel price in USD/lit	1.0	1.25
Diesel price escalation	4%	4%
Estimated LCOE in USD/kWh	**0.569**	**0.736**
Estimated LCOE in USD/kWh (considering externalities)	**0.599**	**0.769**

[a] Data Source: NSP, Afghanistan.
[b] Kirloskar Diesel Generator.

4.3. Path-C: Providing access to electricity with national grid line extension

In Nepal, about 185,000 households have been electrified through the grid line under the community rural electrification programme, which used 1781 km of Medium Voltage (MV)

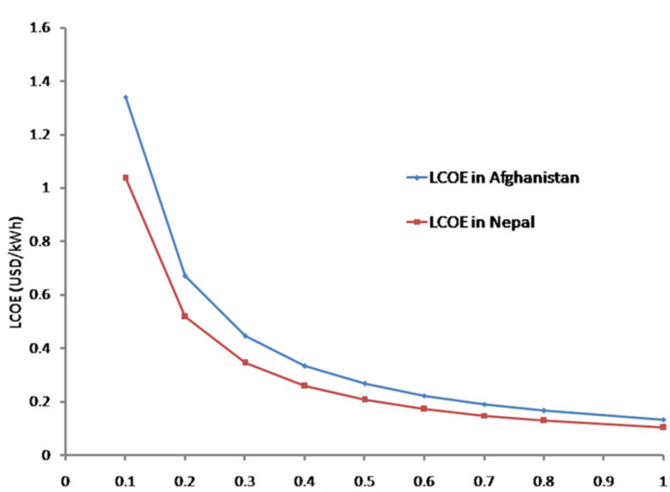

Fig. 3. Variation in LCOE in a 25 kW MH-project as a function of load factors.

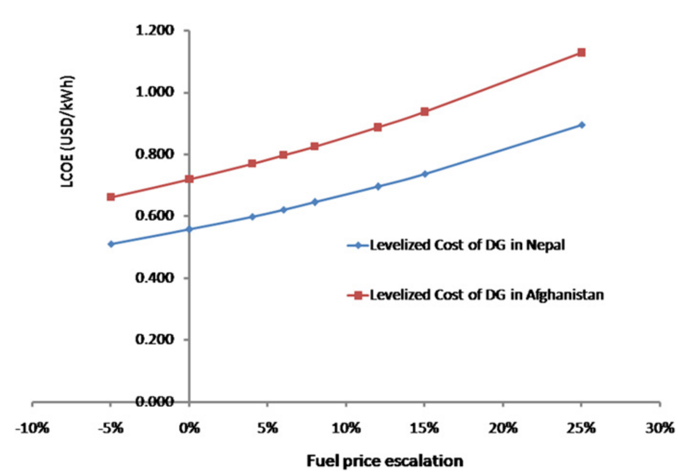

Fig. 4. Variation in LCOE with fuel price escalation in a DG.

transmission lines, 5792 km of low voltage distribution lines and 2905 numbers of transformers installed by the end of FY 2009/10 [35]. In Afghanistan, the transmission grid infrastructure has been badly damaged due to war [37], and it will take several years to be rebuilt. Afghanistan faces a huge challenge to extend the grid due to the difficult terrain to be overcome and scattered settlements to be served [66]. At present, extension of the grid in rural areas is not a prime issue. Therefore, we analyzed the extension of grid in the case of Nepal only.

The cost for grid line extension in rural areas depends on the average energy demand per household, the load density (i.e. number of households per km^2 periphery of service area), number of households to be served and the distance from the grid line. The technical and cost parameters for grid line extension in Nepal are tabulated in Table 7.

The analysis was done with combinations of the following variable sets, which resembles the rural conditions of Nepal: (i) the load density of 10 households per Km^2 (Mountains region), 50–75 Households per Km^2 (Hilly regions) and 100–200 households per Km^2 (Terai Regions – plain area bordering with India); (ii) household to be served from 50 to 1000; and (iii) distance of grid line extension from MV substation from 6 km to 25 km [70,71]. For the analysis of grid line extension cost, the marginal cost of electricity supply to the load centers is required. Average Incremental Cost (AIC) can be used as a subset of marginal costing techniques and be adopted as a proxy in electricity system analysis [68]. This cost has been projected to be 5.83 cents/kWh for the year 2014 in Nepal [68]. The same value had been adopted for this analysis. Besides, transmission and distribution cost per Km was estimated using unit cost model based on the current market price. The analysis was then done with the technical and cost parameters as given in Table 7. Productive end uses and future load growth may impact the levelized cost using the grid line extension, if the rural areas have good chances of developing rural industries and develop high load growth rates. For simplicity, we did not consider these two factors in our estimation.

The estimated LCOE in case of grid line extension is tabulated in Table 8 for different load profiles. LCOE from a grid extension largely depends on the numbers of household to be served, followed by the load density and the distance from the Medium Voltage (MV) substation of the grid line to the village. The analysis showed that serving a village with 1000 households with the load density of 200 households/Km^2 and 6 km from the MV substation had the lowest LCOE (0.106 USD/kWh). This is the case of rural areas in the Terai region. Meanwhile, the LCOE for serving a village of 50 households, with scattered settlement (10 Households/Km^2) and 25 km away from the MV substation was very high (1.34 USD/kWh). This is a typical case of remote villages in mountainous regions. The analysis revealed that the grid extension is only suited for the electrification of rural areas in the Terai region and some accessible hilly areas with larger population to be served. Most of the rural areas are characterized by scattered settlement and small number of households located far away from the grid lines, and under such cases, off-grid technology is often more competitive.

Table 8
LCOE (USD/kWh) from the grid based power supply at different load profiles in Nepal.

Load density (household/Km^2)		Households to be connected in grid				
		50	100	200	500	1000
MV substation distance = 6 km						
10	Mountain	0.519	0.371	0.297	0.253	0.238
50	Hill	0.407	0.259	0.186	0.141	0.126
75		0.398	0.250	0.176	0.132	0.117
100	Terai	0.393	0.246	0.172	0.127	0.113
200		0.386	0.239	0.165	0.120	0.106
MV substation distance = 10 km						
10	Mountain	0.692	0.457	0.340	0.270	0.246
50	Hill	0.581	0.346	0.229	0.159	0.135
75		0.571	0.337	0.220	0.149	0.126
100	Terai	0.567	0.332	0.215	0.145	0.121
200		0.560	0.325	0.208	0.138	0.114
MV substation distance = 20 km						
10	Mountain	1.125	0.674	0.448	0.313	0.268
50	Hill	1.014	0.563	0.337	0.202	0.157
75		1.004	0.553	0.328	0.193	0.148
100	Terai	1.000	0.549	0.323	0.188	0.143
200		1.000	0.549	0.323	0.188	0.143
MV substation distance = 25 km						
10	Mountain	1.342	1.064	0.675	0.442	0.365
50	Hill	1.230	0.909	0.521	0.288	0.210
75		1.221	0.896	0.508	0.275	0.197
100	Terai	1.216	0.890	0.502	0.268	0.191
200		1.209	0.880	0.492	0.259	0.181

Table 7
Technical and cost parameters for grid line extension in Nepal.

Description/Specification	Value
General escalation factor	0.05
Average load demand (kWh/month/HH)[a]	0.25
Transmission line	
AIC of electricity supply (USD/kWh)[b]	0.058
11 kV line extension cost (USD/Km)[c]	4608
Annual O & M cost of 11 kV transmission line including transformer (USD/Km/yr)	252
Transformer 11 KV[d]	3796
Distribution line	
Distribution line length per Km^2 load area (Km/Km^2)	4
Distribution line extension cost (USD/km)[p]	2403
Annual O & M cost of distribution line (USD/Km/yr)	120
Service wire connection and house wiring (USD/HH)	83
Overall transmission/distribution line loss	0.1
Life span	40

[a] Source: GIZ, 2011 [67].
[b] ADB, 2004 [68].
[c] Estimation using unit cost model.
[d] NEA, 2011 [69].

4.4. *Influence of capital subsidy in the competitiveness of technologies*

Subsidy is one of the policy instruments used in many developing countries to promote and accelerate electricity access. However, if the subsidies are technology based, it is possible that the specific technology supported by the subsidy will be favored and limit the dissemination of other potential technologies. For example, the subsidy policies and programmes supporting solar PV and micro hydro technologies have been instrumental in the formation of markets for these technologies in the last two decades in Nepal [13]. Meanwhile, the WHS market was not explored in the past due to absence of subsidy and specific support programme. As a matter of fact, the development of WHS is still in demonstration phase. However, the government of Nepal has introduced subsidy for WHS in the recent years. This has opened the space for WHS to become a competitive solution in many isolated areas where there is excellent average wind speed. The present subsidy level for various technologies in Nepal is shown in Table 9.

Unlike Nepal, Afghanistan has been promoting off-grid electrification without any commonly defined subsidy policy. Different rural electrification programmes supported by different donors have set their own level of subsidy and, in most cases; the subsidy is

Table 9
Subsidy for various off-grid technologies in Nepal.

Technologies	Subsidy in USD (as defined in policy)	Subsidy in USD/kWh[a]
Solar PV (40 W_p)	83 per system	0.147
Wind turbine (400 W)	1354 per kW (Max)	0.104
Micro hydro (25 kW)	1736 per kW (Max)	0.032

Source: AEPC, 2009 [43].
[a] Estimated for higher value of solar insolation and wind speed.

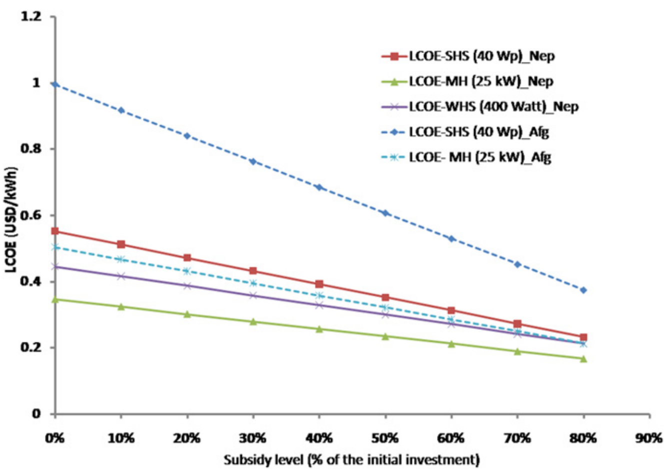

Fig. 5. LCOE as a function of subsidy (Nepal and Afghanistan). Note: SHS: Solar Home System, MH: Micro Hydro, WHS: Wind Home System.

80%–100% of the total technology cost. However, excessive subsidies reduce the significance of competitiveness and may divert from the most cost effective pathways for electrification.

Fig. 5 shows the role played by subsidy when considering LCOE for various technology options. SHS needs the highest level of subsidy to become attractive in relation to other alternatives. In general, the subsidy has a significant impact on the competitiveness of the various technologies. However, at higher subsidy levels, the LCOE of all technologies tend to converge, reducing the importance of market competitiveness. Therefore, defining appropriate subsidy levels is also important when the government chooses pathways.

5. Are Nepal and Afghanistan following cost effective pathways?

The LCOE for various technological pathways in Nepal and Afghanistan are summarized in Table 10. Micro hydro is clearly the most attractive option in remote areas both in Nepal and Afghanistan. But after looking at the least cost alternatives, it is equally important to discuss the current pathways chosen by these countries to verify whether the adopted pathways are cost effective. Surprisingly, LCOE is often overlooked when electrification programmes are designed.

Our analysis has shown that grid extension is a least cost option in Nepal only in (i) the villages of Terai region, where there is high load density and larger number of population to be served and (ii) in the densely populated hilly rural areas (assuming 200 households in a village) which are closely located (within 10 km) to MV stations. However, grid extension in the rural Nepal is not free from undue political interventions and thus is sometimes extended to locations where it is not cost effective [72].

Promoting micro hydro based mini-grid might be a better option as this is the most cost effective option among the various pathways analyzed for remote rural areas. In places where there is no micro hydro potential, isolated home systems (for e.g. SHS) can be an attractive option.

Rural energy subsidy policy has promoted the expansion of micro hydro based mini grid and SHS in the rural areas of Nepal. Existing subsidies promote solar PV in areas where micro hydro is unfeasible. Nevertheless, in practice, the technologies have been promoted in parallel by two technology specific programme components within AEPC, and often the cost effectiveness is overlooked. In fact, the market of SHS is growing fast and even in areas where there is potential for micro hydro based mini grid. The subsidy provided for solar home systems is attractive enough to motivate the richer portion of the population which can acquire access to electricity more quickly [33]. The diesel generator is not a cost effective alternative for the electrification of remote rural areas and also the government policies do not support such installation. The adopted pathways for rural electrification in Nepal seem functional and are promoting electrification. However, it needs some adjustment to make the pathways smarter and more cost effective so that larger segments of the population can be reached.

In the case of Afghanistan, no defined pathways were observed for the rural electrification. There is a de facto split in the roles of various governmental organizations, and efforts from various

Table 10
LCOE from various technologies in Nepal and Afghanistan (USD/kWh).

Pathways	Technology	Nepal	Afghanistan	Lower (**L**) and upper (**U**) LCOE conditions	Best fit situation
Path-A	SHS	0.55–1.10	0.99–1.61	**L**-high insolation **U**-low insolation	Isolated remote location with high insolation and where MH is technically unfeasible.
	WHS	0.44–3.1	–	**L**-high wind speed **U**-low wind speed	Isolated remote location with high wind speed; and where MH is technically unfeasible.
Path-B	MH	0.25–0.35	0.34–0.67	**L**-larger MH plant in accessible area **U**-smaller MH plant in remote area	Locations in hilly and mountainous regions (>10 km away from the MV-substation)
	DG[s]	0.599	0.769	Accessible areas	Accessible location but with no grid line, and where other resources are unfeasible or unattractive.
Path-C	Grid extension	0.106–1.342	–	**L**-a village in Terai with 1000 HHs and load density of 200 HHs/Km^2, and 6 km from substation **U**-a village in Mountain, with scattered settlement (10 HH/Km^2) and 25 km away from Substation.	Location mainly in Terai region and some densely populated hilly areas which is within 10 km from substation; and have high load density (200 HHs/Km^2) and large number of households to be served.

Note: SHS: Solar Home System, WHS: Wind Home System, MH: Micro Hydro, DG: Diesel Generator Solar Insolation 3.5–7.0 kWh/m^2/day in Nepal and 4–6.5 kWh/m^2/day in Afghanistan Average wind speed 3.4–6.5 m/s.
[s] The estimates were for the accessible areas. 25% escalation in the fuel price due to local transport of fuel in remote areas can increase LCOE by 60%.

donor agencies are fragmented. Afghanistan lacks a clear cut energy policy framework and executable master plan [73]. Technologies are heavily subsidized, thus market competitiveness is not being developed. A Renewable Energy Policy is being drafted since 2009 but has not yet been finalized [74].

The grid line in Afghanistan has been severely damaged during the war and it can take several years to rebuild it. Townships are likely to be prioritized in this case. Thus, the rural electrification agenda in the country will profit from a strategy focused on off-grid technologies. The study has shown that the micro hydro is the most cost effective option in hilly areas of Afghanistan where the resources are available. Fortunately, both government supported programmes NSP and ERDA have focused on mini grid based micro hydro projects in recent years. For example, ERDA has been supporting micro hydro projects in the provinces of Badakhshan, Bamiyan, Ghor, Takhar, Samangan, and Panjsher [40].

Traditionally, DGs were installed for rural electrification in Afghanistan. However, those installations did not turn to be sustainable solution from the evidences [75]. As also indicated in our study, DG is not a cost effective option when environmental externalities are taken into account. This transitional period should be immediately phased out in favor of better alternatives. Thus, there is an immediate need to replace existing nonfunctional diesel based schemes. The use of DG shall be restricted when other options are not available. Despite the high LCOE for SHS, NSP has electrified about 72,000 households with solar PV across Afghanistan, and MRRD has planned to implement 2327 SHS in the provinces of Badghis, Ghazni, Samangan, and Helmand [41,74]. Defining and driving the electrification process in a cost effective way will be important for the development of Afghanistan. The design and implementation of renewable energy policy may help in defining the pathways utilizing the local available renewable resources in cost effective way but such policy is still not in place [74]. The possibility of wind technology in Afghanistan has not been analyzed in this study due to unavailability of proper data but could be an important alternative thus justifying further detail investigation.

6. Conclusion

This paper has analyzed technological alternatives and pathways in the electrification of rural areas of Nepal and Afghanistan. We used LCOE to compare the cost of various technological pathways in the two countries, and evaluated the cost effectiveness of present electrification processes. The LCOE for all technology options compared were higher in Afghanistan than Nepal despite the similar resource conditions in the two countries. Political insecurity, unstructured energy supply markets, and weak institutional setups could possibly explain these high costs, indicating also extra barriers in the electrification process. In any case, when designing electrification programmes, resource availability and LCOE values help to indicate the most cost effective options. Given financial scarcity, policies should try to encourage the promotion of cost effective technologies. In this context, subsidies can play an instrumental role to make renewable technologies cost competitive. However, as seen from the analysis, heavy subsidies for all kinds of technologies at the same time make competitiveness irrelevant and this may hamper the formation of energy markets. Thus, deciding on the appropriate level of subsidy is important as policy makers choose pathways and try to maximize the access rate within available natural and financial resources to meet the rural service demand.

The choice of technology and the pathway adopted in the case Nepal seems in the right direction though some flaws within the delivery modality need to be addressed. In Afghanistan, political commitment and clear strategic directions for rural electrification are needed. Formulation of a national rural energy policy to support renewable based resources like micro hydro and solar PV will be advantageous to promote sustainable development in the country. In this context, Afghanistan can benefit from the experiences of Nepal in the process of rural electrification and market formation of renewable energy technologies.

The LCOE analysis as per carried out in this paper is based on resource availability, existing market costs, prevailing policies and near-term developments. One of the basic limitations of this methodology in evaluating pathways is its static nature. We carried out some sensitivity analysis to reflect the uncertainty associated with the various parameters. However, the long term and much more complex risks and uncertainties associated with market and technological development, policy and regulatory changes need other types of analysis linked to the specific country development strategy. This was beyond the scope of this study. Still, LCOE analysis is very useful in determining cost effective pathways that can be adopted in the short term to promote electrification among the poor, and sustainable development at large.

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