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Role of renewable energy technologies in rural communities' adaptation to climate change in Nepal

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ABSTRACT

The aim of this paper is to analyze the role of renewable energy technologies (RETs) such as biogas, improved cooking stoves (ICSs), micro hydro (MH) and solar power (SP) in helping rural communities in Nepal to adapt to climate change. The analysis considers the energy efficiency of different RETs as well as their socio-economic and environmental impacts. The efficient use of biomass in new technology, such as biogas and ICSs for cooking, has increased energy security and reduced the negative effects of traditional biomass usage. MH and SP systems are replacing candles and kerosene lamps, and are the most promising RET models for electricity generation in rural Nepal. The improved illumination from these technologies also produces better education, health, environments, and social harmony in rural communities. This study uses the Long-range Energy Alternatives Planning model (LEAP) model to develop a plan for long-term RETs use in Nepal, and specifically focuses on household energy use in rural areas. It assesses the role of biogas and ICSs in rural communities and climate change adaptation in Nepal, along with the potential role of MH and SP technologies. According to the LEAP analysis, the planned implementation of MH for 20-year long-term will result in the reduction of 2.553 million tons of CO_2 emissions. Similarly SP, biogas, and ICSs will result in a reduction in CO_2 emissions of 5.214 million tons, 35.880 million tons, and 7.452 million tons, respectively.

1. Introduction

Millions of rural communities in developing countries such as Nepal still lack access to safe and reliable energy. Access to energy is as fundamental to human welfare as clean water, agricultural productivity, health care, education, job creation, and environmental sustainability. Rural communities in Nepal spend more than one third of their household expenditure on energy services. Moreover, they devote a large portion of their time to energy-related activities, with women and young girls spending more than 6 h a day gathering wood and water, cooking, and processing agricultural products. Access to modern energy services can therefore make a real difference to the lives of people in rural communities in Nepal [1].

In general, energy use has positive effect on living standards, but research has also shows that energy consumption and climate change have a cause–effect relationship [2]. For this reason, one of the key sustainability challenges is to increase energy access for rural communities without causing negative impacts on the environment. Moreover, the depletion of natural resources and a changing climate has created more energy security challenges, especially in developing countries such as Nepal [3]. The traditional use of biomass fuel and imported petroleum fuels in rural Nepalese households has caused high carbon emissions [4]. These traditional techniques need to be replaced by energy efficient technologies, which can protect natural resources and reduce carbon emissions. If traditional biomass and petroleum fuels are not replaced with affordable and efficient alternatives, they will continue to negatively affect the environment, and the livelihoods of people who depend on it for their income and survival.

Climate change adaptation technologies and practices differ between individual communities and countries, and depend upon access to financing and technological knowledge [5]. Alternative and improved RETs can provide opportunities for communities to adapt their lifestyles to the changing climate. Thus, there is a need

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to assess and evaluate current energy systems, and ensure that societies can adapt to climate change impacts [1]. Furthermore, understanding the impact of climate change on clean energy generation is important for climate resilience planning. Such planning increases the longevity of energy systems and ensures a sustainable supply [6]. The development of long-term strategies for low carbon-emission energy systems is therefore very important.

Energy planners and decision makers use various models to perform demand and supply analysis, develop forecasts, identify gaps in demand and supply, produce options for intervention, and perform impact assessments. Several key models have been developed in recent years for energy planning, including the Long-range Energy Alternatives Planning model (LEAP), which is used to predict the future pattern of energy consumption, the problems associated with this pattern of energy use, and also the potential impacts of national or regional energy planning policies [7,8]. This system also tracks long-term energy demand and supply in a given region, and has been used to identify the most effective measures to mitigate global warming [8,9]. LEAP is designed around the concept of long-range scenario analysis, whereby scenarios are self-consistent storylines of how an energy system might evolve over time. Using the LEAP model, policy analysts can create and evaluate alternative scenarios by comparing their energy requirements, social costs and benefits, and environmental impacts [10].

This study uses the LEAP model to develop a plan for long-term RETs use in Nepal, and specifically focuses on household energy use in rural areas. It assesses the role of biogas and ICSs in rural communities and climate change adaptation in Nepal, along with the potential role of MH and SP technologies.

2. The cause and effect relationship between energy and climate change

Human-driven energy use, including the supply, transformation, and delivery of energy, is the dominant contributor to climate change and currently represents around 60% of greenhouse gas (GHG) emissions [6,11]. Energy-related GHG emissions have been growing steadily, but vary considerably among regions and countries.

2.1. Global perspective

Current patterns of energy production and consumption are unsustainable and threaten local, regional, and global environments. Excessive uses of biomass and fossil fuels have particularly negative environmental impacts, contributing to GHG emissions, land degradation, air pollution, and water and soil acidification [6]. In developing countries such as Nepal, the risk of environmental degradation from energy consumption is particularly high, and the use of cleaner and more efficient technologies such as ICSs, biogas, MH, and SP can mitigate these environmental risks.

Climate change has a considerable effect on energy supply and demand. For example, the projected change in precipitation patterns coupled with glacial retreat means that hydropower (HP) production could increase by 5% or more in northern Europe, and decrease by 25% or more in southern Europe [12]. These changes in energy supply will affect large areas of Europe that rely on HP for energy generation. Extreme events have a major impact on centralized power systems that serve large areas and use resources that are sensitive to climate change [12]. The consumption of energy in climate-sensitive regions is also likely to change: the amount of energy required for space and water heating will decrease, while the energy required for space cooling and industrial water cooling (e.g., in thermal power plants or industrial mills) will increase. The energy required for other climate-sensitive processes such as pumping water for irrigation and municipal uses will also increase. Changes in energy consumption will also occur in other sectors of the economy, such as transportation, construction, and agriculture [13].

2.2. Nepalese perspective

Nepal is responsible for only about 0.025% of annual global GHG emissions, but is highly vulnerable to climate change [14]. Increasing temperatures, especially in mountain areas, is resulting in the recession of glaciers and snowfields [15]. This will affect the supply of water for irrigation, household use, and hydroelectricity. In addition, receding glaciers often leave behind large glacial lakes that can break through terminal moraines and cause catastrophic floods. Global climate change will also result in shifting monsoon precipitation patterns that will threaten Nepal's current agricultural practices, infrastructure, and bio-diversity [16].

Renewable energy resources in Nepal will be directly affected by climate change [4]. Changes in river flow, for example, will have a direct impact on MH projects. Increases in the number of cloudy days and changes in the precipitation type (e.g., from snowfall to hailstones) will affect solar power generation. Furthermore, the increased incidence of forest fires will threaten the availability of wood for fuel.

Climate adaptation planning is very important for the sustainable development of RETs in Nepal, and is essential to climate change impact and vulnerability assessments. The urgent assessment of potential climate change impacts on rural communities is therefore paramount for the survival of rural communities [17].

3. RETs for rural areas in Nepal

3.1. Current energy use in rural Nepal

Nepal is one of the least developed countries in the world, and the residential sector accounts for a very high proportion (89%) of primary energy consumption [18]. Biomass is the main source of energy, and contributes around 87% of the total energy consumption [19]. Approximately 75% of rural communities use firewood for cooking [20].

Because traditional cooking technologies consume a large amount of biomass, rural people spend a considerable amount of time and energy collecting fuel. Due to the burden of fuel collection, women and children are prevented from engaging in educational, social, and income-generating activities. Hazardous emissions from biomass fuels used for cooking and heating can also cause health problems, such as acute respiratory problems, increased child mortality, and eye ailments [21,22].

The introduction of grid electricity into rural areas in Nepal is also very costly because of the difficult mountainous terrain and the erratic distribution of rural communities [22]. Without electricity, young people use kerosene lamps or candles to study, which are expensive and do not provide sufficient illumination [23].

Lack of domestic fossil fuel reserves, and the low purchasing capacity for imported fuels, has compelled Nepal to look for RETs such as MH, SP, biogas, and ICSs. However, Nepal is rich in renewable energy sources, with an estimated 42,000 MW of commercially exploitable hydropower, 100 MW of MH, 2100 MW of SP, and 3000 MW of wind power annually. It is also estimated that 1.1 million domestic biogas plants could be developed in Nepal [19]. Due to the abundance of renewable energy sources, Nepal could provide sustainable energy to rural areas by promoting the use of RETs [5]. The potential use of RETs in Nepal has been considered as an important approach for sustainable development of the rural communities.

Table 1
Gender analysis matrix for MH and biogas user groups [29].

	Labor	Time	Resources	Culture
Women (MHP)	Less work for processing and lighting kerosene	Saved time for processing, filling kerosene and lighting lamp	Possibility of access to income-generating and social activities (incense-making and adult literacy, poultry-keeping)	Positive change in women's and men's attitude to women's mobility
	+	+	+	+
Biogas Plant	1 Less work for collecting firewood and cleaning 2 More work with frequent breakdown of biogas 3 More work for water collection for biogas operation and for toilet use	1 Saved time for cleaning and collecting firewood 2 Long time to cook big meal 3 More time in water collection for mixing with biogas and to use in toilet	Possibility of increasing vegetable production through compost waste using biogas slurry	1 Good practice of using toilet 2 Acceptance of biogas cooking by elders 3 Acceptance of biogas cooking by elders
	+−−	+−−	+	+++
Men (MHP)	No change in men's work	More time for chatting and gatherings with electric light	1 Possibility of income generation, e.g., sawmills and poultry farming 2 Access to information through radios and televisions	1 Increased gatherings and entertainment 2 Young men hanging around radios and televisions
	/	+	++	+−
Biogas Plant	No change in men's work	No change	Possibility of generating income	Positive attitude to using the toilet
	/	/	+	+
Household (MHP and Biogas plant)	Saved women's labor for other activities	Saved women's time for other activities	1 Possibility of increasing income 2 Possibility of irrigation 3 Decrease in labor from young men	1Positive attitude of men and women to women's mobility, girls' schooling 2 + Positive attitude towards sanitation
	+	+	++−	++

Note:
+ indicates the positive effect
− indicates the negative effect
/ indicates no change.
Source: Field survey, 2002.

3.2. Role of RETs in climate change adaptation in Nepal

The Intergovernmental Panel on Climate Change (IPCC) observed that the requirements for promoting sustainable development and enhancing adaptation capacity are similar [24]. Addressing these requirements can therefore deliver both socio-economic development and climate change adaptation capacity. Adaptation to climate change basically requires an effort to improve social conditions (e.g., poverty alleviation), economic conditions (e.g., security of energy supply), and ecological conditions (e.g., natural resource management, ecology and ecosystem sustainability, as well as new technologies to cope with a changing environment) [25].

The way in which energy services are produced and consumed affects all three pillars of sustainable development, i.e., economic, social, and environmental [26]. The main principles behind creating sustainable energy systems are to improve energy efficiency, transform and make effective use of conventional fuels, and use renewable energy sources more widely [27]. RETs, such as SP, MH, and biomass can provide access to sustainable rural electrification [21], and it is clear that switching to these clean energy technologies would enable increased climate change adaptation and mitigation capacity.

Dried dung has a heat efficiency of only about 10%, while ICSs have an efficiency of 25–30%, which is almost double that of traditional biomass stoves [28]. Biogas produced from the dung has a heating efficiency of up to 60% [28], and so the use of ICSs with lower emissions can save fuel and reduce environmental impacts [21].

SP and MH can provide modern and sustainable rural electrification. These systems can either replace fossil fuels, such as kerosene and diesel, or reduce their consumption in rural households [5].

Improved access to domestic energy and electricity has a significant impact on rural communities in Nepal, providing better light, reduced manual labor, increased income, better education, better health, accelerated gender equality, improved environments, and social harmony [28]. Table 1 presents the positive and negative effects of biogas and MH on the livelihoods of rural people based on a survey carried out by Mahat. Various researchers have carried out energy planning and analysis for various scenarios in Nepal.

4. Scenario development and analysis

The LEAP model was used to develop three 20-year scenarios of energy needs in rural areas, with 2012 as the base year. All three scenarios use the same demographic characteristics, and the energy efficiency of each technology is fixed throughout the projection period. The base year demographics and energy data were obtained from the National Population and Housing Census [30] and Practical Action Nepal, 2009 [18].

The three projected scenarios are:

1) Business as Usual scenario (BAU)
2) Renewable Energy scenario (RE)
3) Energy Saving scenario (ES) by replacing incandescent lighting with compact fluorescent lamp (CFL) lighting.

The total energy demands for the three different scenarios are shown in Table 2.

Table 2
Total energy demand for three different 20-year scenarios using the LEAP model.

Scenario	Total energy demand (million GJ)		Energy for cooking (million GJ)		Electricity for lighting (GWh)	
YEAR	2012	2032	2012	2032	2012	2032
BAU	206.23	169.67	203.48	165.69	761.32	1105.91
RES	206.23	92.48	203.48	89.29	761.32	886.48
ESC	206.23	90.04	203.48	89.29	761.32	207.47

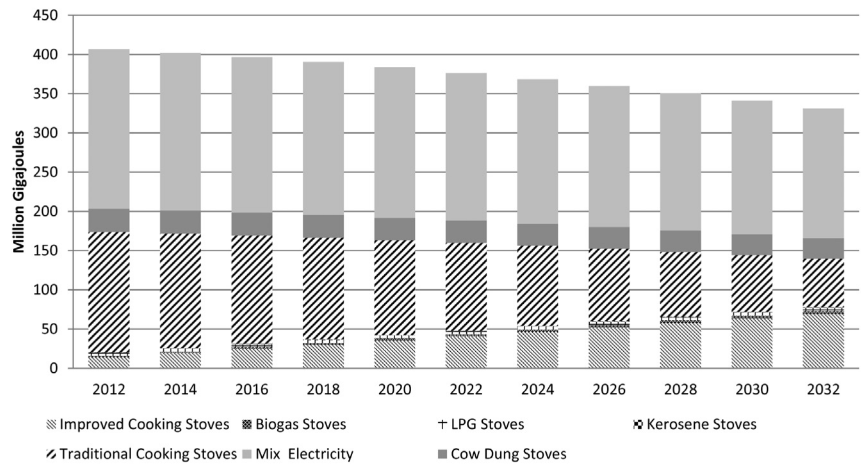

Fig. 1. The BAU scenario for cooking activities.

4.1. Business as usual scenario (BAU)

The BAU scenario (Figs. 1 and 2) is based on current energy consumption trends and technology intervention. The technology intervention is based on the targets and achievements of the electricity and energy sector in the Three Year Interim Plan (2007/2008–2009/2010) in Nepal [30].

The model assumes that each household uses a single device-type for a particular end use. Under this scenario, residential energy consumption for rural communities will decrease from 206.23 million GJ to 169.67 million GJ in 2032. The decrease is mainly due to increased urbanization, and the subsequent shift towards RETs. The energy requirement for cooking will decrease from 203.48 million GJ to 165.69 million GJ in 2032, but the energy needed for lighting will increase from 761 GWh to 1106 GWh. Wood will remain the major source of fuel for cooking in rural areas in 2032, providing 131.15 million GJ of the total 165.69 million GJ required.

4.2. Renewable energy scenario (RE)

The RE scenario (Figs. 3 and 4) assumes that specific policies are implemented to accelerate the deployment of RETs, based on the interim plan developed for 2010–2013 [30]. For electricity supply, it is assumed that MH and SP will provide between 18% and 40% of the total household energy usage. The remaining household energy requirements will be provided by mixed electricity from grid and off-grid sources except SP and MH by 2032.

In terms of cooking, this scenario assumes that 19% of households will use biogas stoves, 30% will use electrical devices, and the remainder will use ICSs. The RE scenario also assumes that manufacturing capabilities for advanced technologies like solar, MH, and biogas will improve in Nepal.

Under this scenario, residential energy consumption for rural households will decrease from 206.23 million GJ to 92.48 million GJ in 2032. Energy requirements for cooking will decrease from 203.48 million GJ to 89.29 million GJ in 2032, but energy needed for lighting will increase from 761 GWh to 886.5 GWh. Wood

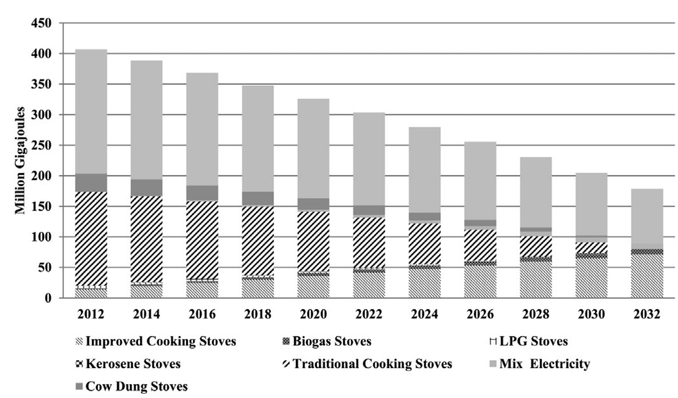

Fig. 3. The RE scenario for cooking activities.

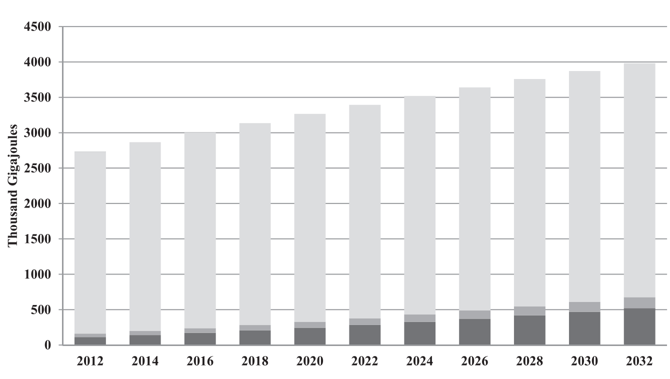

Fig. 2. The BAU scenario for lighting activities.

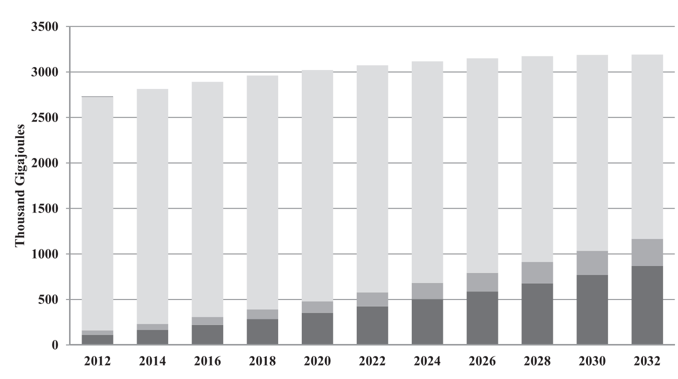

Fig. 4. The RE scenario for lighting activities.

Table 3
Total carbon mitigation potential for the RES.

RETs	GHG emission reduction rate (eq/kW/year) (ton CO_2)	Total planned RETs for 20 years (2013–2032)	Emission reduction for 20 years (ton CO_2 equiv)	Assumptions
Micro hydro	2.3	74 MW	2,553,000	Life: 15 years
Solar Power		1.58 million plants	5,214,000	Life: 15 years
Biogas	2.3	0.78 million Plants	35,880,000	Life: 20 years
ICSs	1.2	2.07 million Plants	7,452,000	Life: 3 years

will still remain the major source of fuel for cooking, but the amount of wood required by households will decrease because of the use of ICSs. Wood will provide for 71.14 million GJ of the total 89.29 million GJ required for cooking in 2032. The total 20-year energy demand will be 2091.47 million GJ for the BAU scenario, and 1678.47 million GJ for the RE scenario. The total carbon mitigation potential of the RE scenario is shown in Table 3. The GHG emission reduction rate per plant was obtained from Nepal, 2011.

4.3. Energy saving scenario (ES) by replacing incandescent lighting with CFL lighting

The ES scenario is based on the assumption that all incandescent lamps will be replaced with CFL lighting. The implementation of RETs in this 20-year scenario is the same as the RE scenario. It is also assumed that households using incandescent lamps and CFLs consume 264 kWh [31] and 40.9 kWh [18] of energy annually, respectively. Households with solar lighting installed are assumed to use CFL lights, and the remaining households are assumed to use incandescent lights.

The LEAP model (Fig. 5) shows that replacing incandescent lights with CFL lights will save a considerable amount of electricity. In 2032, the total electricity demand for the RE scenario is 886.48 GWh compared with 207.46 GWh for the ES scenario. The total electricity demand for the ES scenario is therefore almost four times less than for the RE scenario, resulting in a saving of 679 GWh.

However, if the energy required to produce electricity is accounted for, then the RE scenario and the EE scenario require 9252 GWh and 5495 GWh of energy, respectively, resulting in a total saving of 3757 GWh in the EE scenario. This analysis shows, therefore, that even if RETs development in the RE scenario and ES scenario are similar, and the use of efficient light bulbs could make a vast difference to energy consumption over a 20-year period.

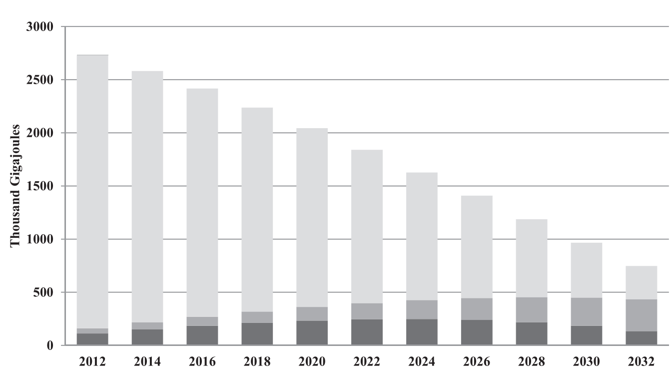

Fig. 5. ES scenario for lighting activities.

5. Analysis of the economic, environmental, and social benefits of RETs for rural Nepal

The rise in population and living standards around the world is causing a significant increase in energy demand and competition for fossil fuels. As the demand increases, the cost of non-renewable finite resources continues to rise. The cost of renewable energy, on the other hand, has the opposite trend and falls over time as technology improves [32]. Renewable energy is more efficient, reliable, cost-effective, and environmentally friendly. Furthermore, the expansion of renewable energy stimulates the economy, creates jobs, increases energy security, and improves the health of communities and the environment [33].

5.1. Social benefits

Greater access to energy for domestic use and electricity using RETs can have a significant social impact such as time saving and the empowerment of woman, improved access to better quality education and improved health on livelihoods in rural areas [34].

5.1.1. Time saving and the empowerment of women

The use of electrical mills, instead of manual agro-processing, saves 155 h per year for women and 85 h for men [35]. The use of biogas and ICSs for cooking, and the generation of electricity using MH and SP, can significantly reduce the time required for household activities. This study shows that the installation of a biogas plant can save a household approximately 3 h of labor per day, which is equivalent to a total saving of over 1000 h a year. This time saving primarily comes from the reduction in labor required for gathering fuel for cooking.

The high efficiency of biogas also makes cooking and washing up faster and easier, and women can do other activities while cooking on biogas stoves [36]. The time spent cooking using ICSs is reduced by 15–20% compared with traditional stoves, which is a total of at least 2 h per week [37]. As firewood requirements are also reduced by around 50%, family members spend much less time gathering fuel, and less physical labor is required to cut trees and collect firewood [21].

This reduction in workload from electrical mills, biogas, and ICSs, has provided Nepali women with opportunities to earn additional income, organize and attend meetings, increase awareness, achieve literacy, and gain financial security [36]. These technologies have also increased male participation in chores such as cooking, cleaning, and agro-processing. There is also a significant increase (nearly double) in social involvement of both men and women, and these activities have brought increased social harmony among the rural people.

5.1.2. Improved access to better quality education

Electric lighting from MH and SP provides higher quality illumination than kerosene lanterns. The light from MH is more than 100 times brighter than the light available from kerosene lamps [31]. The increased illumination provides opportunities for additional work hours for adults and study time for children, as well as better security, comfort, and safety [38]. Electricity from MH and SP can also improve rural education by enabling the use of advanced equipment in schools, which attracts skilled teachers to rural communities. As electricity extends study time at home, it also helps students to achieve better grades and therefore encourages them to attend school for a longer time [39].

According to the Regional Equality and Diversity Partnership (REDP), the number of children/youth between the ages of 6 and 14 without primary level education has decreased from 25% to 7% [35]. There has also been a decrease in the boy–girl school enrollment ratio from 1.20 to 1.13. Children from households with electricity spend 50 min on evening study, while children from households with no electricity spend only 34 min on evening study each day. Boys and girls from households with electricity complete an average of 0.4 and 0.21 more years of schooling, respectively, compared with boys and girls from households with no electricity [31].

5.1.3. Improved health

The use of biogas and ICSs significantly reduces indoor air pollution due to the more efficient use of fuel for cooking, lighting, and heating. This, in turn, reduces acute respiratory infection and conjunctivitis, which are common effects of indoor pollution. MH and SP may also lead to decreased fertility rates, child mortality, and eye problems. Furthermore, increased access to radio and television will help to increase public knowledge of health issues, such as modern contraceptives and child immunization [39]. Other benefits of electricity in rural areas also include the refrigeration of vaccines and the use of advanced medical equipment in health clinics [33], and better water and sanitation services.

In areas with electricity, there is an average of 11 health workers per 10,000 people, compared to 2 health workers per 10,000 people in non-electrified areas [35]. The use of MH reduces suffering from respiratory diseases by 6 h per month for girls and by 1.6 h per month for boys [30]. These RETs are of particular benefit to rural women, relieving them from tiresome working hours and indoor air pollution [35]. Further, it has been found that around 84% of women from households equipped with MH can voice their fertility issues.

The risk of fire (from the use of kerosene lamps, butter lamps, and candles) has also been significantly reduced by the use of RETs. In places where mobile networks are available, the ability to charge a mobile phone has not only facilitated communication but also provided access to radios, TVs, and computers that can provide farmers and fishermen with weather forecasts or information on crops and other market prices [33].

5.2. Economic benefits

RETs development has made large contributions to economy of rural Nepal, and has both direct and indirect benefits at the household level. They directly contribute to economic growth and poverty reduction, and create opportunities for income generation, reduce unit costs, and enable increased income from agriculture. Indirect economic benefits come from saving time for other productive activities, improved health and education, improved access to and supply of clean drinking water, and reduced local environmental degradation [28].

5.2.1. Increased income generation

Lighting provided by MH and SP enables households to continue their domestic income-generating activities further into the evening. Women can sew or engage in other small-scale activities after daily household chores are finished, and electronic media, such as TV and radio, exposures them to new entrepreneurial ideas [23].

Access to electricity has increased the average annual household income in Nepal by US$121 (8%) [35]. Establishment of new businesses increased from 4 to 40 per district annually after the installation of a MH system. There has also been a reduction in the average annual household energy expenditure. Households with electricity spend only US$19 annually, which is much less than the US$41 spent by households without electricity [35]. The increase in income and prosperity after the introduction of RETs shows that the production and consumption of renewable energy has far-reaching economic benefits.

5.2.2. Creating employment opportunities

Establishment of renewable energy services, such as MH and biogas, require a significant amount of labor, which provides additional employment opportunities for local people. It also creates long-term employment opportunities, as these facilities require staff for their operation and maintenance.

5.2.3. Money saving

Renewable energy services also contribute to economic growth by reducing unit costs [28]. According to a World Bank study, kerosene is around 400 times more expensive than MH, when it is measured in terms of light intensity. Households equipped with MH also enjoy a consumer surplus of almost NRs 700 [26]. Aside from having poor efficiency, kerosene is also very costly. The cost of using kerosene lighting is as high as US$3-4 per kWh, while cost of elecricity generated from one of RETs is only USD$0.5-1 per kWh [38]. Household lighting has been estimated to save between US$5–16 per month in poor households in developing countries [40]. This shows that electric lighting lowers the cost of energy in rural communities.

RETs have significantly reduced the risk of fire (from the use of kerosene lamps, butter lamps, and candles), and the associated loss of life and wealth. In places where mobile networks are available, the ability to charge a mobile phone has not only facilitated communication but also has created commercial opportunities. Households that previously relied on kerosene or candles have saved significant amounts of money from installing solar lighting. The ever-increasing cost of liquid petroleum gas (LPG), is too high for rural farmers with no cash income, and the transportation of LPG cylinders to remote villages is costly or not feasible [37].

Biogas is commonly the best alternative energy solution for rural households. It is relatively cheap and efficient, and local people can construct biogas facilities using existing local resources [21]. Each biogas plant produces 1.75 tons of organic fertilizer each year, thereby reducing the dependence on imported chemical fertilizers, and saving a total of almost $300,000 nationally [33]. On the other hand, ICSs have become a practical solution for very poor families, where even biogas is not feasible [37].

5.2.4. Income through the Clean Development Mechanism (CDM)

Nepal has generated income from biogas under the Clean Development Mechanism (CDM). ICSs, MH, improved water mills, and SP systems are all in the process of being registered as CDMs [5].

The CDM, for each ton of CER, kfW offers 9.8 Euro as per agreement [4]. Biogas plants developed in the RE scenario, will contribute 0.78 million EURO, and have the potential to reduce CO_2 emissions by 35.88 million tons over the next 20 years. Based on the Certified Emission Reduction, the total income under the CDM from the biogas sector in Nepal will be €351.624 million. Similarly, for a total MH output in the RE scenario is 74 MW, the total potential reduction in CO_2 emissions will be 2.553 million tons. The total income from MH under the CDM will be €25.02 million, which is comparable with the potential income from SP and ICSs. These incentives make the development of RETs cheaper and more feasible in rural Nepal.

Further saving can be realized at the household scale by replacing incandescent bulbs with CFL. Incandescent bulbs consume about 264 kWh/year per household [31]. If they are replaced with CFL lighting, each household will consume only 40.9 kWh/year [18], resulting in a saving of around 223.1 kWh/year. This is a significant saving for rural people, and the energy can instead be used for other productive and income-generating activities.

5.3. Environmental benefits

The use and promotion of RETs in Nepal, especially MH, SP, biogas, and ICSs, has made significant contributions to the improvement of the local, national, and global environment [23].

5.3.1. Local perspective

Electricity from MH and SP is being increasingly used for cooking and lighting in rural Nepal, and is replacing the traditional use of kerosene [41]. From the local perspective, the use of biogas instead of firewood for cooking has helped to improve the indoor air quality of rural communities [21]. Installation of biogas plants has also resulted in the better management and disposal of animal dung and human excrement, which has helped to improve sanitary conditions in rural communities [36]. Installation of ICSs has also helped in reducing wood use by around 50%, and indoor air pollution decreased by about 80% [21].

5.3.2. National perspective

From a national perspective, biogas and ICSs have helped to reduce pressure on deforestation [21,36], saving about 14,268 tons of biomass per year, or 8917 ha of forest. ICSs use saves 420 tons of biomass per year, which is equivalent to 262 ha of forest. Each biogas plant can save an average of 3 tons of wood or 38 L of kerosene per year. This has important implications for watershed management and soil erosion. Digest, the slurry collected from biogas plants, can be used as manure and can help reduce the depletion of soil nutrients. This, in turn, will reduce the pressure for agricultural expansion and land clearance, a principal cause of deforestation in Nepal [36].

The electricity from MH and SP has reduced the likelihood of using dry-cell batteries or kerosene by 80%, and has therefore limited the environmental damage caused by disposal of used batteries, air pollution, and GHG emissions associated with burning kerosene [35]. MH power saves an average of 3 L kerosene/month per household in Nepal [42]. Furthermore, households using MH electricity emit on average about 3.6 kg less carbon than non-MH households per month [31].

5.3.3. Global perspective

Climate change is a global issue affecting all countries, and the development of RETs for lighting (MH and SP) and cooking (biogas and ICSs) has been reducing global carbon emissions. As less firewood and kerosene are being used, there will also be a substantial reduction in GHG emissions in Nepal [23]. It is estimated that biogas and MH technology will result in a net reduction of 2.3 tons/year of CO_2 equivalent per plant [4]. The emission reduction for SP and ICSs are estimated to be 0.22 tons/year and 1.2 tons/year of CO_2 equivalent per plant, respectively [4]. The planned implementation of MH will result in the reduction of 2.553 million tons of CO_2 emissions. Similarly SP, biogas, and ICSs will result in a reduction in CO_2 emissions of 5.214 million tons, 35.880 million tons, and 7.452 million tons, respectively.

6. Conclusion

RETs, such as MH, SP, biogas, and ICSs, have a significant role in the socio-economic and environmental development of rural Nepal. These technologies are cheaper, more environmentally friendly, and easy to operate and manage by local people. Access to RETs for household activities is expected to reduce energy shortages, and the negative effects of traditional biomass and fossil fuels.

Adaptation to climate change in rural Nepal requires efforts to deliver and upgrade social conditions (poverty reduction), economic conditions (energy security), and ecological conditions (natural resource management, ecosystem sustainability, and technology transfer for coping with a changing climate). The transition from traditional energy sources to modern energy sources can reduce poverty and pressure on vulnerable natural resources.

This study has shown that RETs play an important role in reducing poverty and increasing access to modern energy services in rural areas. The use of biogas and ICSs has resulted in increased cooking efficiency, less wood consumption, reduced indoor smoke pollution, and greater safety. MH and SP systems are the most promising RET models for providing rural electrification. Electric light provides extended income-generating work and study hours, and helps to enhance living standards by providing increased opportunities to undertake productive activities. Electricity also provides easy access to mobile telecommunications and entertainment systems. More importantly, the deployment of these RETs has increased the empowerment of women, and brought social harmony to rural societies. Ultimately, the improvement in rural livelihoods from RETs (biogas, ICSs, MH, and SP) has increased the resilience of rural communities to climate change in Nepal.

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