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Role of renewable energy technologies in climate change adaptation and mitigation: A brief review from Nepal

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ABSTRACT

Renewable energy plays a crucial role in both climate change mitigation and adaptation in highly climate-vulnerable nations such as Nepal. This paper reviews various types of renewable energy technologies and their status, potential for adoption, relationship to climate change, and mitigative and adaptive roles in Nepal. Nepal has installed micro-hydro projects, solar power, improved cooking stoves, biogas technology, improved water mills, and wind energy to mitigate and adapt to climate change. There is a growing potential for renewable energy development in Nepal, such as hydropower, solar, wind energy, biogas, and improved cooking stoves. Roughly 70% of Nepal's energy consumption is generated from traditional energy sources while renewable energy accounts for approximately three percent. The gradual increase in the use of renewable energy has reduced greenhouse gas emissions and enhanced carbon sequestration. By adopting renewable energy technologies, Nepal has reduced emissions by 221,129 tCO_2e from 2017 to 2018. Nepal's second Nationally Determined Contribution targets a 15% increase in national energy use from renewables with a reduction of 23% of CO_2 emissions by 2030 using biogas and improved cooking systems. Furthermore, a significant increase in the adoption of renewable energy has become a pivotal strategy in adaptation to climate change in social, health, and economic sectors resulting in time savings, alternative income sources, improved health and educational status, local job opportunities, and the promotion of social capital. The benefits of adapting to climate change and mitigating CO_2 emissions via renewable energy are significant at the local, national, and international levels. This study recommends that the government of Nepal focus work on energy policy reviews to address local energy demand and climate change issues by utilizing renewable energy resources at the local level, which has global implications.

1. Introduction

Globally there has been a shift to utilize renewable energy sources to mitigate environmental crises resulting from a changing climate [1–3]. Renewable energy technologies (RETs) have been introduced as a popular means of adapting to climate change while mitigating greenhouse gas emissions in both developed and developing nations. Renewable energy from resources such as solar, wind, hydro, tidal, ocean waves, and geothermal [4] provide an alternative to conventional energy and are an important adaptation strategy for those who depend on natural resources for energy needs [5].

Energy is a basic human need [6] and the demand in Nepal is dramatically increased in recent years. Nepal is highly dependent on traditional energy sources such as firewood, livestock dung, and petroleum and has hindered the development of larger renewable energy projects [7]. Over one-third of rural households' expenditures in Nepal

Abbreviations: RET, Renewable Energy Technology; ICS, Improved Cooking Stove; GHG, Greenhouse Gas; LDC, Least Developed Country; NAPA, National Adaptation Programs of Action; LAPA, Local Adaptation Plans of Action; GDP, Gross Domestic Products; CCP, Climate Change Policy; NDC, Nationally Determined Contributions; FY, Fiscal year; LPG, Liquefied Petroleum Gas; Mtoe, Millions of tonnes of oil equivalent; CO_2, Carbon dioxide; AEPC, Alternative Energy Promotion Center; CSP, Concentrating Solar Power; PV, Photovoltaic; TPES, Total Primary Energy Supply; SWERA, Solar and Wind Energy Resource Assessment in Nepal; NGOs, Non-Governmental Organizations; KG, Kilogram; BAU, Business as Usual; GJ, Gigajoule; CFL, Compact Fluorescent Light; CDM, Clean Development Mechanism; CER, Certified Emission Reduction.

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is dedicated to purchasing energy. Women and children allocate the majority of their time, over six hours per day, for the collection and processing of energy sources, including forest products such as fuelwood, fodder, and agricultural residues [5], leaving little time for basic education and income generating activities. Moreover, the traditional method of burning biomass for cooking causes poor indoor air quality resulting in increased respiratory diseases among rural populations, especially women and children, who spend long hours in the kitchen [8]. These traditional energy systems are socially, environmentally, and economically unsustainable while reducing human health [9]. The transition to RETs offers hope for a positive change in human livelihoods, the national economy, and the environmental resilience of rural Nepal to climate change [5,9].

Categorized as a least developed country (LDC) [10], Nepal is recognized as a highly climate-vulnerable nation [11,12] although Nepal's contributions to global greenhouse gas emissions are very low [13]. Rural populations who are dependent on natural resources such as forest products and agriculture for their basic energy needs are severely impacted by climate change [14,15] as these resources are very vulnerable to changes in climate [16]. Moreover, developing nations such as Nepal face grave energy security problems due to the combined effects of natural resource depletion and climate change [8]. The use of non-renewable energy sources combined with extensive use of traditional energy sources such as timber, fodder, mulch, agriculture residues, and animal by-products increases both climate vulnerability among rural communities and greenhouse gas (GHG) emissions.

Renewable energy has remarkable benefits on people's standard of living [17]. However, recent studies in RETs show that the use of traditional energy in rural communities contributes significantly to GHG emissions. There is a cause-and-effect relationship between energy consumption and climate change [5]. Nepal needs RETs that benefit rural communities with limited detrimental impacts on local ecosystems. For example, 68.74% of the total population relies on traditional forms of biomass fuel such as fuelwood, agricultural residues, and dried cattle dung for cooking, leading to increases in carbon emissions in rural Nepal [9,18–20]. In addition, the increasing dependence on imported fossil fuels such as oil and petroleum products, has added to carbon emissions in Nepal [21].

At present, Nepal has made a remarkable effort in the adoption of multiple forms of RETs [22]. Solar energy, hydroelectric power, wind energy, improved cooking systems (ICS), improved water mills, and biogas plants are some examples of RETs that have been adopted in Nepal to assist rural communities in increasing their standard of living while adapting to climate change through accessible local clean energy sources [23]. The implication of RETs such as solar power, improved bioenergy (biogas for cooking), micro-hydropower, and ICS provide rural communities with energy for essential services that include electricity, cooking, mobility, and communications that bolster their adaptive capacity in the face of a changing climate [24].

RETs also contribute to a reduction in GHG emissions as they reduce the dependency on the forest and overharvesting, minimize air pollution, and decrease negative impacts on the natural environment [9]. Both endogenous (community's financial and technological status, and socio-economic standard) and exogenous factors (nation's poor governance, low access to resources and technologies in global economy) determine the climate change adaptation and mitigation of GHG through RETs [23]. RETs provide an opportunity to adapt to the changing climate in both rural and urban areas in Nepal. As Nepal is transitioning from traditional energy sources to RETs, it is imperative that the country evaluates how this transition could assist rural communities in adapting to climate change through lowering carbon emissions to mitigate GHG production [17]. Further, climate change adaptation planning must explore the impact of climate change on clean energy generation, which reinforces the longevity of energy systems and safeguards sustainable energy supply [5,25].

Nepal has developed several plans and policies regarding RETs and climate change over time. Cross-sectoral ministries have developed a range of plans and policies that include Rural Energy Policy (2006), National Electricity Crisis Resolution Action Plan (2008), 10 Years Hydro Power Development (2009), National Adaptation Programs of Action (NAPA, 2010), Local Adaptation Plans of Action (LAPA, 2011), Renewable Energy Subsidy Policy (2013), National Energy Crisis Mitigation and Energy Development Decade (2016), Sustainable Development Goals- Status and Road Map (2016–2030), Climate Change Policy (CCP, 2019), Nationally Determined Contributions (NDC, 2020), and more [7,9,26,27]. Although these policies have their unique objectives, all of them are directly and indirectly linked with energy security, promotion of RETs, and climate change adaptation and mitigation. For instance, NDC (2020) aims for the reduction of GHG emissions by establishing several RETs such as hydropower, electric cooking stoves, solar energy system, electric vehicles, biogas technology, enhancing afforestation, etc. [28]. Moreover, LAPA, NAPA, and CCP have incorporated multiple activities that enhance the use of RETs at local as well as a national scale for promoting climate adaptation and mitigation.

However, these policies have failed to meet their target in the last decade (2010–2020). Indeed, 68.74% of the population remains dependent on traditional energy. Further, Nepal lacks a comprehensive assessment of all forms of RETs in the country. While several scholars have reviewed RETs in Nepal, much of this work is now outdated and lacking in current data. Some studies discuss only a few RETs rather than the entire range of technologies. Nepal doesn not have a detailed review on the importance of RETs in the environmental sector, including climate change adaptation and mitigation. This paper discusses energy consumption patterns and highlights various types of RETs and their status in Nepal. The paper highlights the roles of these renewable energy technologies in climate change mitigation (GHG emissions reduction) and adaptation, promoted through social, economic, health, and educational programs and policies among rural communities in Nepal. The paper concludes with recommendations for policies suitable for Nepal's political structure and offers suggestions to further enhance the use of RETs among rural communities in developing nations such as Nepal to improve citizens wellbeing while advancing adaption strategies to the changing climate.

2. Status of national energy consumption in Nepal

Around 80% of the total population in Nepal resides in rural areas. They lack efficient access to energy resources [7]. Moreover, Nepal is prone to natural catastrophes such as landslides, soil erosion, flooding, storms, and earthquakes due to its mountainous geography. These challenges make it difficult and costly to connect the entire rural population to the national energy grid [29,30]. Furthermore, agriculture dominates the economy of Nepal. Of the total population, 67% depends on agriculture which contributes 33% to the Gross Domestic Product (GDP) [31]. Agriculture in Nepal has the potential to be severely affected by a changing climate, which will have a severe impact on the livelihood of rural residents.

It is reported that 90% of the population has access to electricity in different forms [20]. In Nepal, 71.1% of households are connected to the national energy grid [32], with an additional 23% of households obtaining electricity from off-grid sources that are uncertain and unsustainable in regular flow [32,33]. However, those households that are connected to the grid, experience frequent hydro-electric load shedding in the winter when the flow of water in the rivers is reduced [34].

Rivers originate from the base of the high Himalayas and are considered the greatest assets for renewable energy sources in Nepal. Nepal has a capacity to produce tremendous amount of hydroelectric energy but several rural households are not connected to electricity energy sources, despite household consumption being the primary consumer of energy in Nepal [35]. This lack of access to household energy affects 6.6 million people in Nepal from sustainable energy system, despite having a large hydropower capacity over the past several decades [34].

The lack of a well-organized national energy grid system and other forms of energy sources, results in a large proportion of the population dependent on traditional energy generated from biomass for cooking and heating. In the Fiscal Year (FY) 2018/19, the energy consumption from traditional energy accounted for 68.74%, followed by petroleum products accounting for 18.23%, coal 5.92%, electricity 3.88%, and renewable energy by 3.21% (Fig. 1, Table 1) [20]. Although, 90% of population has access to electricity, obstacles such as load shedding and irregularity in electricity production and distribution have compelled a large percentage of population to rely on traditional energy sources. Moreover, the electricity is only available for lighting purpose in rural Nepal; however, people depend on traditional energy for cooking and heating purposes.

In Nepal, energy consumption consisted of 28.04% from commercial sources and 3.21% from renewable energy technologies in the FY 2019/20 [20]. This latter figure is a slight increase from 2.5% in FY 2014/2015 (Table 1). The use of Liquefied Petroleum Gas (LPG) has been increasing in both urban and rural areas. This demonstrates that Nepal has increased the consumption of energy from RETs, which has the potential to reduce GHG emissions and enhance climate change adaptation. However, the trend also indicates that there is an increase in the consumption of commercial energy sources such as coal and petroleum products. Government can aid in meeting the demand for commercial energy by RETs by facilitating the construction of mega hydropower projects utilizing available water resources.

In FY 2018/19, the consumption of energy at the household level (43%) is highest, followed by the industrial sector (38%), and the trading sector (7%, Fig. 2, Table 2). Recently, the consumption of electricity remains the greatest from the household sector by 1,731.34 GWh, followed by the trade sector with 1,553.90 GWh (Table 2) [36]. This data indicates that 90% of households have access to electricity but inconsistently available. However, the trend suggests that electricity consumption in the industrial sector is dramatically decreasing (Table 2), which might have been replaced by petroleum products and coal (Table 1). As the reliance on petroleum products and coal in industrial sectors promotes GHG emissions, the government and other stakeholders should design policies and encourage industrial sectors in shifting towards RETs (see Table 3) [20].

Recent data from an economic survey shows that energy imports to Nepal are much greater than exports. Although, Nepal is promoting RETs in generating energy, the import of energy is still rising every year. Unfortunately, over the past six years, the rate of export of energy is decreasing annually whereas the import rate is significantly rising. Domestic consumption of energy remains the greatest over the past six years, followed by the industrial sector and the total energy consumption trend is rising every year. Similarly, the wastage of electric energy is

Table 1
Energy consumption by energy source in over six years in Nepal. Unit: Millions of tonnes of oil equivalent (Mtoe) [20].

Energy sources	Fiscal Year					
	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
Traditional	78.40	72.40	74.50	68.90	68.56	68.74
Firewood	71.20	65.80	67.60	62.50	62.27	62.44
Agricultural residues	3.50	3.20	3.30	31	3.08	3.08
Cow dung	3.70	3.40	3.50	3.30	3.21	3.22
Commercial	19.99	19.10	25.28	27.55	28.22	28.04
Coal	4.60	5.20	4	27.90	6.31	5.92
Petroleum products	10.80	16.20	13.80	18.70	17.57	18.23
Electricity	3.70	3.90	4.10	4	4.34	3.88
Renewables	2.50	2.30	3.50	3.20	3.23	3.21
100 % total in (Mtoe)	**11,768**	**12,866**	**8,257**	**9,019**	**9,212**	**9,310.48**

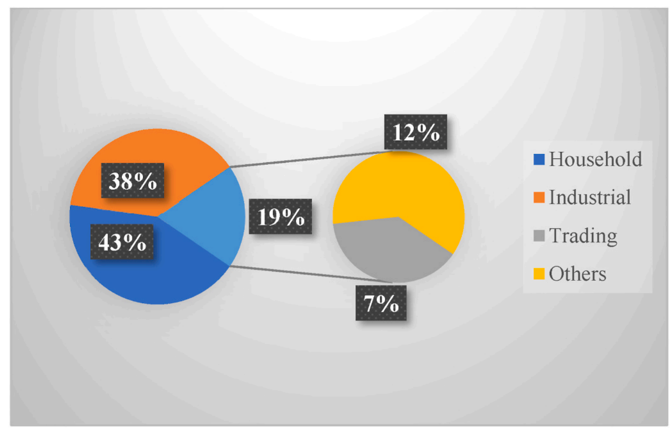

Fig. 2. Nepal's energy consumption by sector until mid-March of FY 2018/19 [36].

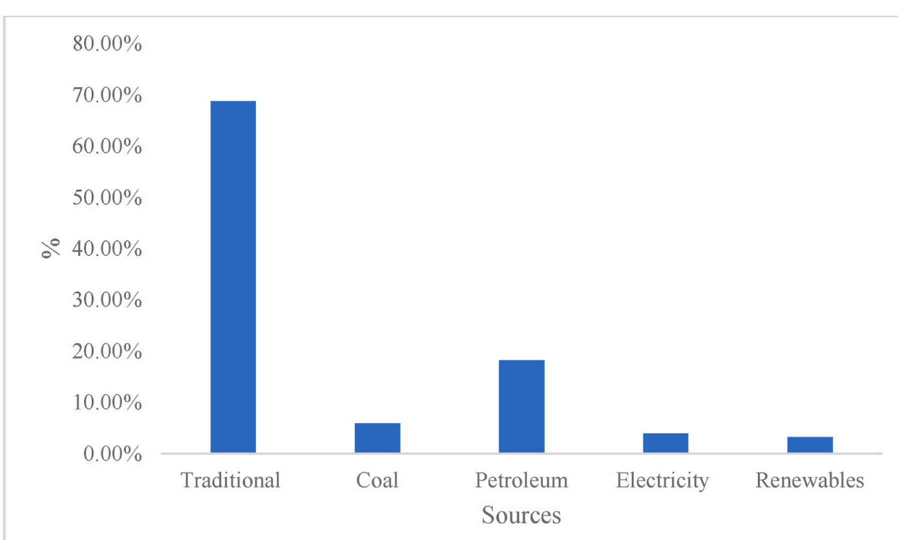

Fig. 1. Energy generation consumption by different sources in Nepal [20].

Table 2
Sector-wise Electricity Consumption over the past six years in Nepal (In Gigawatt hours) [36].

Sectors	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19 (Till Mid -July)
Household	1,571.39	1,679.35	1,792.95	2,150.21	2,403.63	1,731.34
Trade	285.42	300.25	286.48	1,735.05	2,074.16	1,553.90
Industry	1,251.69	1,352.15	1,205.69	352.37	407.59	301.50
Other	387.82	411.96	433.85	587.06	729.21	515.32
Total	**3,496.31**	**3,743.71**	**3,718.97**	**4,824.60**	**5,614.59**	**4,102.06**

Table 3
Status of Power Generation and its Consumption in Nepal (In Million kW Hour) [20].

FY	Domestic	Industrial	Commercial	Other	Total con.	Electric loss	Export	Generate & import	Under Exchange Agreement	
									Import	Export
2013/14	1,526.84	1,246.7	285.16	385.56	3,444.36	853.83	0	4,681.1	1,070.46	0
2014/15	1,688.5	1,362.61	302.57	415.78	3,772.62	1,194.04	3.17	4,966.67	1,367.66	3.17
2015/16	1,792.95	1,205.96	286.48	430.7	3,718.97	1,358.21	3.15	5,077.18	1,782.86	3.15
2016/17	2,150.21	1,735.05	352.57	536.18	4,776.5	966.5	2.69	5,743.06	2,175.04	2.69
2017/18	2,403.63	2,074.16	407.59	637.91	5,526.12	1,531.81	2.83	7,057.93	2,581.8	2.83
2018/19	1,731.34	,1553.9	301.5	474.74	4,063.62	929.8	1.84	4,993.42	1,834.17	1.84
2019/20	2,029.06	1,697.87	371.75	582.93	4,683.23	453.25	1.62	5,595.10	1,508.30	95.80

growing significantly every year [20].

Traditional cooking systems remain widespread in Nepal. Among 68.74% of the population who use traditional cooking systems, 62.44% are dependent on firewood, 3.08% use agricultural residues, and 3.33% depend on animal dung [33]. Women and children are the most impacted in the use of traditional energy usage, devoting time daily to collecting and transporting fuelwood to the home. This can hinder their educational and social development as well as limiting their ability to devote time to alternate means of income generation [5]. Moreover, the use of kerosene lamps and candles is still common in rural areas that do not have access to proper electricity system. This is expensive, does not provide sufficient lighting [29], and kerosene emissions are the primary source of indoor air pollution. Respiratory diseases from indoor kerosene use result in more than 7500 deaths of women and children annually in rural areas [29,37,38].

3. Energy and climate change relationship

Energy access has risen markedly in the last decade, demonstrating its positive impact on quality of life [30,39,40]. Reducing fossil fuel consumption and transitioning to RETs both in household and industrial areas will reduce emissions, while enhancing the quality of life. Proliferation in the consumption of non-renewable energy sources such as petroleum products, oil, nuclear power, and conventional forms of energy at both household and industrial level is a major source of GHG emissions [41–43].

The world remains largely reliant on fossil fuels accounting for 81% of total energy consumption. This is largely supplied from oil (32%), coal (27%), natural gas (22%), and 19% from other forms of energy [41,42,44]. Only 2% of energy consumption is provided by RETs [45]. These conventional energy sources represent approximately 60% of total GHG emissions [25,46]. Globally about 80% of CO_2 emissions and two-thirds of total GHGs emissions are generated from the production and consumption of all forms of energy, which has resulted in a dramatic increase in the annual mean atmospheric CO_2 concentration to 400 ppm from 280 ppm in the 1980s [47–49]. In Nepal, GHG emissions are generated from the household level use of traditional energy sources such as firewood, agricultural residue, and animal dung, followed by industrial level use of fossil fuels and petroleum products such as oils and kerosene [5,7,9].

Developing nations including China and India play a crucial role in contributing GHG emissions, where there has been a rapid increase in demand and consumption of energy in the past few years [48,50]. In developing countries, conventional energy is used to generate electricity [50] and about 40% of the electricity generated worldwide is from such sources. Coal, in particular, is a primary source of polluting gases such as carbon dioxide, nitrogen oxide, and sulfur dioxide [51]. Moreover, in developing nations traditional use of biomass resources account for around 56% of total primary energy [43]. This has exacerbated the rate of deforestation that accounts for more than 15% of GHG emissions [52]. Furthermore, about 42% of the carbon emissions are generated from the electricity and heat sectors all around the world [53].

The continued widespread use of traditional biomass energy in Nepal serves as an indicator of poverty and reiterates the need for reliable and affordable electricity generation [54]. The installation and operation of RETs is influenced by climate change in Nepal [5]. The continuous rise in temperature has accelerated the melting of snow and glaciers in high mountains [55], which has caused fluctuation in the flow of rivers that have affected the hydropower plants, irrigation projects, and water mills [5]. The alteration of monsoon precipitation patterns causes a negative impact on energy production [56]. For example, during dry seasons, the production of electricity in hydropower plants can plummet more than 30% [7]. Moreover, as glaciers recede, and glacial lakes overflow, catastrophic events such as flooding, and landslides occur hindering electricity dissemination.

The trend of operating micro-hydro plants has grown in popularity in Nepal [29]. The frequent alteration in the flow rate of water due to the impacts of climate change affects these small projects impeding rural livelihood development [5]. Other RETs are also highly affected by climate change in countries like Nepal that have unpredictable mountain weather [21]. The fluctuation of dense cloud cover in Nepal's hills and mountains, along with precipitation variation, have a detrimental impact on solar energy generation [5,57]. Increasingly, forest fires destroy the availability of forest products such as fuelwood and fodder in Nepal, negatively impacting the feasibility of improved biomass energy systems [37].

The effects of climate change on rural livelihood and well-being were demonstrated clearly in the last two decades. The need for the energy transition from conventional energy to renewable sources is urgent to reduce emissions while providing accessible energy that will improve the daily livelihood requirements of rural settlers. Thus, the sustainable installation and implementation of RETs are more urgent now than ever before.

4. Types of important renewable energy technologies in Nepal

Energy resources in Nepal can be classified as traditional, commercial, and renewable [7,36]. Fuelwood, agricultural residue, and cattle wastes are traditional forms of energy, while electricity, LPG, kerosene, diesel oil, coal, and other petroleum gases are commercially used forms of energy. The most popular and important RETs include solar energy, wind energy, micro/macro hydropower, ICS, improved water mills, and biogas technology [9]. Table 4 presents the total number of RETs installed in Nepal by the Alternative Energy Promotion Center (AEPC), Ministry of Energy, Water Resources, and Irrigation. Adoption of RETs in the past 10 years is presented in Table 8. The estimated potential for different RETs is shown in Table 5.

4.1. Solar energy

Solar energy is a perpetual and sustainable form of energy. It does not pollute the environment by producing GHGs and toxic gases such as CO_2, SO_2, and NO_x during energy generation [43]. A unit square meter of the area receiving average sunlight generates 1700 kWh power every year globally [59,60]. Solar energy occurs in two ways: 1) concentrating solar power (CSP) that is suitable for large-scale and commercial arenas, and 2) photovoltaic (PV) power which is used for residential and commercial purposes [43,57]. Globally, the use of PV solar has increased from 3 GW in 2003 to 219 GW in 2015 and 430 GW in 2018 [61].

Nepal has the potential for at least four types of solar energy technology: grid-connected PV, solar water heaters, solar lanterns, and solar home systems. Nepal averages 300 days of sunshine per year, receiving 3.6–6.2 kWh of solar radiation due to its higher altitudinal location [62]. Nepal has 6.8 hours of average sunshine hours per day with an intensity of the solar insolation that range between 3.9 and 5.1 kWh/m^2/day [63]. If one assumes 4.5 hours of sunshine per day and the use of PV modules with 12% efficiency, the total energy that can potentially be generated is 80,000 GWh per day [64]. This potential energy would comprise approximately 17% of the total primary energy supply (TPES) for the year 2008 for Nepal [65].

According to the AEPC's 2008 report on the Solar and Wind Energy Resource Assessment in Nepal (SWERA), the total commercial potential of solar technology for grid connection is calculated to be 2,100 MW (Table 5) [7,9]. It is also calculated that if 0.25% of Nepal's total land area was covered with solar panels with only 20% efficiency, this would fulfill the national electricity demand [66]. Solar offers the most reliable and promising energy source for Nepal.

Energy generated from PV solar panels has not been connected to the national grid system, but rather largely utilized at the household level in rural settings. Additionally, solar energy is becoming popular among business and household systems in Nepal due to its low cost and eco-friendly characteristics [7]. The cost of the solar PV panels is decreasing every year such that the price at present is half of what it used to be seven years ago, and the price is predicted to decline by another 60% over the next decade [67]. The price of batteries and other forms of energy storage technologies have also decreased by approximately 80% over the last decade [68]. This would make solar energy highly accessible to both rural and urban Nepalese communities.

Table 4
Cumulative achievement in RETs installation in Nepal [58].

Programs	Unit	Achievement till FY 2018/19
Mud improved cooking stoves	Nos.	1,423,242
Solar home system	Nos.	911,097
Domestic biogas	Nos.	425,511
Micro/Mini Hydro	kW	32,159
Institutional solar PV system	Nos.	1993
Metal improved cooking stoves	Nos.	85,805
Improved water mills	Nos.	11,018
Urban solar home system	Nos.	21,144
Solar drinking water and irrigation pump	Nos.	1,364
Solar/wind mini-grid system	kW	563
Large biogas plant	Nos.	247

Table 5
The estimated renewable energy potential of Nepal [7].

RETs	Potential	Coverage
Mini/Micro hydro	>100 MW	Possible in 55 districts of Nepal
Domestic biogas	1.1 million plants	For existing livestock population
Solar energy	2,100 MW	4.5 kWh/m^2/day radiation and 2% country area
Improved cooking stoves	>2.5 millions	Assuming 75% of households eligible
Improved water mill	25-30,000 MW	–
Wind energy	3,000 MW	Assuming 10% area with more than 300 W/m^2
Biofuel	100,000 tons	

4.2. Hydropower

Hydropower is currently the most common form of RET in Nepal. However, only two percent of national hydro resources are currently in use [36,66]. This shows that the hydro resource could be a clear option for future economic development in Nepal [9]. Continuously flowing rivers from the base of the high Himalayas comprise approximately 2.2% of total global water resources [63], which is four times larger compared with the world's average water resources [69]. This is a tremendous asset for hydropower generation in Nepal. More than 6000 rivers in Nepal flow from north to the south (higher altitudinal zone to lower altitudinal zone) [70] with an annual flow of 174 billion cubic meters of water [71]. The estimated theoretical, technical, and economically feasible hydro energy potential of Nepal is around 83,000 MW, 45,000 MW, and 42,000 MW, respectively [64].

In 2019, Nepal's total installed hydropower capacity was 1,127 MW [72]. At present, 88 hydropower projects are in operation in Nepal. Currently, additional 113 hydropower plants are under construction. This shows that Nepal's potentiality in generating hydropower energy is very high. But due to several challenges such as economic, political, geographical, and technical challenges, Nepal has not been able to harvest electricity at its full capacity. Most of the currently operating hydropower plants are based on running river systems, so a reduction in the flow of rivers during the winter season results in the lower production of electricity by 30% or even more [7]. The use of local technology in off-grid electricity circulation is well-known in rural areas of developing countries. Nepal is one of the best examples in the successful construction and maintenance of more than 400 small-scale micro-hydropower plants in off-grid systems between 2007 and 2014 at the local level using locally available resources. These small-scale micro-hydropower plants have a current production potential of 1,095 kW electricity supporting more than 150,000 rural families [7,29].

The amount of electricity production and population access to electricity for different provinces is presented in Table 6 [20]. Gandaki Province (Province 4) produces the largest amount of electricity

Table 6
Electricity production and access to Electricity by Province [20].

Provinces	Electricity Production (MW) (Till mid-July, FY 2018/19)	Population with electricity access (%) (Till mid-March, FY 2019/20)
Number 1	136.19	86.3
Number 2	0.00	87.25
Bagmati	400.88	95.83
Gandaki	519.83	87.48
Lumbini	22.13	89.07
Karnali	6.25	27.74
Sudurpashchim	43.43	67.33

(519.83 MW), whereas Province 2 does not generate any electricity. Similarly, Bagmati province has the highest percentage of the population (95.83 %) with electricity access whereas Karnali (Province 6) has the lowest access to electricity with only 27.74 % [20]. Karnali province is the largest province by area yet has the lowest population with sparsely distributed development activities and is renowned as the most remote province in Nepal.

Although Nepal is the second richest country in water resources and has thousands of perpetual rivers, the potential of naturally available resources to generate electricity has not been utilized. The distribution of hydropower plants is a complex and very expensive work in Nepal, due to poor economic status, lack of technical and scientific knowledge, equipment, skilled manpower, and unstable politics. Transporting heavy equipment and extending transmission lines to connect the scattered rural settlements is challenging over Nepal's mountainous terrain. This is compounded by frequent natural disasters, such as soil erosion, landslides, and floods, which also limit the construction of hydropower projects and transmission lines in Nepal. Hydropower projects also have profound impacts on the environment, socio-economic aspects, culture, and financial sectors of the nation [73]. Thus, Nepal lacks the adequate capital to construct and operate large hydropower projects and has to depend on financial aid from developed nations. Several hydropower projects have been constructed in Nepal with financial aid from India and China [66].

4.3. Biomass energy

Globally, biomass is considered as a potential source of alternative energy [74–76]. Biomass is defined as the biological substances obtained from living things such as wood, agricultural crops and residue, forest residues, municipal solid waste, animal wastes including dung and fats, aquatic plants, and algae, and wastes from biomass-based industries [77]. On a global scale, marine and terrestrial ecosystems are the major sources of biomass and generate a total of 77 billion tons per year [78]. In addition, marine and terrestrial ecosystems share 47% and 53% of biomass resources, respectively. Similarly, humans utilize terrestrial resources as the major biomass resources that account for 50% (20.35 billion tons per year) of the total available biomass for the daily use [79]. Out of 18% of total energy generated from RETs, biomass holds a share of 14% and supplies 10% of the world's primary energy [80–82]. In Nepal, natural resources such as forests, agriculture, and livestock are the primary resources of daily biomass energy production [9].

4.3.1. Traditional biomass energy

At present, Nepal's 44.8% of total land is covered by forest [19]. Moreover, the majority (three-fourths) of traditional biomass energy used for fuel is generated from the forest lands followed by agricultural land, shrublands, barren land, and grassland [9]. Agriculture is the major source for income to rural livelihoods. About 68% of the population depend on traditional biomass to meet their energy requirements [5,7,20,36]. Several residual products generated from agricultural products and oilseeds from flowers like sunflower, and other fiber products, such as jute, subsidize the limited availability of wood products in the rural areas. These types of agricultural residues used for energy in rural communities account for the third-largest biomass energy source followed by wood and animal dung [9]. Fig. 3 presents the traditional firewood cooking stove common to rural Nepal.

However, the techniques of using these biomass resources can determine their positive and negative impacts on rural livelihoods, the economy, and the environment. Traditional biomass energy use is a primary cause of increasing indoor air pollution [83], responsible for the deaths of more than 4 million individuals worldwide [90] and 7,500 individuals in Nepal annually [38,84]. In response to these issues, several organizations have successfully installed improved cooking stoves in rural communities under biomass programs for more than two decades. It has been one of the most successful pollution mitigation programs in Nepal, as it collaboratively works with the local stakeholders including non-governmental organizations (NGOs), governmental organizations, and community-based organizations at the local level [9]. The extension in the use of ICS that are made from mud and metal (Fig. 4) produce comparatively less smoke than the traditional stoves and help to reduce indoor air pollution and respiratory diseases in rural communities [7]. However, a large proportion of the population in Nepal is unable to receive subsidies from the government and are dependent on traditional cooking stoves. This has increased human mortality due to pollution and exacerbated GHG emissions at the household level.

Up until 2018/19, the AEPC distributed 40,000 ICS in rural Nepal.

Fig. 3. Traditional firewood stove for cooking in rural Nepal. Source: Author.

Fig. 4. Improved cooking stove constructed with mud. Source: Author.

Moreover, until this time, this organization has achieved the cumulative installment of 1,423,242 mud ICS and 85,805 metal ICS (Table 4), which has supported the efficient use of biomass energy sources and created smoke-free zones [58]. The government of Nepal has increased the subsidies for the construction of ICS all around the country. The ICS (metallic stoves) and institutional gasifiers are more successful in Nepal than other biomass activities. In addition to ICS, briquette, and pellet industries are being developed, which might prove successful in the future.

4.3.2. Biogas technology

Livestock plays a crucial role in the Nepalese farming system, nutritious food production, and daily energy production. With the advancement in science and technology, Nepalese communities have begun using livestock by-products to produce energy utilizing biogas technology [5,9,22,58,85]. Livestock in rural communities is fed with organic wastes, which would otherwise be left for decomposition produce GHG like methane and nitrous oxide [86]. Methane gas release is more hazardous than carbon dioxide, as it has about 84 times more heat-trapping capacity [87]. The promotion of biogas technology for cooking in rural communities reduces the use of traditional energy, which directly supports climate change mitigation by reducing GHGs emissions and minimizing deaths from respiratory diseases caused by indoor air pollution [85–88].

In the local language, the rural communities in Nepal refer to biogas technology as *"gobar (dung)"* gas since it is generated from livestock dung. At present, all 283 municipalities and 460 rural municipalities of Nepal have installed biogas plants (Fig. 5). However, the higher elevation regions are too cold for sustainable use of biogas technology. The total target and achievement of different types of biogas plant installation in Nepal until mid-March of the FY 2018/19 is presented in Table 7 [58]. The installation of household-level biogas plants is successful because several other adaptation-based organizations along with AEPC provide financial and technical aid in different places of Nepal. However, in urban areas, LPG is quite popular. Table 4 shows the total number of installed domestic and large biogas plants: 425,511 and 247 respectively until FY 2018/19 [36]. The domestic biogas potentiality of Nepal is 1.1 million plants followed by 100,000 tons of biofuels (Table 5).

Although all local levels in Nepal have access to biogas technology, it is not the definitive solution to Nepal's energy crisis. Biogas plants need an ideal temperature of 35–37 °C for the generation of energy; however, the high hills and mountain regions have cold temperatures throughout the year, restricting the production of energy [9]. Moreover, the design and construction of biogas plants requires capital that rural households

Fig. 5. Household level biogas plant. Source: Author.

Table 7
Target and achievement of biogas plants installation in Nepal till mid-March FY 2018/19 [58].

Types of biogas plants	Achievement in FY 2018/19	Target
Urban biogas	20 (20 %)	100
Large biogas plant	60 (120 %)	50
Biogas plants for households	9,451 (47 %)	20,000
Household biogas targeted for *Dalits* and indigenous people	3,750 (75 %)	5,000
Rehabilitation of earthquake affected biogas	0 (0 %)	–
Community and institutional biogas	25 %	–

and community institutions do not have. Although the government and other NGOs have subsidized the construction of biogas technology, the individual household still needs to bear the installation cost ranging from $143 to $357- quite high compared to per capita income [89].

In FY 2018/19, there was a decline in the number of sheep, buffaloes, donkeys, and yaks by 0.2–3.7% in Nepal [36]. Thus, many households do not have enough livestock to the biogas digesters. In addition, households in high altitudinal regions are not able to collect enough water to operate biogas plants [90,91]. While some households can access financial and technical support from organizations in these regions, poor households with no livestock rarely get this support. Also, once the plants are installed at the household or institutional level, the problem of ineffective management and maintenance due to lack of technical and financial capital is often seen [9].

4.4. Wind energy

Wind energy is one of the most popular RETs that has been adopted widely throughout the world [92]. In the last decade, there was a significant increase in the global production of wind energy to over 20% per year [51]. Wind energy is prioritized globally as it plays a vital role in climate change mitigation by reducing GHG emissions [24]. Approximately half of the global wind power capacity has been installed only in the last 5 years, and this has become a crucial source of new power generating capacity in highly developed countries [93]. The utilization of wind energy increased nearly 8 times (39 GW–318 GW) between 2003 and 2013 and increased to 600 GW in 2018 [92]. The additional benefit of installing wind energy include its size and a lower cost of production with the increase in turbine size.

In Nepal, the expansion of wind power is quite low. However, the capacity is relatively high due to its geographical and topographical features [7]. While the World Bank has estimated Nepal's potential wind energy production at about 3,000 MW (Table 5), little expansion of wind energy has occurred [69]. The tall and windy mountain ranges in the northern region of Nepal are highly suitable for wind turbine installation. The time and installation cost for wind turbines is quite low, averaging about 6 months to set up a wind farm of 100 MW production capacity [7]. However, the lack of road access in rural mountains of Nepal due to complicated geography, lack of infrastructure, limited research data, and sparsely populated human communities have been the largest hindrances to wind farm installation [7,9].

In 1987, with the aid from the Danish government, the Kagbeni wind energy project having a production capacity of 20 kW was installed in the Mustang district of Nepal. A lack of regular maintenance stopped the project [9]. Under the support of the Technical University of Denmark, Nepal is currently developing 80–100 m wind resolution map in 10 different regions to create the Wind Atlas of Nepal [94], which would assist wind turbine development with greater coverage. Currently, the cumulative achievement in energy generation via solar/wind mini-grid system is 563 kW (Table 4). In the FY 2018/19, the AEPC generated 30 kW energy from wind/solar hybrid systems [58]. Similarly, AEPC installed a data logger, carried out a resource mapping program, and conducted 5 additional feasibility planning programs. However, as of

2018, the net production capacity of wind turbines established in Nepal was 113.6 kW. APEC supported 65 kW of this energy production, Practical Action supported 3.5 kW, and the rest of the 45.1 kW was supported by private sectors [7].

5. RETs and climate change mitigation in Nepal

This section will highlight the importance of RETs in climate change mitigation by reducing GHG emissions. Multiple studies have argued that the increase in the use of RETs such as hydropower, solar, wind turbines, biogas, etc. will reduce GHG emissions [86,95–98]. Currently, several countries in the world have given considerable focus on renewable energy sources because of the negative impact of GHG emissions on the environment generated from non-renewable energy sources. A one percent increase of biomass energy production would result in a reduction of GHG emissions by 0.089% [3]. Some studies in European Union nations argue that the replacement of fossil fuels by RETs significantly (approximately ½) decreased GHG emissions [2]. Although some literature criticize that generating RETs requires the use of other forms of energy that still emits GHG [97], several studies depicted that transitioning to RETs from non-renewable and other forms of conventional energy resources will help to mitigate climate change by reducing emissions and making new pathways for further benefits [1,97, 99–101].

Nepal's contribution to global GHG emissions is very low – accounting for just 0.027% of total global emissions [13]. However, the use of traditional energy at the household level for cooking and transportation produces a large amount of CO_2 at the local level. Replacing traditional energy resources such as fuelwood, kerosene, leaf and litters, agricultural residue, and animal dung by ICS and biogas will reduce the amount of carbon emissions at the household level [5,7,9,102]. This would ultimately reduce the dependency of rural communities on forest and agricultural residues, which would in turn assist local communities in forest conservation, resulting in additional sequestration of carbon [103]. Replacement of traditional biomass consumption would save around 14,268 tons of biomass in a year, which is equal to 8917 ha of forest. Moreover, replacement of older vehicles that consume a larger proportion of imported fossil fuels including petroleum products and diesel with new means of transportation such as electric vehicles thereby reduce CO_2 emissions.

Decomposition of organic wastes produced at the household level is a source of methane and nitrous oxide [86]. However, the use of these wastes for livestock feeding and using dung for biogas production reduces the emission of these harmful gases [9,22,86]. The emissions from households dependent on micro-hydro produce about 3.6 kg (KG) less carbon on average than a household without dependent on micro-hydro [104]. Additionally, the promotion of electricity and solar power has reduced the use of kerosene by 80% [105]. Similarly, the promotion of micro-hydro power has saved approximately three liters of kerosene each month for each household [106]. Furthermore, the promotion of ICSs alone can save about 420 tons of biomass (262 ha of forest area) in a year whereas a single biogas plant alone can save three tons of wood (38 liters of kerosene) annually in an average [5].

Study has shown that consideration of various RETs in Nepal could mitigate about 4.45 million tCO_2e of GHG emissions annually till 2030 if the technologies proposed after 2012 were implemented (Fig. 6) [27]. In terms of shares of the RETs in GHG mitigation, biogas could account for the biggest share in mitigating GHG emissions with the potential of 2.29 million tCO_2e (51.4%) by installing 822,774 biogas plants followed by installation of 898,487 ICSs with the potential of 1.84 million tCO_2e (41.4%) after 2012. The stand-alone and mini-grid micro-hydro plants could account for 170,000 tCO_2e (3.8%) mitigation potential by installing 73.2 MW of their combined capacity. Similarly, the solar PV home system could account for 114,000 tCO_2e (0.8%) mitigation potential by installing 215,903 solar PV home system [27]. Nepal submitted its second NDC in 2020 under the Paris Agreement for the period 2021–2030. The NDC is focused on climate mitigation to support collective effort in emission reduction pathways consistent with the Paris Agreement (1.5 °C warming limit). According to the NDC, Nepal aims to fulfill 15% of national energy demand from RETs by 2030 [28]. Nepal aims to promote electric vehicles extensively to reduce the demand for fossil fuel from 40 Gigajoule (GJ) to 36 GJ in the Business as Usual (BAU) scenario in 2025. This will decrease fossil fuel use by 9% and reduce GHG emissions by 8%. In addition, by 2030 Nepal aims to provide 25% of households with electric stoves for cooking. It also aims to install an additional 500,000 ICS. The country aims to install 200,000 biogas plants at the household level and 500 large-scale biogas plants by 2025. By 2030, these targets will reduce emissions by approximately 23%. Nepal aims to expand energy generation via RETs from 1,400 MW to 15, 000 MW by 2030. In addition to electric stoves, ICSs, and biogas plants, Nepal aims to generate 5–10% of RETs from mini and micro-hydropower, solar energy system, wind turbines, and bioenergy

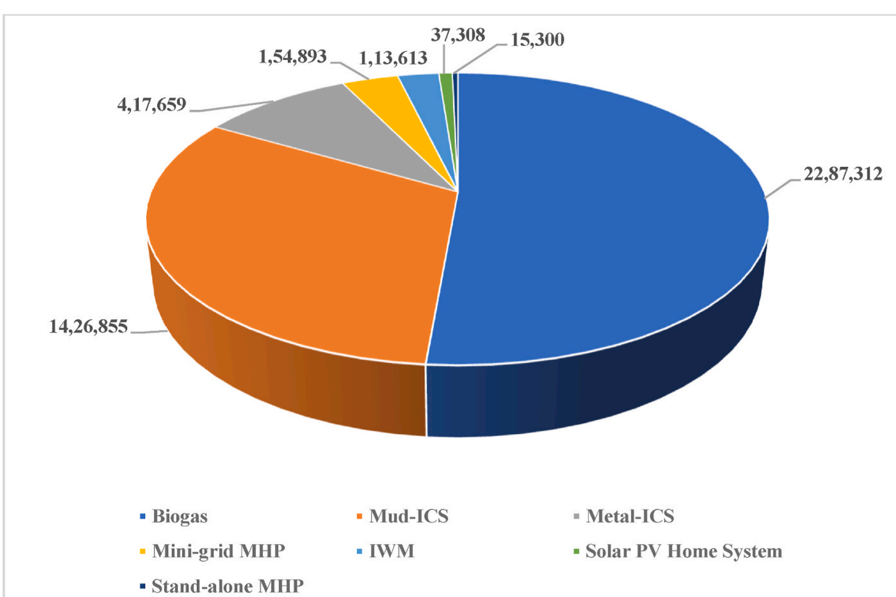

Fig. 6. GHG mitigation potential of different RETs in Nepal, tCO_2e [27].

[28].

The household-level use of the RETs such as ICS, and biogas plants are flourishing in almost every district of Nepal. The largest amount of GHG emissions reduction have been achieved by adopting ICS [58]. The estimated total carbon mitigation potential for different RETs in Nepal is presented in Table 9. The government's statistics show that the estimated annual emissions reduction achieved via RETs in the Fiscal Year 2017/18 and 2018/19 (until mid-March) are 134, 326 tCO_2e, and 86, 803 tCO_2e respectively (Table 10) [58,107]. Table 10 depicts that installation of ICS played a crucial role in reducing GHG (46,388 tCO_2e) followed by domestic biogas (28,353 tCO_2e) and solar PV Home Systems (6,045 tCO_2e) in FY 2018/19. Mini/micro hydropower reduced GHG emissions by 3,342 tCO_2e [58].

6. RETs and climate change adaptation in Nepal

This section highlights the roles of renewable energy technologies in climate change adaptation in Nepal. The climate change adaptation strategies promoted through health, social, and economic sectors that help local livelihood to adapt to the changing climate are discussed. In the present context, the use of solar energy at the household level in rural villages and big industries in urban areas, replacement of traditional cooking stoves by ICSs, generating electricity by wind turbines in high mountains are some of the examples of adaptation activities. The adaptation activities should be focused on a way that addresses the need of highly climate-vulnerable groups, including women, children, farmers, etc. RETs play a crucial role in climate change adaptation in different ways across scales.

Nepal is one of the most climate-vulnerable nations and has been adopting several adaptation strategies over time [15,108,109]. Currently, adaptation programs and policies have focused on RETs. For instance, NAPA, LAPA, and CCP have incorporated RETs in their adaptation strategy and implemented them in different parts of Nepal [27]. They are focused on household-level solar projects, micro-hydro projects, ICS, biogas, solar water pumps, water mills, etc. that have been beneficial to climate-vulnerable communities in rural areas. RETs have huge benefits in Nepalese rural lifestyles, economy, education, environment, and health sectors [5,7,9,110]. The proliferation of renewable energy promotes climate adaptation by promoting energy security, increasing employment opportunities, ensuring easy and local access to energy, and improving human health [111].

Economically, renewable energy is comparatively inexpensive compared to non-renewable energy sources [112] because of the rapid improvement in technology and availability of local resources for production. For example, mud ICS, briquette, and dung for biogas plants can be obtained quickly at a local level in Nepal. In addition, micro-hydro plants and watermills are easy to establish due to the presence of perpetual flowing water resources in the country. Moreover, in the last few decades, policy planners have started to incorporate RETs in cross-sectoral policies in Nepal [113]. Adaptation strategies via RETs are economically viable, environmentally friendly, locally available, and socially adaptable. The following sections address climate adaptation in three areas including the health, social, and economic sectors of Nepal.

6.1. Health sector

Malnutrition is a serious health issue among children in Nepal. Climate change exacerbates the problem as it directly impacts food production, security, and children's health [12]. RETs help families to save time on household chores, which could be utilized to grow, cook, and feed nutritious meals to their children. Therefore, RETs can play a crucial role in reducing malnutrition in Nepal. Moreover, different means of communication technologies like television, radio, Internet, and phones may be used as adaptation measures to increase awareness about climate change impacts and adaptation. Nepal has already used mass communication methods to raise awareness about different social issues such as disease, use of contraceptives, balanced diet, child immunization, etc. [114].

Traditional energy generates indoor and outdoor air pollution. Replacing traditional energy sources with RETs can significantly reduce air pollution. The clean energy system in cooking and lighting can decline the rates of respiratory infection, eye diseases, and child mortality [5,103]. Replacing old vehicles that produce excessive CO_2 gas will reduce urban air pollution. Electricity generated from micro-hydro power helps to adapt people by creating a clean and healthy environment both in rural as well as urban areas. This minimizes respiratory infection by 1.5 hours each month for males and 6 hours each month for females [115]. The chances of a fire in rural houses due to the use of firewood, litters, candles, and kerosene is high. The rising temperature in the Terai, Hill, and Mountain regions has further exacerbated the probability of household-level fire casualties in Nepal. Transitioning these energy sources to solar power, and micro-hydro power would reduce household-level human casualties [5].

Health institutions such as hospitals, health posts, and clinics in rural districts of Nepal are facing difficult situations in preserving vaccines, operating new technologies and equipment, and sustaining health workers [111]. Areas with proper electricity facilities have 11 health workers per 10,000 patients. Areas with no electricity have only 2 health workers per 10,000 patients [105]. Locally generated electricity from various RETs can help support successful operations to preserve vaccines and other temperature-sensitive medicines [111]. RETs will also encourage health workers to permanently settle in rural areas that will ultimately enhance the health security of rural communities.

6.2. Social sector

Quality of life, gender equality, quality education, social networks, and employment determine the adaptive capacity of a locality. Better access to energy sustains social life. In developing nations like Nepal, better access to energy for both household and commercial purposes secures multiple forms of adaptations like saving time, an opportunity to quality education, promoting communication, women empowerment, employment opportunity, and better health quality [100].

Installation of RETs at the local level requires a huge number of local laborers. For example, the construction of mud ICSs do not require scientific knowledge and can be made from locally available resources like mud and stones. The construction of biogas plants and micro-hydro projects also requires extensive labor. Local people who do not have other employment can participate in the construction of these RETs [5].

Table 8
Adoption of alternative energy sources in Nepal [36].

	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Solar Home System	60,602	36,135	57,059	35,627	96,495	87,038	103,061	56,770	16,084	9,291	16,572
Mini/Micro Hydro	1,193	1,695	2,453	3,258	3,366	3,288	3,646	1,910	1,245	957	939.5
Improved Cooking Stoves	39,839	61,760	90,960	103,276	94,751	128,345	135,811	310,281	73,161		
Biogas Plant	19,479	19,511	17,907	18,979	17,635	31,512	30,078	16,706	20,536	15,707	8,346
Solar Dryer	596	338	272	202	140	202	30	22			
Improved Water Mills	1,168	986	353	971	1,256	341	641	673			

Table 9
The estimated total carbon mitigation potential for different RETs in Nepal [5].

RETs	GHG emissions reduction rate (eq/kW/year) (tCO_2e)	Total planned RETs for 20 years (2013–2032)	Emission reduction for 20 years (tCO_2e)	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

Table 10
Greenhouse Gas Emissions reduction form different RETs [58,107].

RETs	2017/18	2018/19
Wind/Solar mini grid	460	345
Institutional/community/commercial biogas plants	513	295
Solar drier/cooker	626	244
Improved Water Mill	741	588
Solar PV Home Systems	9,543	6,045
Mini/Micro Hydro Power	3,526	3,342
Domestic Biogas Plants	58,344	28,353
Improved Cooking Stoves	58,669	46,388
Institutional Solar PV System	1,683	–
Solar Drinking Water/Irrigation Systems	220	–
Total	**134,326 tCO_2e**	**86,803 tCO_2e**

Generating employment opportunities at the local level will help people adapt to shifting social and environmental challenges caused by climate change. In rural areas, laborers are required to carry construction materials from the district headquarter to other parts of the district as there is a lack of a transportation system. Large-scale solar and micro-hydro projects require staff on a daily basis for daily operation and frequent maintenance, which secure long-term job opportunities to local people.

Children in rural areas are deprived of quality education as they lack access to computers, lab equipment, and the Internet due to the lack of electricity. In Nepal, like in the health sector, teachers hesitate to travel to rural areas because they lack access to electricity, lighting, the Internet, and a quality lifestyle. This reduces the quality of education in rural areas. Moreover, students face problems in quality education as they must use kerosene lamps and candlelight to study. The promotion of electricity generated locally from solar power, micro-hydro power, and wind energy would help to adapt to those issues and promote quality education [5,7]. Electric lamps are brighter [104], safer, and healthier [116] than candles and kerosene lamps. RETs can increase the availability of electricity in rural schools that promotes wide use of scientific equipment, which could motivate students to achieve better learning outcomes [114].

Women and children spend more than 6 hours per day fetching water, processing subsistence crops, and searching for energy resources in the forest and agricultural land [7,9]. Both women and men travel long distances or adopt manual agro-mills at home, spending a large amount of time processing raw crops to edible form. But the introduction of RETs would reduce time spent on these chores. The transition of manual agro-mills to electric mills reduces time by 155 hours each year for women and 85 hours for men [105]. Similarly, the construction of biogas plants at a household level would help in saving around 3 hours of time every day, which accounts for 1000 hours in a year in total [5]. In addition to these, the use of electrical technologies in cooking and washing will save time for women. Compared to conventional cooking stoves, the use of ICS alone helps to reduce the cooking time by 15–20% [117]. Moreover, the use of ICS, biogas stoves, and electric rice cooker reduces firewood searching and cooking time by 50% [59], which could be used in doing other beneficiary activities [103].

The time saved by using RETs could be used in alternative income generation or taking care of children for nutritious feeding and quality education. Moreover, women who adopt RETs in rural communities are often involved in social organizations that strengthen their social networking, promote awareness campaigns, and attain informal education institutions [103]. Mothers' groups, women's groups, and women community forest users' groups are some examples of networks and institutions led by women in rural Nepal at the present time, which were rare only a few years ago. These groups bolster social bonds, networks, communication, and skills in developing local solutions to solve social issues like gender discrimination, education promotion, climate change adaptation planning, solving energy crises, and enhancing health quality.

6.3. Economic benefits

The world is trying to transition to a clean energy system generated from biological and traditional sources [3]. A bioeconomy is defined as those activities that are linked with the development of RETs using biological resources and processes [118–123]. Many countries in the last few decades are extensively focusing on promoting RETs.

In developing nations like Nepal, the economic benefits from RETs come directly from the country's economic growth, carbon sequestration and trading, income from diverse sectors, and generating job markets. Whereas some benefits come from different climate adaptation activities, including rural access to electricity, health, water, education, opportunities to alternative sources of income, and controlling environmental hazards and degradation [124]. The price of petroleum products, kerosene, and firewood is increasing. However, installation of household-level solar power, village-level micro-hydro power, and ICS are projected to be cheaper in long run. Thus, the replacement of fossil fuel and traditional energy sources with RETs will help to minimize the cost of energy and support economic growth [7].

The replacement of traditional incandescent bulbs in rural Nepal by compact fluorescent light bulbs (CFL) can help in saving significant amounts of energy which account for 223.1 kWh/year [5]. Energy saved from CFLs could be used in other activities that may help in a rural adaptation by enhancing the economic standard of rural livelihood. The energy consumed by traditional incandescent bulbs is approximately 264 kWh/year per household [124], whereas CFLs account for about 40.9 kWh/year per household energy consumption [35]. The development of micro-hydro power and solar power at the local level has encouraged local entrepreneurship [37] that has promoted new business throughout Nepal [5]. The expenditure on energy has drastically declined among households using RETs. Households generating energy from traditional energy spend USD 41 whereas households generating electricity using RETs spend only USD 19 annually. In addition, the average households have been able to increase their annual income of USD 121 (8%) by using RETs for electricity in Nepal [103].

In Nepal, Clean Development Mechanism (CDM) activities under biogas and micro-hydro projects have helped in generating revenue [59]. Each ton of Certified Emission Reduction (CER) accounts for 9.8 Euro based on the CDM consensus [21]. In the FY 2018/19, Nepal sold approximately 2.45 million Euros and 10.5 million Euros from biogas and micro-hydro projects, respectively [58]. In the next 20 years, biogas is projected to reduce 35.88 million tons of CO_2 emissions, which would be a savings of 0.78 million Euros [5]. Relying on CER, the total revenue under CDM from the biogas and micro-hydro power is considered to be 351.624 million Euros and 25.02 million Euros, respectively [5]. In the history of Nepal, the highest revenue (3.12 million Euros) from selling carbon was generated in the FY 2017/18 [58]. AEPC has recently verified improved water mills under CDM and is expected to earn about 18,895 CERs. Incomes generated from CDM will help to enhance Nepal's adaptative capacity, enrich the economy, reduce the cost of RETs, and support easy access to RETs in Nepal.

7. Conclusion and recommendation

Climate change is a severe issue for LDCs including Nepal. Adopting RETs is a crucial strategy for mitigating the climate crisis. Nepal has abundant natural resources capable to support renewable energy generation via different technologies like hydropower (micro/macro), solar plants, wind energy, biomass (improved cooking stoves), biogas, and watermills. Nepal is progressing in the installation of different forms of RETs each year with support from its government, and other organizations. The generation of micro-hydro power, ICS, biogas, and solar energy have progressed every year and made remarkable changes in some parts of Nepal. We found that in Nepal, currently, 90% of the total population has access to electricity and 71.1% of total households are connected to the national grid. Similarly, 3.21% of people of Nepal generate energy from RETs which was 2.3% in 2015. However, the electricity is unsustainable and inconsistent in providing regular energy to rural areas that stress households depend on traditional energy. Despite Nepal's progress in RETs installation, 68.74% of the population is still dependent on traditional energy generated from firewood, agricultural residue, and cow dung, followed by petroleum products (18.23%), and coal (5.92%) respectively. Nepal has 88 hydropower projects and 400 micro-hydro projects that have played a vital role in providing energy to larger population. Unfortunately, several obstacles like load shedding and irregularity in electricity distribution have forced large percentage of population depend on traditional energy for cooking and other purposes. Similarly, the potential of solar energy is 2,100 MW in Nepal. Besides these, Nepal has put efforts in promoting wind energy, water mills, and biogas technologies as well. Still, a lack of technology, equipment, knowledge, political instability, access to global resources, and finance prevent Nepal from harnessing more energy via RETs.

Widening the use of RETs as socially, economically, and environmentally viable energy resources can potentially play a crucial role in climate change mitigation and adaptation along with the enhancement of the livelihood of people. Wise use of biomass and other RETs for electricity generation for multiple purposes can reduce people's dependence on forests that ultimately reduces GHG emissions and enhances carbon sequestration. Moreover, women, children, and low-income people who fall under the vulnerable category are able to enhance their socio-economic status by utilizing surplus time in extra income generation, building social networks, and enhancing knowledge on health issues, which are the efforts adopted to enhance climate change adaptation in Nepal. This has clearly led us to a consensus that the RETs have played a crucial role to help rural communities better adapt to the changing climate. Replacing kerosene and petroleum products with ICS, biogas, and electric heaters will economize rural household expenditure in energy. Promoting different forms of RETs can expand local job opportunities. Household and community level changes, such as replacing traditional incandescent bulbs with solar and electric bulbs like CFLs, can contribute to local savings. Taken together, these benefits and the country's earnings from CDM will ultimately support economic growth at the national level.

However, several constraints have hindered these opportunities. The lack of a large grid electricity system has obstructed nationwide electrification. Among developing nations, Nepal has one of the poorest standards in electrification rate. The continued use of traditional energy resources causes increased GHG emissions, indoor air pollution, health issues, and a decline in natural resources due to overconsumption for fuel use. Lack of skilled manpower, technology, knowledge, equipment, and mountainous geography have minimized energy harnessing from RETs. Nepal's poor access to global resources, unestablished political system, weak financial resources, and lower capacity to generate and extend electricity transmission in grid systems are additional factors that hinder RETs extension in Nepal. Thus, the Nepalese Government needs to deeply think about the energy economy and social benefits from RETs. It is a crucial time to generate energy via RETs and promote distribution capacity throughout the nation to reduce foreign import and dependency on non-renewable resources.

The findings from this research are significant not only at the local and national scale, but also significant at the transnational scale. This paper discussed, with multiple examples, the importance of replacing non-renewable and traditional energy resources such as oil and petroleum products, firewood, animal dung, and agricultural residues with RETs like micro and macro hydropower, large solar projects, wind energy, and improved biogas technologies. Both developed and developing nations will see a range of benefits in multiple sectors including environmental, social, economic, health, education, etc. across scales if they are aware of the importance of RETs. This paper also suggests that to fulfill the clean energy demand at the local level, every country should try to realize and rely on the locally available resources, so far, to generate RETs.

Having reviewed Nepal's energy demand and its role in climate change adaptation and mitigation, the following recommendations of RET promotion are noted:

i) Nepal should try to extend its large national grid system and distribution capacity as far as possible. If large grid distribution is hindered due to barriers such as rough terrain, difficulty in distributing extension lines, and scarce households, Nepal should decentralize energy sources at regional and local scales. This can be accomplished with the construction of micro-hydro power, solar plants, and wind energy systems across scales. Compared to a few years ago, Nepal now has local governments to assist the provincial and central government in managing the proper distribution of energy sources.

ii) The composition of energy should be sustainable. The right composition of energy is a topic of debate in Nepal, where the country tends to opt for hydropower plants. However, there are other resources like rooftop solar panels and wind turbines more easily, efficiently, and cheaply generated that should be given priority in electricity generation. In addition, Nepal should study and try to adopt the international trend of designing a mixed portfolio of energy resources in building power systems.

iii) The government should be able to compile and make a comprehensive report on the updated energy situation in Nepal. Several ministries and their departments work on the energy sector, but there is not a clear, comprehensive, searchable report on all energy systems. Also, an open-access database on the energy systems of Nepal should be made and updated frequently. Transparent availability of data and understanding the updated energy situation help to tackle energy crises.

iv) Securing rural people and local institution's participation plays a vital role in promoting RETs in Nepal. The social network system is quite strong in rural Nepal, and the trend of cooperative work has flourished in different sectors. This cooperative approach in the energy system has been practiced in some parts of Nepal. For the decentralized functioning of the energy system, the concept of the cooperative should be widened throughout the country supplemented with technical, financial, and legal capitals. The central government should channelize local governments in designing this model for efficient use of local resources in the development and promotion of RETs at a household level.

v) In Nepal, energy plans and policies are prepared and implemented under national government authority. Recently, Nepal has entered a new system of governance, the Federal Democratic Republic of Nepal. The local governments have been functioning for a few years now and they have started designing policy at the local level. Energy sector policies should be now developed and implemented by local governments so that local level access to RETs and wise mobilization of local resources are secured. These plans should be integrated with local government development plans for successfully implementing their goals. Moreover, climate or any environmental plans and policies from diverse sectors should highly advocate RETs as climate change adaptation and mitigation strategies within government plans.

vi) Rural communities that fall under the poverty line and are not able to install expensive RETs like biogas, water mills, solar systems etc. are not even supported with government subsidies. In this case, the local government should manage financing services (soft loans) through microfinance institutions that are already working at the local level, such as financial cooperatives. This can help in debt management and ease poor households who are not capable of dealing with large financial institutions and banks.

vii) Government at all three levels should try to reach more households with subsidies every year to encourage local people to transition from non-renewable energy resources to RETs. This should help replace traditional biomass use with more modern practices, CFL bulb replacements for incandescent bulbs, and replace old transportation vehicles with electric vehicle systems. Collectively, these practices will reduce GHG, reduce indoor air pollution, promote natural resources conservation, reduce health issues, enhance the economy and quality education, and strengthen social capital.

vii) With high potential of Nepal in generating wind, solar, and micro-hydro power energy, the government should prioritize these technologies, do detailed assessment studies, and make separate plans for each for scientific study. This would create a better understanding of the current status of these energy resources and help to make further planning and goal-setting easier to achieve.

ix) Nepal should put the effort into reducing petroleum products imports. To do so, the government should be financially strong to generate energy from its own resources that require investors. Hence, the government should prepare policies that would encourage private sector involvement. Moreover, the Central Bank of Nepal could utilize its political and economic power to stimulate both domestic and foreign investments into the energy sector. Also, strengthening relationships among neighboring nations in South-East Asia for proper collaboration in the energy system would be beneficial to Nepal.

x) Awareness campaigns targeted to local people and school level children should be provided regarding the social, economic, environmental (incorporating climate change mitigation and adaptation), and health benefits of RETs. The local government, other stakeholders, and educational institutions can facilitate and promote such programs. Moreover, these stakeholders can use mass media (radio, TV, and newspapers are the popular means in Nepal) and social media in extensively disseminating information about RETs and their importance to a wide audience.

xi) Finally, in the future the academic and non-academic researchers should focus scientific research on the potentialities, challenges, and barriers of RETs promotion in the new political regime of Nepal. This will generate critical information positioned to help the local, provincial, and national government in making appropriate plans and policies in energy, citizen livelihood, and the environmental sector.

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Suman Acharya did conceptualization, data curation, resources, and writing- original draft, review, and editing.

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