Strategy for 100% Renewable Energy supply in Bhutan

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Abstract

Bhutan's ambitious vision of 100% renewable energy (RE) supply is based on hydropower as the main source of electrical energy supply and it is inevitably linked to the adverse impacts of climate change. As of now, only 5% of the total hydro potential is utilized for electricity generation where 75% of generation is exported to India. Despite the enormous potentials, as Bhutan's transport fuel requirement is 100% import-dependent, the national renewable energy share currently remains at 60%. In addressing this challenge, this study aimed to identify alternative renewable energy supplies and their potentials for Bhutan's 100% RE vision.

The qualitative analysis carried out on the available RE sources indicates that Bhutan has about 50 GW of solar energy potential and 4 GW of wind potential in addition to the existing untapped 30 GW hydro energy potential for electrical energy generation. Additionally, biomass from cattle waste is also suitable for rural cooking energy demand. Combined potential of these RE sources have the capacity to mitigate adverse impact of climate change.

While Bhutan has achieved 34% renewable electricity supply, this study aimed to find substitutes for transport fuel and coal employing clean renewable electricity leading to a 100% renewable energy supply. As hydro electricity supply is relatively cheap (USD 4.00 cent) it is foreseen that electro-mobility (i.e. electric vehicles) and electrical energy substitution for coal for Bhutan is economically conducive. Therefore, this study concludes that 100% renewable energy is feasible in Bhutan. The policy addressing switch to electric car and ban of coal usage is strategically implementable.

Key words

Renewable energy Potentials, 100 % renewable energy strategy

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Contents

List of acronym

GDP*: Gross Domestic Product*

GNH*: Gross National Happiness*

LCOE*: Levelised Cost of Electricity*

LCA*: Life Cycle Analysis*

PV*: Photovoltaic*

ADB*: Asian Development Bank*

TERI*: The Energy and Resource Institute*

DGPC*: Druk Green Power Corporation*

UNDP*: United Nation Development Program*

UNEP*: United Nation Environment Program*

IEA*: International Energy Agency*

SAES*: South Asia Energy Security*

CCS*: Carbon Capture and Sequestration*

IREINA*: International Renewable Energy Agency*

USAID*: United State Agency for International Development*

GHG*: Green House Gas*

NREL*: National Renewable Energy Laboratory*

SNV: *Netherland Development Organization*

Conversion used

1 KW=1000 W

1 MW=1000 KW

1 kWh=3.6X10^{6} *J*

1 Km=1000 M

1 Kg=1000 g

$1=Nu.50

Chapter 1

1.1 Introduction

A sustainable Energy source is a backbone for GDP growth. While energy plays key role in GDP growth, many countries opt for least-cost strategy which results in use of conventional energy sources from fossil resources which is heavily depleted. Due to the fact that Bhutan does not have fossil resources, it is opting for 100% renewable energy supply. However Bhutan is still net importer of fossil resources. Therefore an alternative that results in secure and 100% renewable energy supply source is crucial for Bhutan. Also economy is based on water resources, which is subject to adverse impact of climate change. Therefore identifying alternative to such challenge, this study will analysis on 100% renewable energy strategy for Bhutan.

Brief country profile: Bhutan is a small landlocked Himalayan nation occupying 38394 Km^2 area. The suitable geographic elevation of Bhutan makes hydropower generation attractive for Bhutan. Bhutan exports excess hydropower electricity to India, which is the main source of GDP. World Bank data shows 9.4% GDP growth rate of Bhutan. The GDP growth rate accounted for development of commercial scale hydropower and tourism. Rural electrification project is one amongst many success stories for energy supply in Bhutan. Today most of the rural households are electrified from central grid energy supply coming from large scale hydropower. There are 20 political regions (Districts) administered by elected government who are obliged to follow the National philosophy of Gross National Happiness (GNH). Approximately 1 million people occupy 20 different districts. More than 90% of the inhabitants have access to electricity. However it still requires revisiting energy statuesque of Bhutan mainly due to adverse impact of climate change. This study therefore aims to provide detail energy potentials of Bhutan.

The outline of the paper is as follows:

First chapter explains the research background. The same chapter gives the literature views on challenges, and opportunities for renewable energy supply. Second chapter is a brief methodology explanation. The third chapter presents potential analysis followed by strategies to 100% renewable energy supply for Bhutan. The last chapter provides summarized version and recommendation of the findings.

1.2 Research problem:

Bhutan's vision; 100% renewable energy supply is subject to many constraints as major renewable electricity resulting from large scale hydropower is exported to India whereby 100% fossil fuel import from India as bilateral trade agreement which precludes 100% renewable energy strategy in Bhutan. Additionally hydropower is subject to adverse impact of climate change. Therefore finding an alternative that result in clean and secure energy supply source supplying in 100% is crucial for Bhutan.

Hypothesis:

100% renewable energy supply source can be achieved by increasing renewable based electricity demand in coal and transport sector.

Research question:

1. What is the renewable energy sources potential for 100% renewable energy strategy in Bhutan?

Sub question

2. What is the renewable energy generation cost in Bhutan?
3. What major share 100% renewable supply impact different energy demand of Bhutan?

1.3 Objective:

1. Find out different renewable energy potential in Bhutan
2. Understand the current energy demand of Bhutan
3. Find out energy generation cost
4. Identify an alternative to existing energy supply
5. Recommend strategies to 100% renewable energy supply

1.4 Literature review

Bhutan is a country with rough mountain terrain. Therefore central grid power extension to all rural areas is techno economically not attractive. Distributed generation system is next alternative option for 100% renewable energy supply. Literature shows feasibility study for distributed type energy supply with different options like PV-diesel Hybrid, PV-wind-diesel, PV-battery and Wind-diesel energy supply in four different locations for providing to secure energy villages remote. The study concluded that the distributed energy supply-mix is economically feasible over central grid supply (Tshering , 2012). However there is no further work carried out although it seems to be appropriate for energy supply in Bhutan. There are other drivers that urge distributed renewable energy supply-mix in Bhutan as outlined in the following literature.

Though the estimated potentials of 30,000MW installed capacity from hydropower has shown Bhutan's future in a better position in Southeast Asia, it still suffers a serious climatic pressure on the rivers formed by glaciers. The annual report of Druk Green Power Corporation of Bhutan (DGPC) presented the electricity generation was declined by 257GWh in 2011 compared to 2010 (DGPC, 2011). Though the generation decline is due to yearly weather change and precipitation change, it still gives an insight that climate change would bring similar negative impact in future. This decrease in energy generation has directly affected the revenue earned from the energy generation from hydro power with a decline of 2$ billion in 2011 compared to 2010. According to Asian Development Bank (ADB) finding Hydropower challenges in Bhutan, it identifies some serious environmental consequences. "Addressing the environmental and social issues associated with large-scale hydropower development will be a major challenge for Bhutan, in the context of possible changes to hydrology in the Himalayas as a result of climate change" (ADB, 2010). The environment and energy journal for Bhutanese study also figured out the same consequences as Bhutan's renewable energy resources (e.g. water and forests) which have proved to be indispensable for development are vulnerable due to the adverse impacts of climate change and environmental degradation (Uddin, 2006). As per this journal the Hydropower is renewable energy source that depend on the size of the dam. According to the Journal article for renewable energy study, the hydro power are classified as Small, mini and micro-hydro plants (usually defined as plants less than 10 MW, 2 MW and 100 kW, respectively) play a key role in many countries for rural electrification which is classified as renewable source (Yuksek, 2005). Most of the hydropower in Bhutan is large scale ranging from 500MW to 1100MW. In the energy potential study carried out by The Energy and Resources Institute (TIRI) India cited in the Druk Green Power Corporation annual report of Bhutan, all the proposed project plants are classified as large scale hydropower dam. The grid electricity is supplied by large scale hydropower which is transmitted throughout Bhutan. However central grid extensions in many places are techno economically not attractive. To overcome these challenges the energy policy document of Bhutan outlined some future potentials from the renewable energy sources like solar, wind and biomass. In the policy statement the renewable energy sources are targeted at 20MW installed capacity from various source (wind, solar and Biomass) (BEA, 2011). Thus seeing from different literature view there is a potential from renewable energy mix and distributed supply in Bhutan.

There are various source of renewable energy in Bhutan among which Wind, biomass and solar are main renewable energy sources apart from the ongoing hydropower projects. Wind is identified as region specific energy as it is dependent on the wind velocity in different places. The wind speed in different region has been studied by different authors and has found out that the maximum wind speed in Bhutan is 6 m/s in high wind speed zone and 2.0m/s in the low wind speed zone (DOE, 2005). High wind speed zone lies in the northeastern part of Bhutan. As of today wind is unexplored resources in Bhutan though there is a potential.

Major source of biomass in Bhutan is fuel wood as forest firewood. According to Addenda M. Victor and David G. Victor, Bhutan is using forest as biomass and total share of energy is estimated to 87% coming from the forest as fuel wood (Nadejda , 2002). The forest biomass utilization is at the moment is conventional practice that is inefficient burning of firewood in conventional burner. Conventional burning practice result in unsustainable use of biomass that contradicts with forest policy which states that Bhutan will preserve more than 60% of its forest cover. Non-forest source of biomass is not yet utilized.

PV Solar has been utilized for off-grid power supply for rural offices and communication antennas. The solar potential study conducted by Paul Gilman for Bhutan identifies Bhutan's solar power as potentially feasible next option as a renewable form of energy. This report presents that the solar resource shows, Bhutan has an adequate resource for flat-plate collectors, with annual average values of global horizontal solar radiation ranging from 4.0 to 5.5 kWh/m2/day (4.0 to 5.5 peak sun hours per day) (Heimiller, 2009). This shows that next biggest source of energy is from solar. It is not harnessed in large scale because hydropower energy supply from central grid still dominates the energy supply in Bhutan. However solar is seen to be economically feasible option for rural electrification in as solar home off-grid electricity supply. ADB report estimates about 4000 household to be electrified by use of solar off-grid power supply. Since these households are located far away from the national grid, grid extension is techno-economically not feasible (ADB , 2011).

1.5 Renewable Policy Overview

1.5.1 International:

Renewable form of energy plays important role internationally to mitigate the fossil based energy supply as it is becoming more and more expensive every year. Generally, renewable energy refers to energy sources that are continuously replenished by the natural world. Among others, solar, wind, biomass, geothermal, small scale hydro and ocean energy are the most widely used and known sources of renewable energy (Mingyuan, 2003). However Mingyuan figures out some limitation on the promotion of this renewable form of energy in developing countries. In addition to Mingyuan finding (Margolis , 2006) also figures out the same problems as outlined in the energy policy drawback, they are;

- ❖ Lack of government policy supporting energy efficiency/renewable energy

- ❖ Lack of information dissemination and consumer awareness about energy and efficiency/renewable energy
- ❖ High cost of solar and other efficiency/renewable energy technologies compared with conventional energy
- ❖ Difficulty overcoming established energy systems
- ❖ Inadequate financing options for efficiency/renewable energy projects
- ❖ Failure to account for all costs and benefits of energy choices
- ❖ Inadequate workforce skills and training
- ❖ Lack of adequate codes, standards, and interconnection and net-metering guidelines
- ❖ Poor perception by public of renewable energy system aesthetics
- ❖ Lack of stakeholder/community participation in energy choices and efficiency/renewable energy projects.

The barrier listed by the authors is common in many nations wherever renewable energy is concerned. In response to listed barriers, behavioral science formulates some compelling policy which encourages public private partnership. These partnerships have arises in a variety of domains, including retirement savings, microfinance, economic development, and health – as well as in energy use and environmental behaviors (Allcott, 2010). The social dimension addresses different financing mechanism (cooperative financing) for promoting the renewable energy supply mix.

Even developed countries like USA faced the same difficulties to promote renewable energy supply though the technology proved feasible. In United State's energy policy, Grossman notes the greatest uncertainty is simply: "Will the technology be marketable?" (Grossman, 2009). In the same line International Association of Energy Economy addressed the same issues on the difficulties faced by renewable technologies. According to this study, the market penetration of energy-efficiency improvements appears to be much more complicated than assuming that consumers select the least-cost strategy among a set of technology options (Huntington, 2011). The least-cost strategy is also true for renewable energy source which is perceived expensive.

The problems related to least cost strategy for renewable energy supply is seen from different prospective by different authors. To respond the challenges Linares investigates renewable forms of energy as cheap options such as promoting energy efficiency, decrease resource intensity, resource depletion, energy security , reduction in carbon emissions, other pollutant emissions, and in general terms, the environmental impact related to energy use (Linares, 2010). It is argued that indirect cost involved in the conventional energy source is most of the cases not clearly addressed. This is termed as external cost which must be included in cost comparison.

Some authors still argue that renewable energy sources as environmentally friendly still has many limitations. For example European policy for bio-fuel production from agriculture has resulted in the food security issue. This is presented in Analysis of Indirect Land Use Change (iLUC) impacts paper under Low Carbon Fuel Standard (LCFS) policy which states "uncertainties regarding the location, magnitude and timing of indirect land use changes, driven by bio fuels growth, we provide a wide range of illustrative experiments that help to narrow the attention of future research efforts and policy analysis on the issues that really matter to environmental sustainability and human well-being" (EuroCARE , 2010). The bio based fuel supply has negative impact on the land use change. On other hand the leading oil supplying country worries for depilated oil reserve. "The Coal Age came to an end not for a shortage of coal but, contra former Saudi Oil Minister Sheikh Yamani states, the Oil Age may come to an end for a shortage of oil" (Friedrichs, 2010). Therefore fossil energy replacement by bio fuel still remains a challenge to what extend to substitute fossil energy supply. There should be clear cut framework on renewable type of energy supply and indirect impact which influences economy and environment in entire life cycle of energy supply.

International Energy Agency (IEA) is promoting collaboration among different countries in Europe to promote energy security and intergovernmental cooperation. This collective effort of different nation finally addresses different target like sustainability, energy security, fossil energy reserve, innovative technology, climate change, social and economic wellbeing and active dialogue among the member state as well as non-member state to mitigate global energy shortage (IEA, 2011). The similar analysis is made collectively by different authors in Viewpoint Article Italy in which they have figured out some fundamental regulation which implies to improve energy efficiency, use local resources, improve innovation and promote regional cooperation (Lucia, 2012). Thus it appears that energy shortage and policy restructuring is felt internationally important.

1.5.2 Energy Security:

The energy resilient and affordable energy cost is generally called as energy security (Brown, 2003) . There are different indicators to define energy security."Energy security is dependent on many factors such as source of risk, scope of the impact measure, speed of the threat impact, size of the threat impact, sustention of the threat impact, spread of threat impact, singularity of threat impact, and sureness of threat impact" (Winzer, 2011). Considering general definition of energy security Bhutan seems to have secure energy supply as seen in the five yearly development plan of Bhutan which states that by the end of 2013 Bhutan will have 100% excess to clean and affordable energy (RGOB, 2013).

Despite the fact that Bhutan has secure energy supply stated in the policy, the joint study conducted on Southeast Asia Energy Security (SAES) shows various challenges for Bhutan. Bhutan's energy security is threatened by the climatic factor and Regional Corporation. The surplus energy generated is traded with India as a bilateral trade agreement. Therefore Bhutan should play active role in southeast regional grid extension and energy trading. Also Bhutan faces challenges in the transport industry where all the fossil based energy is imported as the bilateral trade with India (Sankar, 2005). Transport sector uses highest fossil based energy supply in Bhutan. Therefore transport sector has bigger impact to Bhutan's energy security as the international oil company has a monopoly market share and is over depleted. "National oil companies now command close to 80 percent of the world's remaining oil reserves and will overwhelmingly dominate world oil production and pricing in the coming decades" (Chen , 2007) .

According to (Hildyard, 2012) the security is misleading to many people in connection to threat and other impact measure which is to be understood as a resource scarcity and affordability in terms of cost to get excess to daily energy demand. However Regional Corporation is key criteria for secure energy supply. As per the statement of (Al-Naimi, 2012) Saudi Arabia understands the vital role oil plays in economic growth and knows the value and progress which can be derived from energy resources – but the price must be reasonable. This statement indicate that regional corporation plays important role in energy trading (reasonable price) because resources are not evenly distributed on earth which might result in monopolistic market as it is already seen in market driven policies. The gasoline shortage of European Union in 2005 indicate how national level corporation impact energy supply. The response to shortage was almost like blessing in disguise as European Union made a mandated goal and policy which states "The EU seeks a

20% increase in Europe-wide energy efficiency by 2020 and has mandated that 20% of all EU energy consumption come from renewable sources and 10% of transport fuel from bio-fuels by 2020" (Belkin, 2008). The goal is now materialized by adopting feed-in tariff policy and energy decentralization. It can also be concluded form this policy that Energy subsidy policy in many developing country is not sustainable solution to secure energy supply.

While regional and national Level Corporation is important for secure energy supply, the scarcity of resources put pressure on geopolitical instability among importer and exporter countries. Similar study has been conducted by (Taylor , 2008) which states, " According to them that's unfortunate, because a nation that is self-sufficient in energy is no more "secure" than one that relies on imports for all its energy needs". In the similar line (Kiratu, 2010) points out that even if a nations are energy self reliant, yet excess to energy is not easy in all location considering energy cost. For energy study security of supply is important subject.

1.5.3 Environment Act of Bhutan key to renewable energy supply:

While energy is very crucial for economic growth, the energy related environment impact needs to be considered. Bhutan has strict environmental regulation and policy to conserve its forest and natural ecosystem. According to the national environment commission of Bhutan "every Bhutanese is a trustee of the kingdom's natural resources and environment for the benefit of the present and future generation and it is the fundamental duty of every citizen to contribute to the protection of the natural environment, conservation of the rich biodiversity of Bhutan and prevention of all forms of ecological degradation including noise, visual and physical pollution through the adoption and support of environment friendly practices and policies" (Constitution of Bhutan, 2007). United nation environment program admits the role played by the government of

Bhutan in terms of environmental policies and practices to the high degree of performance. Bhutan's Vision 2020 and the “Middle Path” along with the development philosophy of “Gross National Happiness” have been vital instruments for raising the profile of environmental conservation amongst policy makers and the general public. However, there is an urgent need to rewrite/revise these documents to make them more sensitive to climate change (UNEP, 2009). This is a mile stone target for Bhutan to mitigate the targeted climate change effects on the melting of glaciers on the Himalayas. Under the environmental framework national forest policy of Bhutan states the stringent ambitious plan for future of Bhutan as Bhutan’s forest resources and biodiversity are managed sustainably and equitably to produce a wide range of social, economic and environmental goods and services for the optimal benefit of all citizens while still maintaining 60% of the land under forest, thereby contributing to Gross National Happiness (Ministry of Agriculture, 2008). Among different environment regulation like National Forest Policy, National Environment Strategy, Bhutan Water Policy, and National Urbanization Strategy, Bhutan Sustainable Hydropower Development Policy is noticed under energy study framework. Similarly there are environmental Laws in place that include the Forest and Nature Conservation Act 1995, Mines and Mineral Management Act 1995, Environmental Assessment Act 2000, Road Act of ix Bhutan 2004, National Environmental Protection Act 2007, Land Act of Bhutan 2007, and Waste Prevention and Management Act 2009 (UNDP, 2009). Thus we see energy related environment problem is already addressed in the national policy of the kingdom of Bhutan. This issues are included in energy management master plan of Bhutan as sustainable hydropower policy.

1.5.4 Bhutan's Energy History:

Since 1988 Bhutan started with the commercial scale hydropower in Chukka with the installed capacity of 336MW, Bhutan is actively engaged in energy harnessing and trading. Due to its geographic location, Bhutan is bestowed with steep landscape and the rivers formed by glaciers have made Bhutan suitable electricity generation hub. The surplus energy generated is traded with neighboring India as a bilateral trade. Bhutan however imports fossil energy from India. According to the renewable energy policy act of Bhutan it clearly addresses the over dependency on the use of fossil energy supply which is to be reduced by the use of different renewable energy mix. The renewable policy acts states "In view of the rising demand and increasing reliance on a particular Energy source, it is critical to broaden the energy mix by means of harnessing other forms of clean renewable energy sources. Further, there is a significant need to supplement the electricity generation in the low river inflow months by other forms of renewable energy sources. Considering the import levels of the fossil fuels, there is a crucial need to minimize the use of fossil fuels by providing alternatives indigenously" (BEA , 2011). Therefore the renewable energy sectors strive to generate 20MW installed capacity from the renewable based energy mix which comes from wind, solar and biomass. As per the evaluation study made by Asian Development Bank, Bhutan's policy and practices have fulfilled the environmental conduct while energy became the economic backbone of nation. ADB state, "By 2009 power sector entities in Bhutan had achieved an adequate level of institutional maturity and sophistication, with the exception of the power sector regulatory agency Bhutan Electricity Authority (BEA). Bhutan Power Corporation (BPC), responsible for domestic power supply, and Druk Green Power Company (DGPC), responsible for operating the export-oriented hydropower projects, have been profitable" (ADB, 2010). This report has also shown the economic condition of Bhutan is sustainable with the hydro power potential of 30,000MW installed capacity. The potential is not diverted to export market alone but also to secure domestic energy supply. Therefore the government of Bhutan has mandated 100% rural electrification. To address rural need the electricity act of Bhutan has subsidized the tariff rate for rural areas. To provide a clean fuel source , energy policy of 2009 notes there is need to provide access to clean cooking fuel to the villages where biomass is traditional source of daily energy needs through a cleaner framework by further disseminating energy efficient cooking technologies, because rural populace have less purchasing power to use modern form of energy (DOE, 2009). Thus we see Bhutan has been in focus to 100% renewable strategy since then it started to use secondary energy supply as electricity especially supplied by hydropower.

1.6 Renewable Energy

There are different definitions used by different authors to define renewable energy sources. According to the book definition, renewable energy is seen as energy within human-inclusive ecology for both present and future (Twidell , 2006). The definition of renewable energy here refers to the energy that is derived inclusive of living ecology where plant, animal, and natural environment interact in daily basis. According to International Energy Agency (IEA) the renewable energy is defined as energy derived from natural processes that are replenished constantly. Technically energy that is potentially available at suitable geographic location is also defined as renewable energy source. However the potential is subject to many technical assessments that include environment, culture, society and likely risk for present and future (UNEP, 2012). While it is seen that the renewable energy as sustainable supply source, it is argued that life cycle analysis is required for technology to be implemented for harnessing, which then is define renewable energy sources as clean energy supply sources. For example the construction of hydropower is seen from feasibility point which includes environment, impact to biodiversity, social impact and economic viability. The argument is on indirect environmental impact like the emission due to transportation of raw materials, material used for construction and import of expertise (Pehnt, 2005). Therefore defining renewable energy requires detail life cycle assessment for feasibility option and environment friendliness in a broader aspect.

1.6.1 Challenges:

Renewable energy is well known to many countries and is one of the promising future solutions for energy crisis, yet it suffers business penetration in reality. Though the technologies are matured enough to be used in place of conventional technologies but the cost still is too high (

Loiter , 1998). The technology and innovation in recent time has brought in cost effective type of renewable energy harnessing technology which actually addresses the problem explained by Loiter. The status of the renewable energy at present is driven by policy and uncertainty of the decision maker because the conventional technologies are still widely used all over the world (Yunna , 2012). According to this study the renewable promotion is difficult especially in developing countries. In developed country the policies are already in place and meaningful decisions are made to address the problem concerning fossil based economy failure but the renewable penetration is still making it difficult to interface in the existing technologies (Purvins, 2011). The study result shows that the cost involved in replacing the old technologies is economically not feasible option and also the interfacing is a big challenge for adopting the renewable power feed into the grid in bulk amount. Though renewable energy supply seems promising, the challenges are still there in terms of increasing innovation, efficiency and cost reduction. The challenges in renewable energy supply need to be addressed at policy level.

1.7 Renewable energy statuesque

Generally known renewable energy sources are from wind, solar, biomass, geothermal, ocean energy and hydropower. The source that is constantly replenished which has minimal environment and social impact (Panwar, 2010). Author identify renewable source of energy based on resource replenishment. However the renewable source is debatable as there is wider aspect that classify renewable source. The classification of these sources depends on the size, geographic location, technology and material used for harnessing the energy which has lower impact to environment and society is identified as renewable energy sources. Following sources of renewable energy are considered to be clean and environment friendly.

1.7.1 Wind:

Wind energy is one of the oldest forms of renewable energy sources. Today wind energy technology is a matured technology and affordable one. There are huge potentials from wind source for electricity. The International Energy Agency projected that the worldwide energy generated from wind is about 12000MW. It is also forecasted that by the end of 2020 the wind will provide 215 million tons of oil equivalent or 970TWh almost half of the energy produced from large scale hydropower worldwide (Sesto , 1998). Recently the wind power scale size has increased from KW to MW per station. However the sizing of the wind power plant has encountered an indirect impact on the bird. It was never realized that the wind would impact the bird until the size of the plant was increased. However it is a myth because the birds are daily killed in the overhead transmission lines more than by wind turbine. Today the location of wind turbine is evaluated based on the biological data and bird migration route. Also the shape of the wind blade and visibility are some of the issues discussed in European Union (Anderson, 1999). Though the wind seemed promising renewable source, yet it has some constraints directly or indirectly. Small and medium scale wind turbine has good potential for distributed generation system. This was already seen feasible in New Zealand with about 90% of the electricity coming from wind as feed-in tariff wind energy. Therefore wind power still seems promising future (Schaefer, 2010).

1.7.2 Solar:

Solar energy is one of the promising sources of renewable energy for future with unlimited capacity. The solar technology is increasing faster than ever before to respond the limited fossil energy supply. Cited in the Renewable and Sustainable Energy Reviews paper of Rajasthan, worldwide Earth receives solar energy at the rate of approximately 120,000TW (1TW=10^{12}W or 1trillionwatt). The Rajasthan desert alone is estimated to harness solar energy of 16,900MW to supply India power need (Pandey, 2012). Solar energy supply has also proven easy and successful distributed generation system in many countries. British Petroleum (BP) data records on the installed solar plant that harness 22928.9 MW in 2009, a change of 46.9% compared to 2008. The policy of feeding surplus energy into the grid has proved an affordable and clean source of energy for future and present energy supply (Solangi, 2010). It is very clear that the future of solar is without doubt the possible option for every country.

Solar technology cost is drastically changing every year which shows perspective of solar power potentials is an alternative to conventional energy supply sources the decreasing market price and the module cost makes solar energy harnessing economically uncertain at decision making level. Since the module efficiency is increasing every year with the possibility of better performance and reliability, the decision making at early stage is still confusion because cost is also decreasing with technology development trend. There is however a gearing pressure on the rising fossil based energy crisis in one side and developing solar technology at the other end. Malaysia having solar irradiance of 400–600 MJ/m^2permonth which seems to be relatively high still cannot make the solar choice due to high solar energy tariff rate (Mekhilef, 2010).

The barrier to the solar power plant development is limited at the hand of policy maker which does not support new feed-in tariff policy and carbon tax that is to be included in the conventional fossil based energy supply. Like other renewable energy technologies, solar energy benefits from Fiscal and regulatory incentives, including tax credits and exemptions, feed-in-tariff, preferential interest rates, renewable portfolio standards and voluntary green power programs in many countries. To address all the issues and international standards for environmental performances outlined in the Kyoto protocol the solar seems still relatively economical. Therefore solar market penetration stills requires regulatory reformation (Timilsina, 2011). Thus solar has huge potentials for future but the renewable policy promotion plays a vital role especially in the developing countries.

Also solar energy is dependent on the sunshine hours which make energy generation un-reliable. Since storing solar energy in bulk amount is difficult, energy from solar is still questionable. Hybrid renewable supply system in first place to address storage of renewable electricity and alternatively storing the renewable sources is attractive. However the hybrid system is subject to energy losses and efficiency is always reduced. Solar hydrogen reversible fuel cell hybrid systems are one of the latest and efficient storage systems but it is expensive to use at commercial level (Maclay, 2010).

1.7.3 Biomass:

Biomass seems to be the cost effective renewable source for future to overcome the fossil fuel shortage, a threat to supply of petroleum products. The biomass energy that comes from biomass feedstock cultivated energy crops on surplus cropland, energy crops on degraded land, agricultural residues, forest residues, animal manure and organic wastes is economically viable option. Overall it is estimated that the global biomass potentials amounting to 33−1135 EJy^{-1} has good scope for future to substitute petroleum by bio based products. However biomass is also likely to pose the food security issues and land degradation if produced in large scale (Hoogwijk, 2003). The biomass energy not only provides energy ,it also gives petroleum products like bio fuel, bio gas, bio plastics and all the byproducts that we get from the oil refinery. Biomass has multiple benefits like sequestering CO_2 and by itself acting as carbon neutral source of renewable energy source. "Theoretically, enhanced carbon sequestration and energy cropping could off-set 2000 –5000 Mt C/yr globally, but a more realistic potential off-set is 1000 –2000 Mt C/yr and there are good reasons to suppose that only 200 –1000 Mt C/yr is actually achievable" (Cannell, 2003). This shows that biomass has promising future for every nation. The feed stocks are available locally which reduces the transport cost.

Biomass also serves as solution to reducing CO2 concentration in the atmosphere. The carbon capture and sequestration (CCS) is already a global issue. According to the collective study conducted on International Journal of Greenhouse Gas Control the authors identifies that global technical potential for bio-CCS technologies is large and, if deployed, can result in negative greenhouse gas emissions (GHG) upto10.4Gt CO2 eq. on an annual basis in 2050 (Koornneef, 2012). Therefore biomass is a good renewable energy source as well as a solution to GHG sequestration.

Though biomass seems good option for renewable energy in future, it still suffers some challenges. The soil that is used for producing biomass feedstock from energy crop requires lots of fertilizer to grow in large quantity, which cause soil degradation unless cover crop is used to clean the soil contamination. In the process of detail life cycle analysis it is figured out that the use of too much fertilizer increase acidification and eutrophication, primarily because large nitrogen (and phosphorus)-related environmental burdens are released from the soil during cultivation (Kim, 2005). Therefore selecting a right feed stock for producing biomass energy is very important. A detail life cycle analysis gives a clear picture for which feed stock to be used for bio mass refinery.

1.7.4 Hydropower:

Hydropower is one of the leading sources of electricity supply all around the world. About 19% of world electricity supply comes from the hydropower, generating with capacity ranging from 1KW installed capacity to 1GW installed capacity. Small scale hydropower with the capacity ranging from 5KW to 1MW is considered techno economically feasible and reliable source of electricity. Hydropower is much more concentrated energy resource than either wind or solar power (Paish, 2002). However large scale hydropower is environmentally not friendly. Large scale hydropower dam enforces large number of inhabitant to be relocated. Large scale hydro dam with capacity exceeding 1000MW has the greater potential to cause adverse effect to biodiversity around dam site. The geographic location is therefore considered deciding factor in choosing dam site for large scale hydro power plant. This negative impact of hydropower is sometimes not disclosed to public therefore it is questionable (Brown, 2008). The authors investigated the Nu River in china which is considered to be one of the environment hot spot. Therefore large scale hydro power dam is economically suitable but it has lot of impact on environment and people living downstream.

Since hydro power is dependent on the available water head to run the turbine, the capacity of energy generation is dependent on the river run-off volume and head seasonally. However with the advanced technology, the storage systems have proved technical solution for seasonal variation. Therefore resent trend is storing flood water in wet season and releasing it in the dry season as a storage system. While energy supply improved by the adaptation of storage system, the downstream water has decline causing water shortage in downstream. This has also shown hydrological cycle change and change in precipitation pattern in the region. This is evident from the study of yellow river in china (Wang, 2006). The study concludes the irrigation in the upstream has increased but there is water scarcity downstream. In total we see that large scale hydropower has negative impact to natural flow of water and biodiversity. Therefore large scale hydropower is still questionable. However small scale hydropower with the storage system is suitable and reliable energy supply in rural areas. Optimizing storage system through hybrid energy supply source is an alternative. The hybrid system is suitable with wind and solar. This is evident from the performance of PV-MH (Photovoltaic Micro Hydro) system operation which is optimal (Muhida, 2001). The author has investigated a PV energy supply supplemented by micro hydro power in Indonesia with the installed capacity of 48-71.1kWp photovoltaic-micro-hydro system.

The climate change has adverse impact on hydropower generation as well as energy demand. With the global warming the extremes of temperature in hot and cold season has become one of the great challenge for hydro source. Due to climate change the hydrological cycle has been effected causing minimal flow of Runoff Rivers in dry season. The decline in generation has resulted cascading effect with energy demand rising for heating and cooling in cold and hot season (Guegan, 2011). The rise in demand is seen as peak energy pricing which has indirect economic burden for the consumer. Tough hydro power seems good source; the future of hydropower is limited.

Chapter 2

2.1 Methodology

This research adopted qualitative descriptive analysis for 100% renewable energy strategies. The study aims to analysis renewable energy potentials, economic and environmental aspect of renewable energy. The results of the study recommends long term sustainable solution with different sources of renewable energy potentials, levelised cost of electricity (LCOE), and emission reduction potential. For the LCOE study ($/kWh) method adopted by HOMER software is used. All the local units are converted into international standard units.

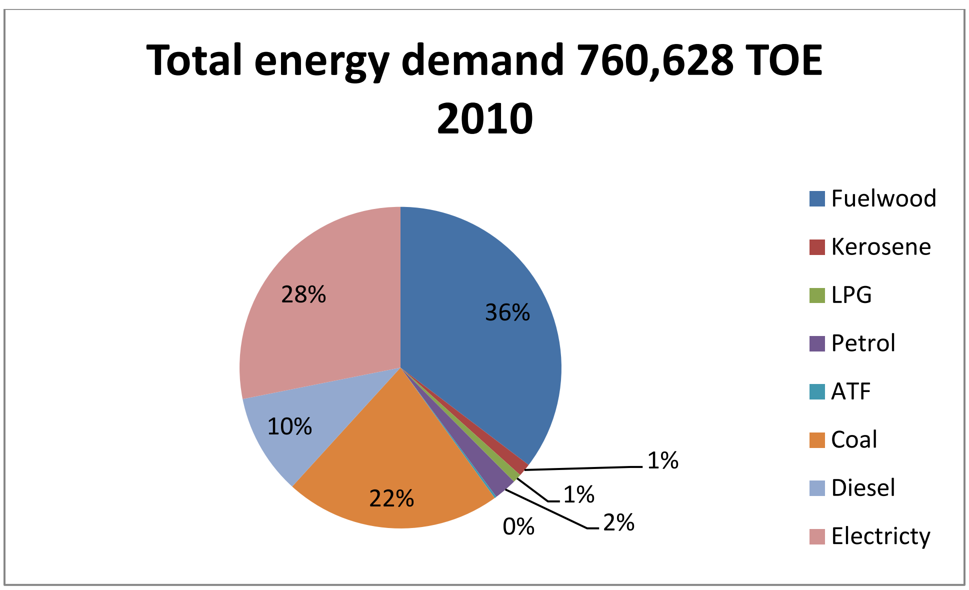
National Renewable Energy Laboratory (NREL) data and Bhutan energy directory data is used to identify the total potential in Bhutan. This data is verified by department of energy Bhutan and presented in the Bhutan energy directory data book. Thus this is a reliable source of information for potential estimation. The potentials on Hydro is conducted by TERI (technical energy resource institute) India in collaboration with Bhutan energy department. Thus result of this study is used as data source for hydropower.

Technology costs are gathered from the Asian Development Bank (ADB) technical assistance reports. Most of the data are secondary source, therefore the result is compared with current market price in Germany. Therefore this method will allow investigating the renewable energy generation cost which is also crucial for developing countries. Secondary data source for energy potentials will have very less significance as the potentials does not change over time.

Chapter 3

3.1 Current energy statutes quo of Bhutan

The energy statistics of Bhutan is published first in 2005 and second time in 2010 with the support of The Energy and Resources Institute (TERI) India after which not much documented data information is available. Also the same data is compiled in the statistics report of 2013 indicating that further research on energy sector is not carried out. This data compilation show total energy consumption 760,628 TOE in different sectors such as heat, electricity, fuel for transport and other energy demand as shown in the following figures (fig 1, fig 2). This data indicate, though electricity supply in Bhutan is 100% renewable other energy intensive sectors are still fossil powered which needs further development for 100% renewable energy strategy.



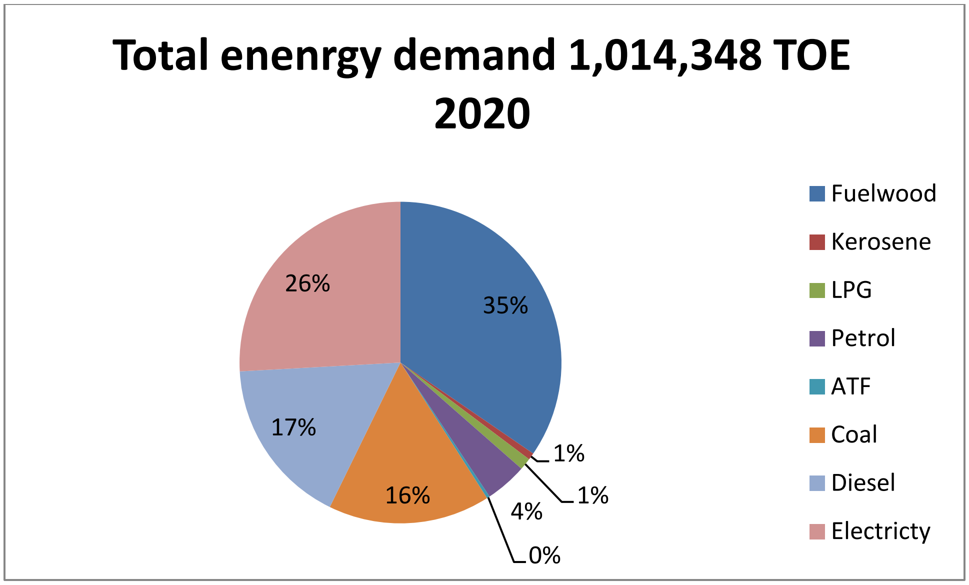
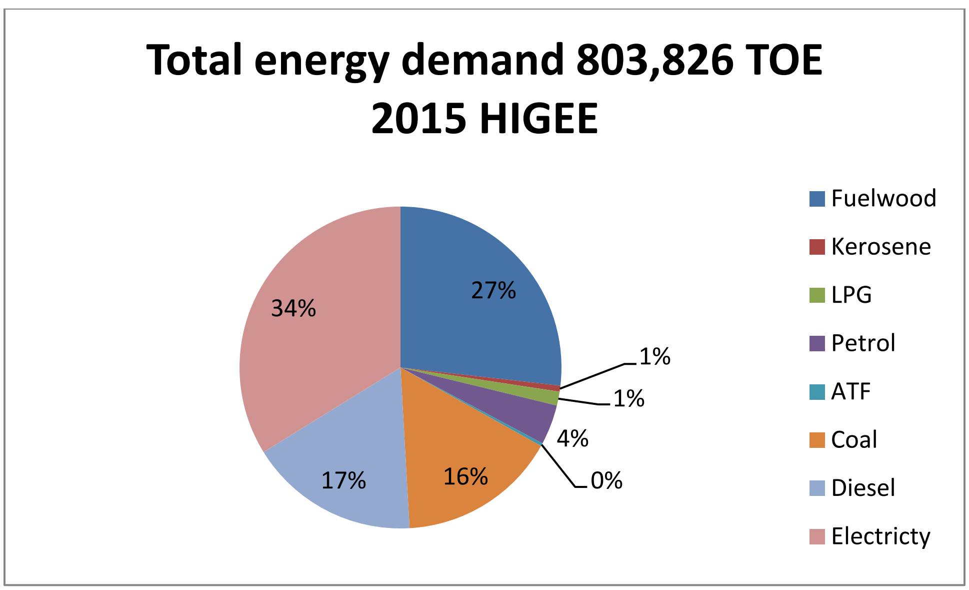


Figure 1 Business as usual case (BAU) energy demand in 2010 and 2020 (Integrated Energy Master plan, 2010)



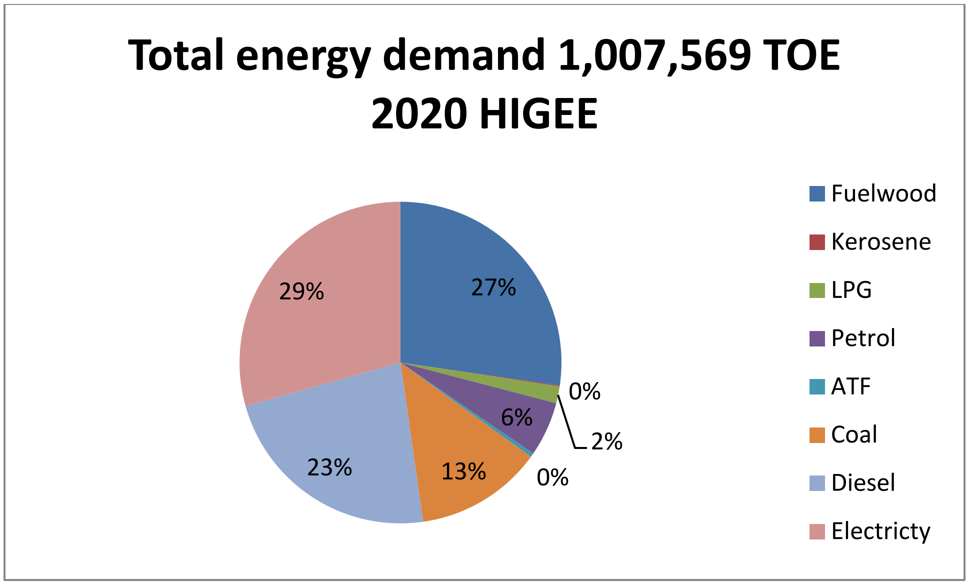


Figure 2: High energy efficiency (HIGEE) case energy demand in 2010 and 2020 (Integrated Energy Master plan, 2010)

Conclusion can be drawn from this data itself that the 100% strategies is too far from reality at the moment unless alternative measures are addressed at early stage such as increasing energy self sufficiency by action such as switching away from coal energy supply source at least to the required minimum conditions.

3.2 Renewable energy potential General overview

The overall renewable energy potential of Bhutan indicates that Bhutan is rich in water resources formed by glaciers. So far Bhutan has harnessed only 5% of technically feasible hydropower potential. However 75% is exported to India as bilateral trade agreement while Bhutan is heavily dependent on import of fossil fuel on India, which shows a gap between the policy documentation and action taken. The other sources of renewable energy are from solar, biomass and wind, which is unexplored because all the energy supply is powered by large scale hydropower. Biomass is second largest share as a fuel wood used in the rural areas. Solar is used for powering communication antennas and rural offices and hospitals. The wind pilot plant was built in one of the district (Wangdi) of Bhutan which has operated for some time with location of 20 m high wind mast in Wangdi (Chophel, 2011). It is not very clear why wind energy did not progress well in Bhutan as there is no wind energy supply share at the moment. There literature shows hydropower as easily available energy supply in Bhutan than any other form of renewable energy sources which dominated the major energy supply share. The energy directory of Bhutan compiled the data in 2012 to highlight different renewable energy sources in Bhutan. In this report 81119 tonnes of municipal wastes and 308045 stalks of straws are available for biomass feedstock, 4 to 5 kWh/m^2 solar irradiance and 3 to 6 m/s wind speed are some of the overall potentials estimated in the renewable sector (DOE, 2005). However the policy indicate that Bhutan is striving towards to generate an installed capacity of 20 MW indigenous renewable energy mix like solar, wind and biomass to supplement lean season energy supply. However no focus is made on the decentralized energy generation system.

Indentifying region specific resources and suitable technology to harness this resource potential remains fundamental study area in Bhutan due to different elevation and geography. Bhutan is divided into different districts and local municipality locally called as Dzongkhag and Gewag. Different district and municipality have different climate zone characterized by elevation, precipitation pattern, sunshine hours, wind speed, agricultural and other residue, forest coverage, and water resources. Northern part of Bhutan is relatively cold compared to southern region. The winter and summer temperature varies from -10 degree Celsius to 10 degree Celsius and 15 degree Celsius to 25 degree Celsius in north and south respectively. In the southern region it is warm and temperate climate with temperature varying from 20-30 degree Celsius in winter and summer. Different climate and weather pattern is determined by the altitude ranging from 100 m in the southern Bhutan and 7000 m in the north (Uddin, 2006) . Different geographic classification makes Bhutan suitable for different energy mix.

Since the settlement is distributed in different climatic zone, one renewable source supply is not appropriate. Depending on the resources available the suitable distributed generation system is an alternative option for powering rural homes. The high solar irradiance in the northern part of Bhutan hypothetically shows that solar is a feasible option. On the other hand high biomass feedstock in southern belt shows small scale biomass plant is suitable. Therefore gathering site specific data and cost effective technology for the proposed distributed system has potential in future (Lhendup, 2008). However hydropower still dominates the energy supply, thus small scale energy generation has remained dormant.

3.3 Potential analysis

The data record for solar, and wind shows theoretical technical energy potentials of 58,000 MW_{DC} and 4825 MW respectively (Cowlin, 2009). On the other hand the total hydro and biomass potentials sum up to 30,000 MW and 3.4 MW respectively (DOE, 2005). However this study considers only animal waste as Biomass potentials for rural areas. The rural biomass data is used from the Netherlands Development Organization (SNV) feasibility study which gives the potentials in the form of total population of cattle and the excreta of animal which is considered as the feedstock for bio gas development. This data record shows 399,253 head counts of cattle population with the rate of excreta at 6 Kg per cattle per day (Bajgain , 2008). This data is overall biogas potential for Bhutan in place of LPG gas and fuel-wood energy demand. The energy distribution by type of energy source is categorized in tabular format hereafter to provide district wise energy potential distribution. The following topic will show region specific different renewable energy potential like solar, wind, hydro and bio-gas.

3.3.1 Solar potential:

Solar potentials are estimated based on the solar irradiance in specific region and the available area for harnessing the solar energy. Following calculation shows estimate of productive area for solar.

$$A_P = A_T \times 0.05 \times 0.3$$

Where A_P = productive area A_T = Total area Assumption: There is 5% of productive available area in the district and 30% of this area is covered by the Photovoltaic Array.

$$P_{DC} = A_P \times \frac{1{,}000{,}000 M^2}{Km^2} \times R_{tilt} \times 0.10 \times 0.86 \times \frac{1 day}{24} \times \frac{8760}{yr}$$

$$P_{AC} = A_P \times \frac{1{,}000{,}000 M^2}{Km^2} \times R_{tilt} \times 0.10 \times 0.77 \times \frac{1\ day}{24} \times \frac{8760}{yr}$$

Where P_{DC} = DC installed capacity , PV module efficiency =10%. R_{tilt}= solar irradiance

Solar irradiance data for each district is as shown in table 1. It has to be noted that the potentials given here should not be confused with installed capacity. Only one third of the total potential may be used for generating electricity (capacity factor of 0.25%) as the sun shine hours in Bhutan are about 8hr. /day". The energy capacity expressed in kWh is the total energy that a region can receive in a year which can be efficiently used for electricity generation. From the table it seems Bhutan has abandon solar radiation which is suitable for off-grid energy supply from a solar array.

Table 1 : Solar potential in each district of Bhutan (Cowlin, 2009)

District	Productive Area (km2)	Average Annual Solar Resource at Tilt = LatitudeKWh/M2	Average Annual DC Photovoltaic Production (million kWhDC/yr)	Average Annual AC Photovoltaic Production (million kWhAC/yr)
Bumthang	40.77	5.2	6,700	6,000
Chukha	28.2	4.8	4,300	3,800
Dagana	25.85	4.8	3,900	3,500
Gasa	47.03	5.3	7,800	7,000
Haa	28.58	5	4,500	4,000
Lhuntse	42.89	4.9	6,600	5,900
Mongar	29.17	4.8	4,400	4,000
Paro	19.31	5.3	3,200	2,900
Pemagatshel	15.33	5	2,400	2,200
Punakha	16.65	5	2,600	2,400
Samdrup Jongkhar	28.16	4.7	4,100	3,700
Samtse	19.58	4.7	2,900	2,600
Sarpang	24.84	4.7	3,700	3,300
Thimphu	26.94	5.3	4,500	4,000
Trashigang	33.07	4.9	5,100	4,600
Trongsa	27.21	4.9	4,200	3,700
Tsirang	9.57	4.9	1,500	1,300
Wangdue Phodrang	60.55	5.1	9,600	8,600
Trashiyangtse	21.74	4.9	3,400	3,000
Zhemgang	36.26	4.8	5,500	4,900
Total	**582**		**90,900**	**81,400**

3.3.2 Wind potentials:

The wind potentials are shown in table 2. Wind energy is the indirect form of solar energy where the uneven heating and cooling effect leads to difference in pressure which causes wind current. This wind current is used as a mechanical energy to rotate wind turbine for generating electricity.

Table 2 : Total wind speed potential categorized by district (Cowlin, 2009)

District	Elevation (m)	Resource Potential	Wind Power Density at 50 m (W/m2)	Average Wind Speed at 50 m (m/s)
Bumthang	1800-5400	Good	400-500	5.5-5.9
Chukha	600-4800	Moderate	300-400	5.0-5.5
Dagana	600-4800	Marginal	200-300	4.4-5.0
Gasa	1800-5400	Moderate	300-400	5.0-5.5
Haa	1800-5400	Moderate	300-400	5.0-5.5
Lhuntse	1800-5400	Good	400-500	5.5-5.9
Mongar	600-4200	Moderate	300-400	5.0-5.5
Paro	1800-5400	Moderate	300-400	5.0-5.5
Pemagatshel	600-3000	Moderate	300-400	5.0-5.5
Punakha	1200-5400	Good	400-500	5.5-5.9
Samdrup Jongkhar	200-4200	Poor	0-200	0.0-4.4
Samtse	200-4800	Poor	0-200	0.0-4.4
Sarpang	200-4200	Poor	0-200	0.0-4.4
Thimphu	1800-5400	Marginal	200-300	4.4-5.0
Trashigang	600-4800	Moderate	300-400	5.0-5.5
Trongsa	600-5400	Moderate	300-400	5.0-5.5
Tsirang	600-4200	Good	400-500	5.5-5.9
Wangdue Phodrang	600-5400	Good	400-500	5.5-5.9
Trashiyangtse	600-5400	Good	400-500	5.5-5.9
Zhemgang	600-4200	Moderate	300-400	5.0-5.5

The wind speed determine the wind energy potential which is marked as good, moderate, marginal and poor in table 2. The volume of wind encountered by the wind blade is proportional to the electricity generation. The potential estimation depends on elevation, solar irradiance and the geographic location. Wind potential is region specific. Since wind turbine requires a suitable site location it is important to note that though the potential in some region seems high, it still cannot be used for generating electricity if the site is not suitable for civil construction. The potential for harnessing wind energy also depends on the predictability of wind speed in different time which may be daily, weekly, monthly and annually. This determines the reliability of wind generated electricity supply. Based on the wind speed availability in the region the feasibility of wind energy generation is estimated. Wind potentials however depend on the install capacity of the wind turbine. The variables used to map wind potentials are elevation, wind power density and wind speed as shown in table 2.

3.3.3 Biomass potential

Table 3 shows the potential from cattle dung in Bhutan by district. Biomass in Bhutan is largely coming from forest fire wood, livestock and municipal solid waste.

Table 3 : Head count of cattle per house hold (HH) in each district and energy value (Bajgain , 2008)

District	Number of Rural HH	Total cattle	HH below 2000mts altitude	Average Cattle per HH	% of HH potential for biogas	DUNG Kg	enegry potentialsMJ	In KWh
Bumthang	2,130	15,584	-	7.3	0	93,504	74803.2	20944.896
Chhukha	7,690	32,006	6,921	4.2	20.07	192,036	153628.8	43016.064
Dagna	3,178	15,435	2,225	4.9	31.28	92,610	74088	20744.64
Gasa	643	13,868	64	21.6	8.84	83,208	66566.4	18638.592
Haa	1,866	15,471	187	8.3	6.76	92,826	74260.8	20793.024
Lhuentse	2,765	15,996	415	5.8	8.02	95,976	76780.8	21498.624
Monggar	6,114	33,619	3,668	5.5	27.46	201,714	161371.2	45183.936
Paro	6,552	22,050	328	3.4	1.56	132,300	105840	29635.2
Pemagatshel	2,575	10,302	1,288	4.0	17.53	61,812	49449.6	13845.888
Punakha	3,060	10,057	1530	3.3	14.91	60,342	48273.6	13516.608
Samdrupjongkhar	6,167	18,842	5,550	3.1	20.57	113,052	90441.6	25323.648
Samtse	9,418	36,634	8,476	3.9	28.41	219,804	175843.2	49236.096
Sarpang	5,685	21,127	5,117	3.7	23.06	126,762	101409.6	28394.688
Thimphu	3,961	17,442	594	4.4	1.33	104,652	83721.6	23442.048
Trashigang	9,687	44,639	1453	4.6	6.18	267,834	214267.2	59994.816
Trashiyangtse	3,223	13,877	1,934	4.3	22.09	83,262	66609.6	18650.688
Trongsa	2,211	10,406	1327	4.7	22.76	62,436	49948.8	13985.664
Tsirang	3,278	12,124	1639	3.7	16.61	72,744	58195.2	16294.656
Wangdue	4,773	24,230	2148	5.1	17.59	145,380	116304	32565.12
Zhemgang	2,828	15,544	2,545	5.5	41.43	93,264	74611.2	20891.136
Total	**87,804**	**399,253**	**47,407**	**4.5**	**15.88**	**2,395,518**	**1,916,414**	**536596.032**

However the potential estimation for this study is from animal waste that can be used to produce bio-gas for cooking. Large scale biomass project for electricity generation is still not seen in Bhutan. While waste as biogas feedstock is an alternative biogas feed stock, however waste is beyond the scope of this study. Thus this study will focus on use of bio-gas energy that can reduce cost for the cooking fuel need.

The volume of bio-gas content in animal waste depends on type of animal waste. In case of Bhutan it is cattle dung whose biogas content is 0.023-0.04 m^3 per Kg of dung. Biogas production depends on C/N (carbon /nitrogen) ratio which is 24 for cattle dung. In general biogas contains five different gases like Methane, Carbon Dioxide, Nitrogen, Hydrogen Sulphide, Hydrogen and water vapor. The methane content is about 50-70% which is the main component of biogas. The calorific value form cattle dung is 20 MJ/m^3 of biogas (Consolidated Management Services Nepal, 1996).

In table 3 the data is extended by including kg of dung, energy potentials in MJ, and energy potentials in KWh. It is estimated that the average cattle waste per day is 6 kg and biogas per kg of dung is 0.04 m^3. 20 MJ per m ^{3} of biogas yield is possible as per the Nepal biogas data. The potential in KWh is converted by a multiplying factor of 0.28. However biogas is used as cooking fuel demand instead of LPG gas in rural home as secure energy source.

$$E_P = T_C \times D_{KG} \times \frac{0.04m^3}{kg} \times \frac{20MJ}{m^3} \times \frac{1}{3.6} kWh$$

Where; $T_C = total\ cattle\ D_{KG} = Kg\ dung/cattle$

One cattle is estimated to give 6 kg dung per day.

3.3.4 Hydropower potentials

Hydropower potential in Bhutan is distributed according to different river basin among the district. The distribution of river in different district is also separated by geographic features and landscape formation. Though the potential hydropower falls in a particular district, the distribution of energy becomes extremely difficult due to difficult mountain terrain. Thus the distribution by district does not necessarily mean that the district will be benefited. However it gives a clear idea on how the river potentials are distributed. Table 4 shows the potentials distributed by district with the installed capacity. Total of 24,000 MW installed capacity is estimated to be technically feasible. Bhutan has ambitious plan to harness about 10,000 MW of these potentials by 2020. However these hydro-powers are subject to climatic threat which is a serious concern for Bhutan. Since all the Runoff Rivers are formed by the glaciers, the sustainability of hydropower is dependent on the snow mass balance in the Himalayas.

Table 4 : Rivers that is identified suitable for hydropower potential categorized by district (Integrated Energy Master plan, 2010)

District	River basin	Number of hydropower potentials with Install capacity						
		500-2000MW	100-500MW	80-100MW	60-80MW	40-60MW	20-40MW	0-20MW
Bumthang	Mangdechhu	1	1	0	0	0	0	1
Chukha	Wangchhu	0	0	0	0	1	0	0
Dagana	Punasangchhu	0	0	1	0	0	0	1
Gasa	Punasangchhu	1	0	0	0	0	0	0
Haa	Amochhu	0	0	0	0	1	0	1
Lhuentse	Drangmechhu	0	1	0	0	0	1	0
Monggar	Drangmechhu	1	0	0	0	0	1	0
Paro	Wangchhu	0	1	0	1	0	0	0
Pemagatshel	nil	0	0	0	0	0	0	0
Punakha	Punasangchhu	2	0	0	0	0	1	0
Samdrup- jongkhar	Others		1	1	1	1	1	0
Samtse	Amochhu	2	0	0	0	3	0	1
Sarpang	nil	0	0	0	0	0	0	0
Thimphu	Wangchhu	0	0	0	0	1	0	0
Trashigang	Drangmechhu	0	0	3	3	1	0	0
Trongsa	Mangdechhu	1	0	0	0	3	0	0
Tsirang	Punasangchhu	0	3	0	0	0	0	0
Wangdue	Punasangchhu	0	1	0	2	0	0	0
Yangtse	Drangmechhu	0	2	0	0	0	0	0
Zhemgang	Mangdechhu	3	0	3	0	1	0	0

However the small scale hydro in the range of 0-100 MW has potential for distributed generation system.

3.4 Potential maps

3.4.1 Hydropower potential map

The potentials map of fig 3 is developed based on Bhutan power corporation (BPC) data. Following maps shows the various potentials in different region of Bhutan.

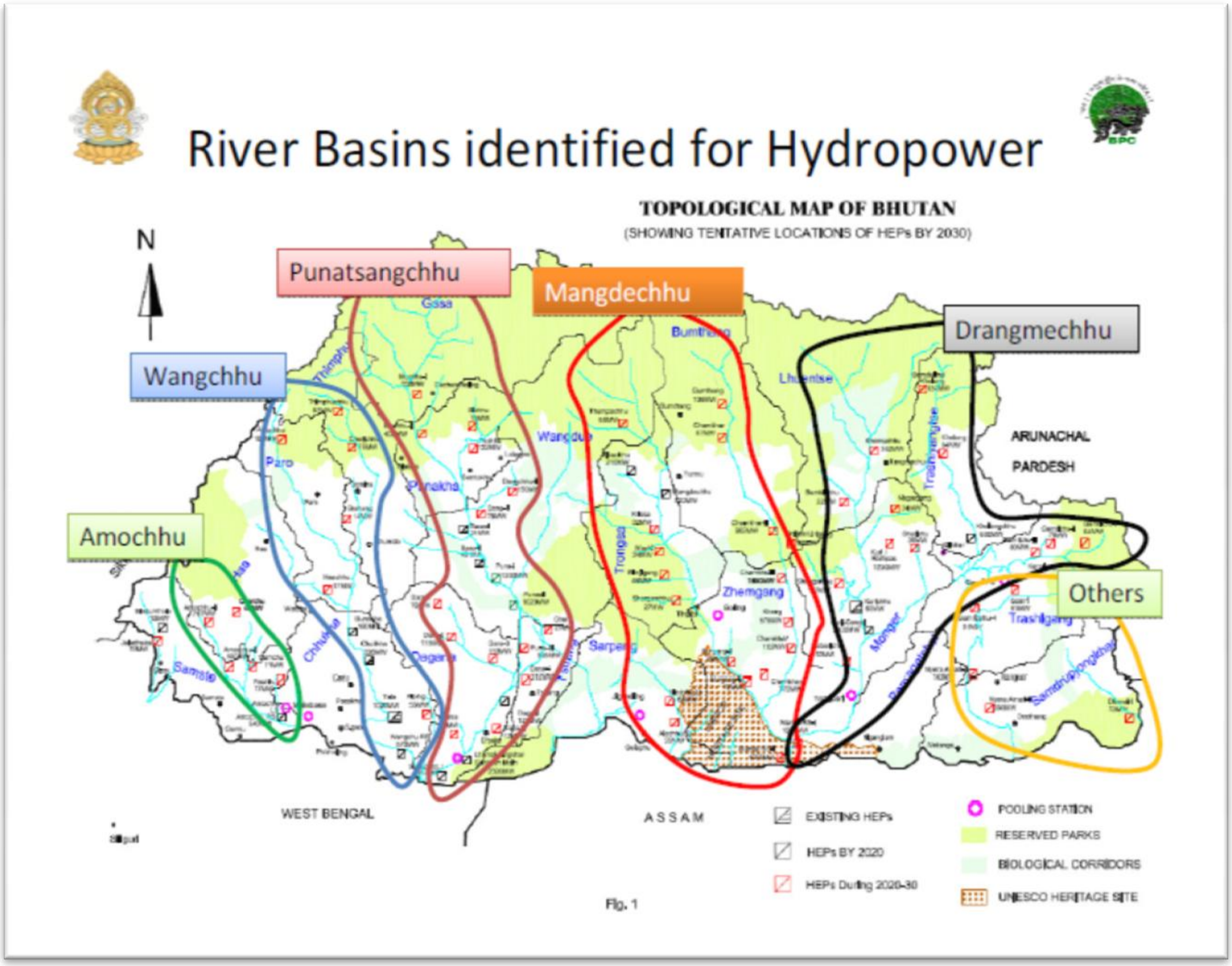


Figure 3 : Hydropower distribution by river basin (Bhutan Power Corporation, 2012)

The map shows different river basin and the potential hydropower site location in different district. It is clear from this riverbasin map that the hydropower potentials are distrubuted throughout Bhutan and the need to adopt distrubuted generation system seems important. Hydropower are likely to be used as feeding into the central gride instead of cummnity based energy supply unless the central gride is too far away from the generation site. Also it depends on the installed capacity of the hydropower plant to feed into the central grid.

3.4.2 Solar potentials map:

The solar potentials map depicts the annual average solar irridance in different region in Bhutan (Fig 4).

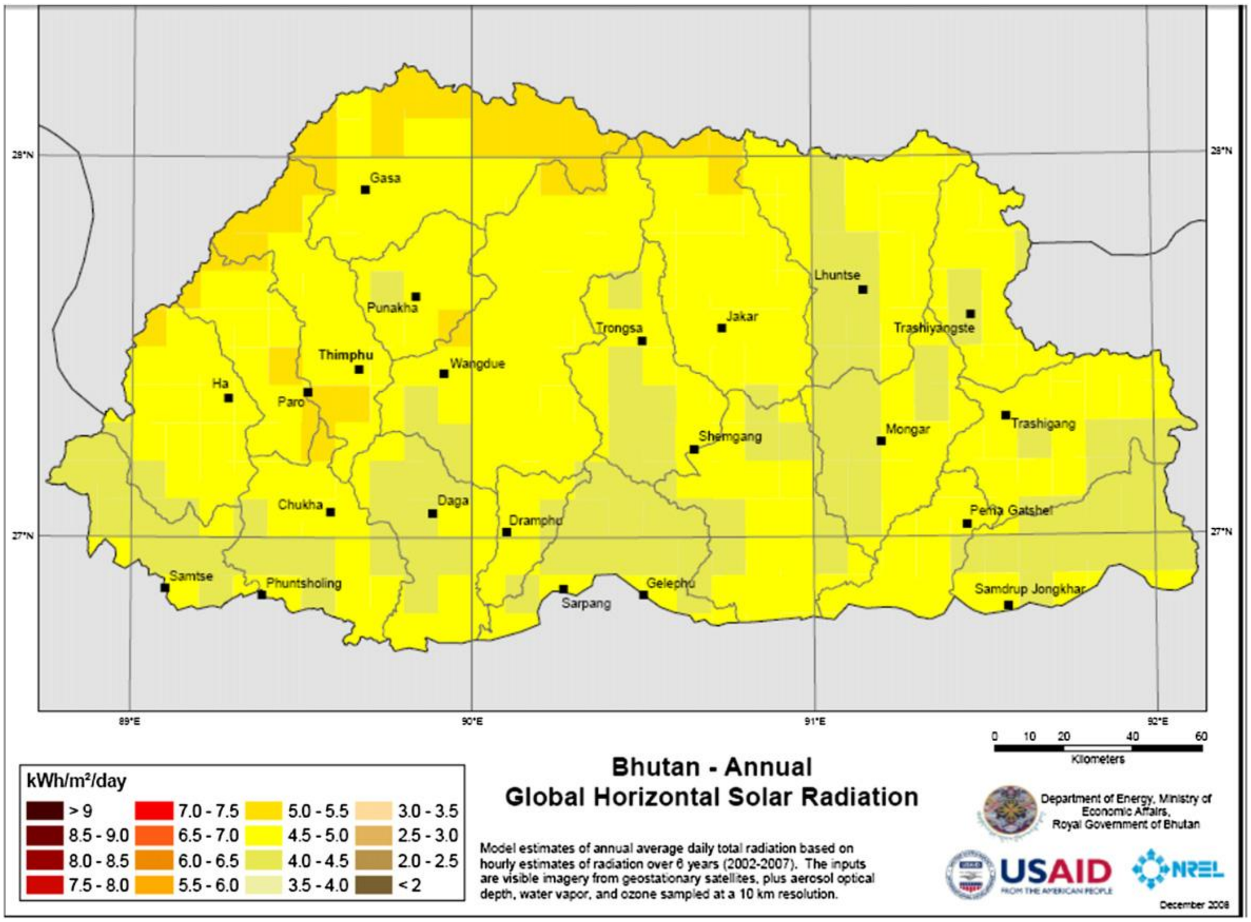


Figure 4: Figure 4 Solar Horizontal radiation average per day (Heimiller, Shannon Cowlin and Donna, 2009)

This map is provided in oder to get a quick overview of overall solar potentials in Bhutan. Since solar energy genaration is dependent on sunshine hours of the day, the detail on daily to monthly data is important for solar potential. To avoid the unnecessary details of daily to monthly variation in solar irrediance which is already shown in the table form , the monthly and seasonal solar potential map is not shown here. However for actual project plan and details design requires daily, monthly, seasonally , annual and shunshine hours in a day is important. This map however shows that the Bhutan has relatively good solar energy potential as the solar irridance is cpmparatively high with the average value of 4-5 k Wh/m^2/day. Since solar energy is available everywhere , distrubuted generation is suitable with solar PV system in Bhutan where the energy can be used for rural household as solar home system.

3.4.3 Wind potentials map:

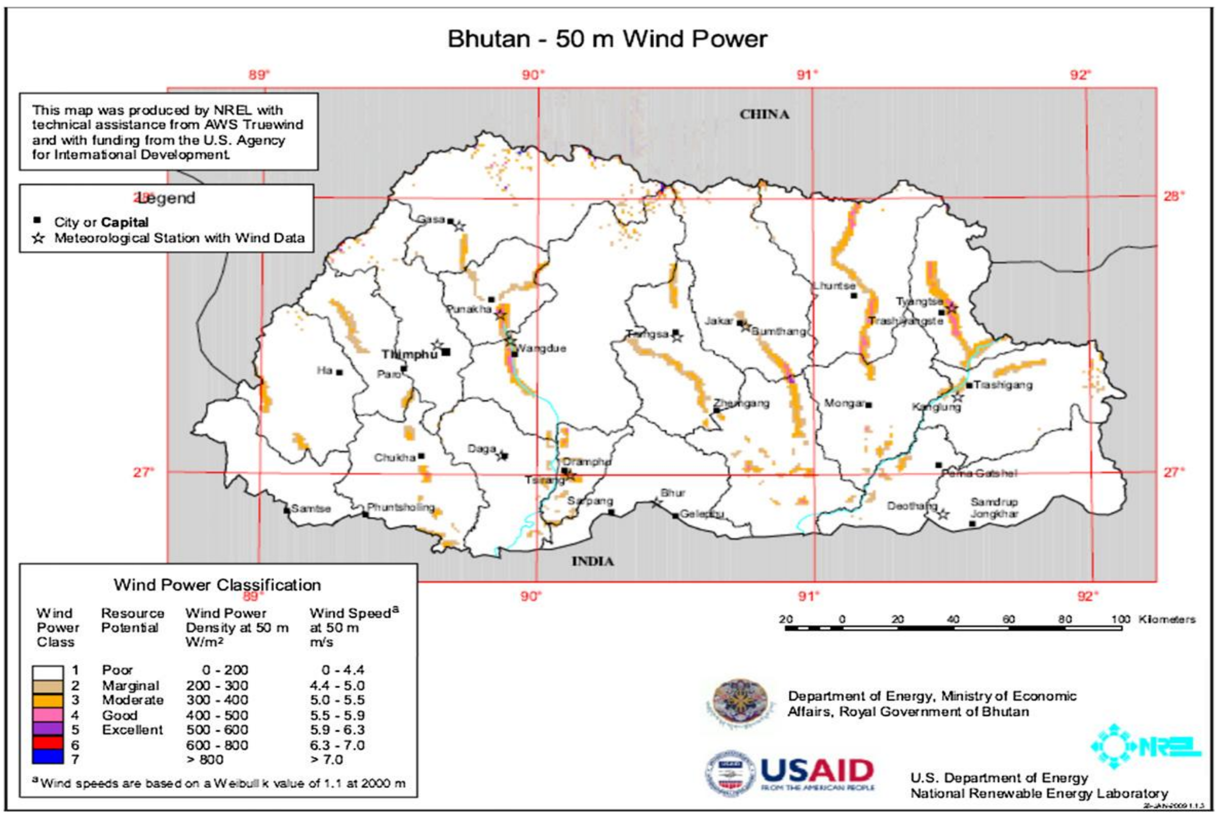


Figure 5: Wind speed in different district of Bhutan: (Heimiller, Shannon Cowlin and Donna, 2009)

The map fig 5 represents wind potentials at different elevation. Unlike solar irradiance, wind energy is not evenly distributed though the potential seems good in some region. Therefore wind energy is good for community based energy supply. However the reliability of wind power is unpredictable as any other source of renewable energy. Since wind power is a function of wind volume encountered by wind blade of the wind turbine, slight change in wind speed leads to large fluctuation in wind energy generation. Wind energy is also suitable for feeding into the grid as a distributed generation system. As seen from the potential map that wind power is not evenly distributed in all places, it is technically not feasible for single household use. The capacity of wind energy generation also depends on the size of the installed wind turbine which is also dependent on the geographic location. Therefore wind energy generation is similar to the hydro power source in Bhutan.

3.4.4 Biomass Potential Map:

The map fig 6 shows the potential by percentage share**.** The potential of biomass shown in Fig 4 is only the animal waste which is considered to be the feedstock for bio-gas in rural areas of Bhutan.

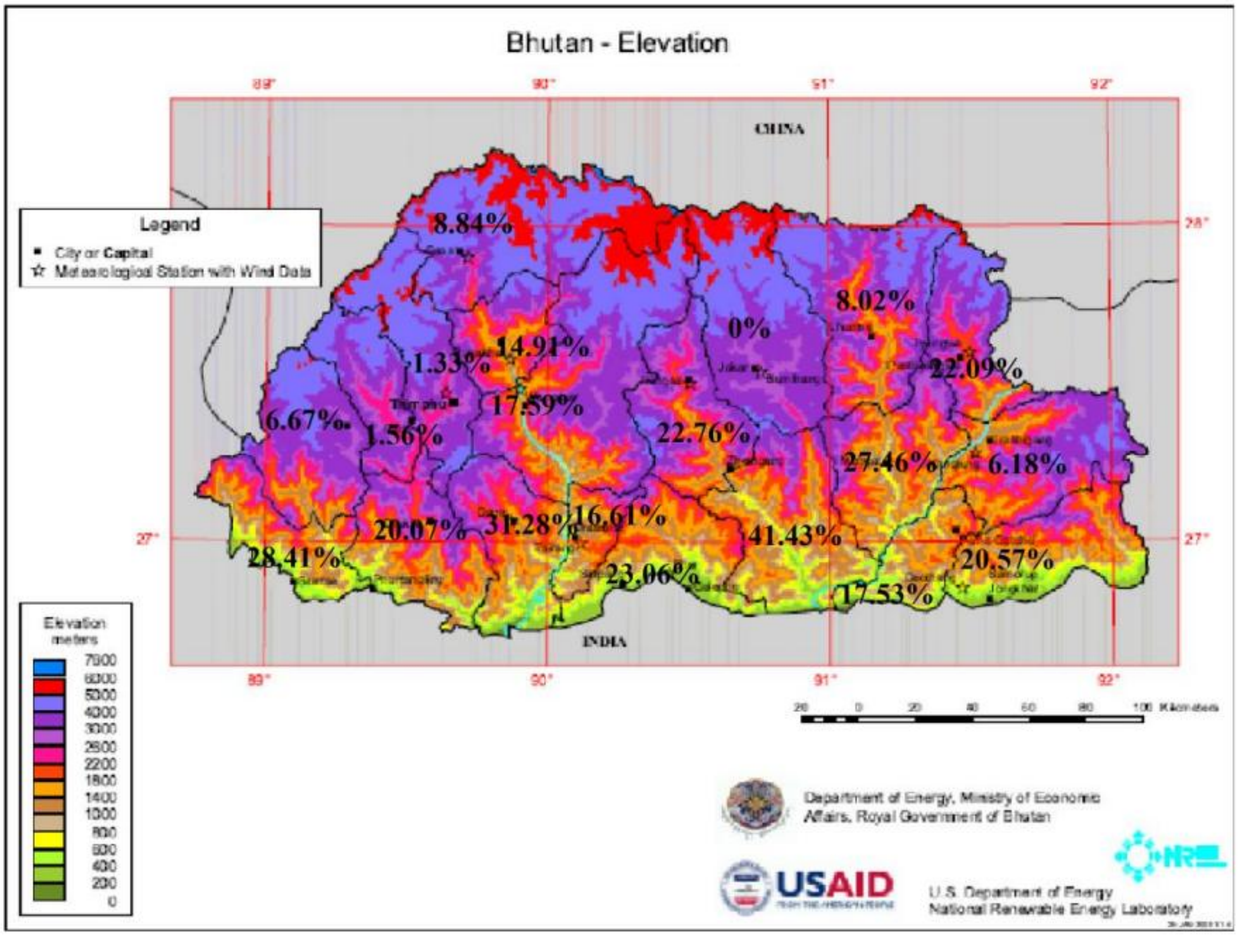


Figure 6: Biomass potential in different district of Bhutan (Cowlin, 2009)

Bhutan is not reach in agro industry, thus the biomass feedstock coming from the agricultural waste is used for feeding the cattle. The available waste for biomass feedstock is basically from the animal waste. It is noticed that even though the population of cattle in some region seems good, the potentials for bio-gas development are less. This is because of the climatic condition and weather condition. Thus the elevation map gives a clear picture on availability of resources and adoptability of the type of renewable resources in different region. Bhutan being mountainous country covered with 70% forest as biomass resources, yet the biomass as direct electricity conversion is not common practice at the moment.

3.5: Economic analysis for harnessing renewable energy potential

While renewable sources are environment friendly in nature, the affordability /cost of harnessing is determining factor for developing country like Bhutan to be implemented. The electricity generation cost of renewable energy source varies for hydro, wind and solar due to energy yield in different geographic location. The electricity generation depends on the capacity factor which is average operating hours of the system. Each renewable energy sources technology has different capacity factors. The overall cost involved for generating electricity from the renewable resources that includes the cost of technology, transportation, labor and miscellaneous cost like training and consultancies fee need to be included in cost calculation. The cost estimates are gathered from the pilot project in Bhutan. Following formula eq(1) is used to determine the levelised cost of electricity (LCOE) from different renewable resources in Bhutan.

$$LCOE = \frac{total\ annualised\ cost}{annual\ generation} \qquad Eq(1)$$

$$Therefore\ LCOE = \frac{i(1+i)^n}{(1+i)^n - 1} * \frac{I}{E_a}$$

$$= CF \times \frac{I}{E_a}$$

$Where\ LCOE = The\ average\ lifetime\ levelised\ cost\ of\ electricity\ generation$

$CF = Capicaty\ Factor$

$I = Investment\ expenditures$

$E_a = annual\ electricity\ generation$

$i = interest\ rate$

$n = number\ of\ years$

Where

$$E_a \ = installed\ capacity * operating\ hours * capacity\ factors$$

Following assumptions are made while calculating the LCOE of hydro and wind

1. Capacity factors wind and hydro are 0.4, and 0.5 respectively.
2. Life of plant wind and hydro are 30 and 50 respectively.
3. Interest rate of 6% considering annual inflation.

Thus it is seen that the annual electricity generation form hydro and wind as

$$E_{wind} \ = 360kW_p \times 8760\ \frac{h}{a} \times 0.3$$

$$= 946{,}080\ \frac{kWh}{a}$$

$$E_{hydro} \ = 100kW_p \times 8760\ \frac{h}{a} \times 0.5$$

$$= 438{,}000\ \frac{kWh}{a}$$

Since solar power generation depends on average yield per m^2 of the active collector area of the panel following calculation is made for solar energy harnessing.

$$E_{solar} = \frac{Average\ yeild}{a.m^2} \times Performance\ ratio \times losses$$

$$performance\ ratio = \frac{collector\ area\ of\ solar\ panel\ m^2}{STC\ of\ solar\ panel\ \frac{KW}{m^2}}$$

Where collector area varies with the solar panel manufacture and STC is the solar panel standard test condition at laboratory which is 1 kW/m^2. Considering solar panel area to be one meter square performance ratio is one m^2 per kW.

$$\therefore E_{solar} = \frac{average\ yeild\ (kWh)}{a.m^2} \times \frac{m^2}{KW}$$

$$Average\ yeild = 4.5\ \frac{kWh}{d} \times 365\ \frac{d}{a}$$

$$= 1642\ \frac{kWh}{a}$$

$$\therefore E_{solar} = \frac{1642\ kWh}{KW}$$

Due to the fact that the biomass is used for cooking the total energy generated is heating value for cooking form one biogas for single household as follows

$1m^3$=20 MJ (1 m^3 biogas has heating value of 20MJ)

Biogas yield =6 m^3/d

Thus biogas as a cooking fuel is an alternative to LPG gas for rural household in Bhutan.

3.5.1 Levelised cost of electricity (LCOE)

Table 5: Total Investment per KW

Renewable source	Installed capacity (KW_p)	Investment($)	$/$kW_p$	kWh/a	Source
Solar	1	1400	1400.00	1642	Market value
Wind	360	2153000	5980.56	1261440	ADB 2010
Hydro	100	635000	6350.00	438000	ADB 2010

Table 6: LCOE of Solar, Hydro and Wind

Renewable source	Interest rate	rate(1+0.06)	Capacity Factor	installed capacity	life	Capital Recovery Factor (CRF)	Investment I ($)	Annual(IXCRF)	Generation (kWh/a)	LCOE
solar	6%	1.06	0.2	1	20	0.087185	1400	122.06	1642	0.07
wind	6%	1.06	0.4	360	30	0.072649	2153000	156413.11	1261440	0.12
hydro	6%	1.06	0.5	100	50	0.063444	635000	40287.12	438000	0.09

As the market value vary for hydro and wind due to geographic location the data from ADB report is used to calculate the levelised cost of electricity (LCOE) for hydro and wind energy source for Bhutan. Sensitivity analysis of renewable energy such as hydro, wind and solar is as shown in figure 5 for small scale power plant at different interest rate.

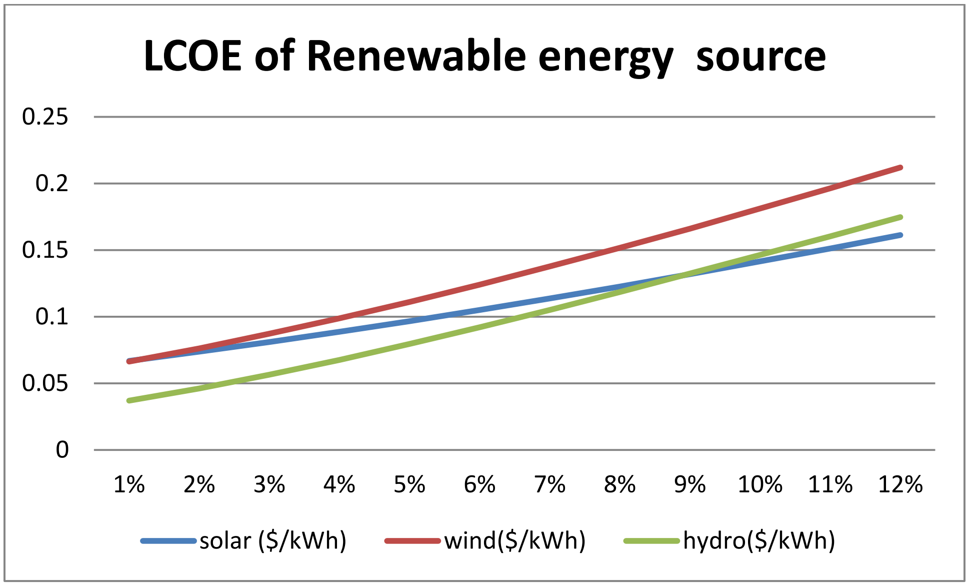


Figure 7: sensitivity result for different interest rate

The economic feasibility analysis of renewable energy largely depends on the cost. The cost deduced to $/kWh. It is seen that the cost varies according to the interest rate and project life for the invested capital. Other variable such as installed capacity depend on type of technology. Hydro power will have higher influence with this variable. In this calculation it is observed that the lower interest rate and higher project life leads to lower LCOE.

The current electricity tariff supplied by commercial scale hydropower plant for domestic supply 1.9 Nu/kWh which amounts to 0.03 $/kWh and export rate of 1.8 Nu/kWh which corresponds to 0.03 $/kWh show comparatively lower range than that of small scale power plant.

Conclusion can be drawn from these costs calculation, which indicates that the harnessing cost for small scale distributed generation is still expensive in context to current grid electricity supply. Further it is noticed that hydro and wind LCOE is highly dependent on geographic features which vary with site location. However this calculation of LCOE gives a quick overview of feasibility situation for harnessing. Due to the fact that the large hydropower electricity tariff rate is lower than distributed sources, other renewable energy source seems economically not feasible at the moment.

3.6 Current energy balance

The energy statistics show that Bhutan is mainly using electricity for both heating and powering other electric devices in cities, whereas firewood is used in rural areas for cooking and heating. LPG gas is main cooking energy source in cities where limited number of LPG gas is found in rural homes. Other primary energy such as transport fuel and aviation fuel is imported. Therefore following conclusion can be drawn from this statistics

- Electricity supply cover 88% housing with 100% hydropower share as main supply source (National Statistics Bureau, 2013)
- Fuel-wood is main source for cooking in rural areas
- LPG gas is imported for city cooking energy demand
- Fuel supply for transport is 100% imported
- Biogas as rural cooking energy demand is attractive

The illustration of Bhutan's energy consumption show 100% strategy is still not achieved though there is surplus energy potential both as distributed supply and central grid supply. While higher generation cost for distributed energy supply source is economically unattractive, cheap large scale hydro power potential is exported at cheap electricity tariff which is notably unattractive either for 100% renewable energy strategies.

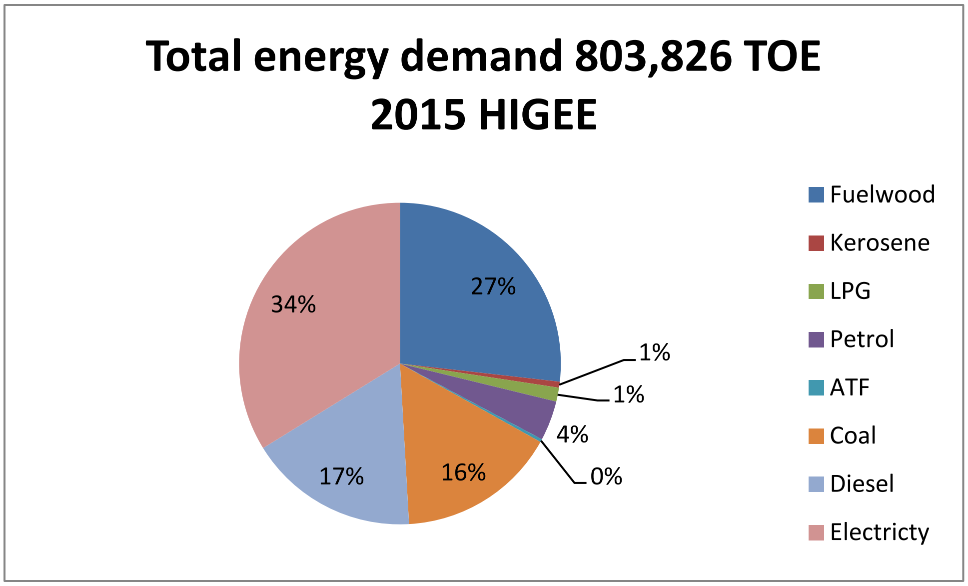


Figure 8: Net energy balance for Bhutan 2015 (Integrated Energy Master Plan, 2010)

The conclusion drawn from this statistics is that even at high efficiency performance Bhutan is still not 100% renewable powered but only electricity is 100% renewable which has a share of only 34 %. Therefore Bhutan at the moment is only 34% renewable. Coal is used as a main energy supply in industry such as iron and steel where melting process requires high heating value where coal is used instead of electricity.

3.6.1 Alternative identified

While Bhutan is exporting electricity to India as bilateral trade agreement, major share of fossil fuel such as transport fuel is imported. To overcome such challenges following are identified vital.

- Use of cheap electricity in place of coal energy demand in industry and factory in Bhutan
- Switch to e-mobility from fossil fuel powered transport sector by cheap electricity
- Increase the use of electric stove instead of LPG gas in the cities
- Adopt biogas as cooking fuel in rural houses as a cooking fuel demand

Integration of renewable energy source in this sector has major positive impact on 100% renewable energy strategies in Bhutan. Further the higher LCOE for distributed generation system has potentials to offset energy demand in these areas as a sustainable and secure energy supply source. Therefore higher generation cost is still mitigatigable. However renewable portfolio in Bhutan need further data compilation as it is observed the outdated information are still used in many reports.

3.6.2 Challenges

Despite the fact that renewable energy potential in Bhutan has opportunities to fulfill energy demand in different sectors such as electricity, heat, fueling e-car and other energy demand, financing renewable energy remains still challenging. Additionally the technical knowhow on renewable technologies leads to poor participation of the local people. Therefore capacity building in technical knowhow and financing such area is expensive.

As Bhutan has high mountain terrain, the transmission of renewable electricity will remain expensive. Therefore special focus on decentralized power generation should address such challenges. Additionally excess to remote places for developing renewable energy supply is comparatively difficult than urban region. Addressing sustainable economic growth without any disparity between remote and urban area will increasing remain challenging as it is global phenomenon that rural urban migration is inevitable. Therefore addressing such challenges are still perceived to have higher impact on decentralized power generation as energy demand is dependent on number of inhabitant in the region. Also low population density in different part of Bhutan leads to higher cost for renewable energy supply. Thus these challenges will remain as a fundamental barrier to renewable energy portfolio.

Chapter 4

4.1 Strategies for 100 % renewable energy supply

100% renewable energy strategy in principle includes all energy demand for heating, cooling, cooking, fueling transport and electricity demand for illumination. While Bhutan has 100% renewable energy supply source which is cheap is exported to India as bilateral trade agreement. However it is seen major share of transport fuel is imported which leads to dependency on fossil resources. Therefore strategies towards 100% renewable energy supply foresees alternative for fueling transport sector of Bhutan with renewable electricity. As shown in the figure 9 that Bhutan has more generation than energy demand in total which is not utilized in 100%, new opportunities for fueling transport energy demand such as use of electric car is identified significant.

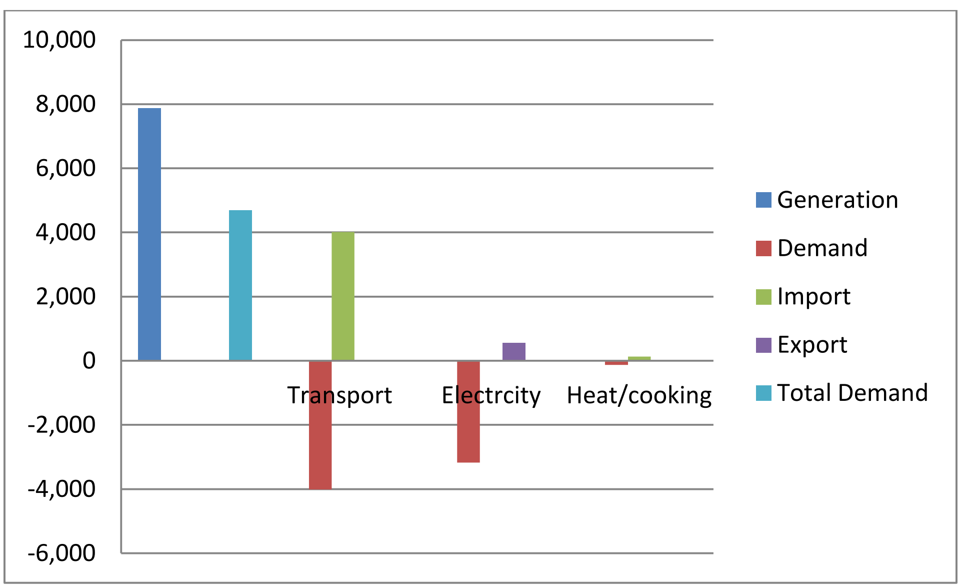


Figure 9: Illustration of energy export and import of Bhutan

Moreover potential showed that Bhutan has other indigenous energy sources such as solar, wind, hydro and biomass with theoretical installed capacity of 50,000 MW, 4000MW, 30,000MW, and 4000MW respectively. Despite high levelised cost of electricity (LCOE) for small scale solar, hydro and wind as 0.07$/KWh, 0.09$/KWh, 0.12$/KWh, respectively, large scale hydropower has a potentials to mitigate energy demand in transport sector. Alternatively the cost of harnessing small scale renewable energy source will have better scope by increasing the energy demand in other sector. The electricity export to India is attractive if in-country energy demand is 100% renewable. Despite high cost for harnessing renewable resources there is multiple added values which is intangible but significant to socio-economic development such as new local jobs, regional energy self resiliency, less environmental stress, emission avoidance, public awareness and protect energy security of the community.

As renewable resources are evenly distributed in different district of Bhutan, it makes more realistic to implement distributed generation system whereby reducing the electricity transmission cost in rural areas. In addition the renewable policy of Bhutan 2012 addresses such challenges for rural electrification. At present all Bhutanese enjoys the subsidized tariff for fuel supply such as LPG gas, which otherwise is available in excess from animal waste for 100% renewable energy for rural cooking energy demand. Therefore strategizing policies that encourage 100% renewable strategies along with citizen empowerment in renewable energy portfolio is economically attractive. Existing subsidy policy on fossil fuel import is not long-term solution as energy demand is expected to grow with development, which results in withdrawal of subsidy in future leading to energy security issues. Therefore to valorize small scale renewable energy potential, distributed supply with special focus on rural electrification is seen vital. Such strategies will foster penetration of renewable portfolio in energy supply system at community level.

There are adequate reasons to promote 100% renewable energy strategies such as environment protection, energy security and creating local jobs. In context to environment it is evident that renewable energy is carbon neutral in nature. Alternatively the international grid connectivity with India has business scope for local energy plant owner such as feeding electricity to the main grid leading to capital import and clean energy export. Such unique co-operation allows excess power produced in Bhutan to be consumed in India. This international grid connectivity has a bigger advantage in GHG emission saving. Emission reduction potentials for every kWh of electrical energy demand from different renewable energy source is environment cleaning cost saving for India as India's economy is energy intensive and carbon intensive. Therefore the cost of electricity in fig 10 may further be considered as cost neutral as external cost due to emission is omitted. Thus this is an indicator for deregulated policy for promotion of 100% renewable strategy in Bhutan involving private stakeholders as main market mover. Therefore it is clear that 100% renewable strategies are conducive for small country like Bhutan whose economy is based on water energy.

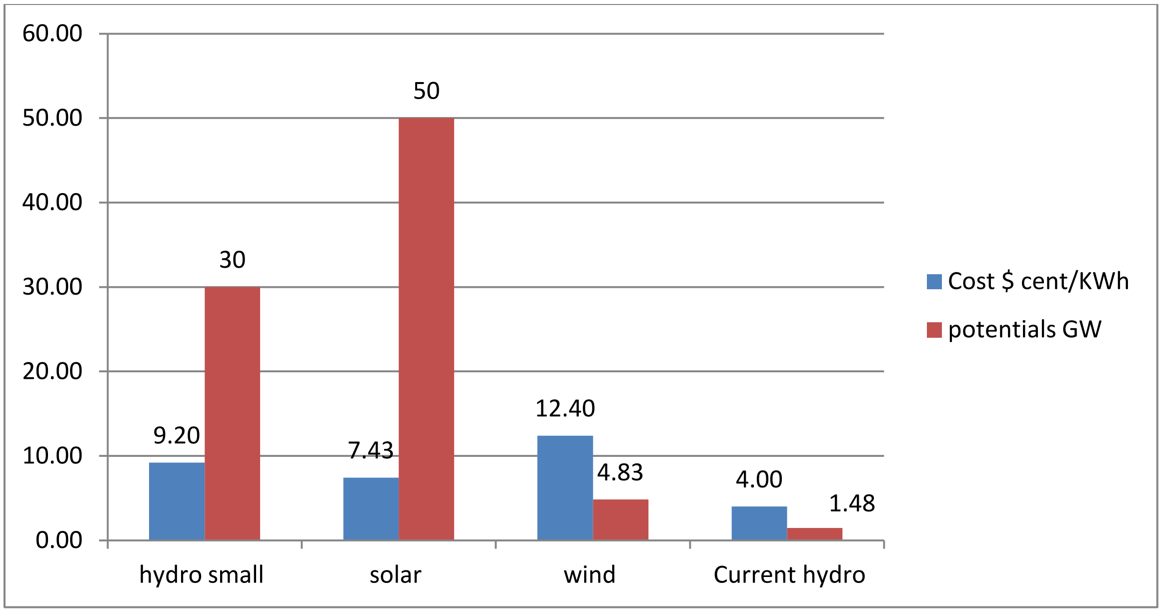


Figure 10: comparative result of cost of renewable energy $/KWh

Substitution of subsidy policy by 100% renewable energy strategy therefore augments socio-economic development in Bhutan. Addressing 100% renewable strategies however requires additional measures in different energy intensive sectors such as transport and agriculture. 100% renewable strategies therefore should focus more on increasing energy demand of Bhutan by empowering people and valorizing the renewable energy potential.

Conclusion can be drawn from the potentials and economic analysis of the entire paper which revels' that Bhutan need to further revisit energy management master plan with special focus on 100% renewable energy strategies as an ambitious goal. Increasing small scale industry such as preservation of agricultural products, and dairy farm product are some notable energy intensive application area. Therefore strategies towards 100% renewable energy supply has much more value added benefits than environment protection.

4.2 Findings

Following are key finding from this study

1. Bhutan has high share of energy demand in transport sector which is using 100 % imported fuel from India as a bilateral trade agreement
2. Bhutan electricity supply is 100% renewable which comes from hydropower as main source
3. Renewable energy potentials in Bhutan are many fold higher than its present and future energy demand.
4. Current energy generation is more than demand but 75% share is exported to India
5. Other energy demand like transport fuel, and LPG gas is 100% imported
6. The net energy demand result in -549 GWh which may be exported
7. Diversifying domestic energy source is vital for Bhutan as Bhutan has clean and cheap electricity supply from large hydropower.
8. 100% renewable energy strategy is attractive both in-terms of economy and country's energy security
9. The other renewable energy sources are comparatively expensive to the existing tariff rate therefore this sector still face financing barrier

Thus the result of this study indicates that the renewable energy potential for 100% supply is alternative best practice option for Bhutan. However further research is required for renewable energy master data as most of the information available are not updated which lead to misconception that renewable energy supply source is expensive as evident from LCOE.

4.3 Conclusion:

This study concludes that the renewable energy sources like solar, small scale hydro, wind and biomass has more than enough potential for Bhutan. However 100% renewable supply is still not achieved by Bhutan as major share (75%) of electricity generated is exported to India. To address such challenges 100% renewable energy strategies is indispensable for Bhutan.

Bhutan's vision of 100% renewable energy strategy therefore is subject to fossil import from India and use of coal for other heat energy demand. The cheap hydropower electricity indicates Bhutan to be one of the countries with 100% renewable supply. However this study concludes Bhutan has only achieved 34% renewable energy supply which covers only the electricity demand of the country.

The current renewable energy policy of Bhutan encourages small scale renewable energy plant ownership by private stakeholders, which is still challenging. The underlying reasons from this study concludes that the generation cost of electricity is high as calculation shows 0.07$/KWh$_{el}$ solar, 0.092$/KWh$_{el}$ hydro, 0.124$/KWh$_{el}$ wind, and at 6% (average for Bhutan) interest rate, which is still higher than the current electricity tariff of 0.04 $/kWh$_{el}$. However there is insufficient information to conclude that the renewable electricity is still expensive for Bhutan as international LCOE is slightly lower than that in Bhutan, which requires further real-time market survey for technology cost and geographic condition as renewable sources, such as hydro and wind installation largely depend on geographic feature.

Thus conclusion can be drawn from these findings that, Bhutan's renewable energy potentials of 50 GW solar, 30 GW hydro, 4GW wind and 4 GW biomass will have bigger impact on 100% renewable energy strategies as renewable energy source is subject to intermittence nature which can be addressed through renewable energy generation mix as an alternative to storage requirement. Further increasing energy storage in areas such as hot water supply, optional storage as electric car and export of excess electricity is seen significant. Therefore 100% renewable energy strategies for Bhutan is additional ambitious target. To conclude this study recommends 100% renewable energy strategies for Bhutan, as it is found that major share of primary energy is imported in Bhutan. Further it is envisioned that 100% renewable energy strategies will lead to energy security, regional added values and sustainable economic growth powered by renewable energy source.

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Annexure

Table 3.8 Key Elements of Pilot Wind Power Subproject at	
Element	**Quantity**
Wind Turbines and Site	
Unit capacity of the wind turbine	180 kW
Number of wind turbines	2
Total generation capacity	360 kW
Hub height	31 meters
Turbine blade length	10.5 meters
Number of blades per turbine	2
Average wind speed (measured at Tsirang site)	4.8 meters/second
Total land area required Permanent uses (foundation)	81 m2
Temporary uses (during construction)	300 m2
Wind MastHeight	20 meters
Number of wind masts	1
Access road (from roadway to the site)	800 m x 5 m
Connection line to the power grid	163 km

Table 3.7 Cost Estimates (in US $1000) of the Pilot				
A. Investment Costs	2011	2012	2013	Total
Consultant services	110	60	40	210
Wind turbines, site & electrical works		405	940	1345
Access road		50	40	90
EMP and social mitigation		25		25
Additional wind monitoring	73			73
Subtotal	183	540	1020	1743
B. PIU Costs				
Labor, office, equipment	27	27	27	81
C. Total Base Costs (A + B)	210	567	1047	1824
D. Contingencies	38	102	190	329
Total cost	275	669	1236	2153

Table 3.9 Sengor pilot micro hydro(100KW) project cost in USD	
Sengor project	**Actual**
Construction of Community Centre/Electricity Office	$ 45,000.00
Civil Engineering Works	$ 255,000.00
Electro-mechanical Equipment & Spares	$ 140,000.00
Project Planning, Engineering Design, Site Supervision	$ 30,000.00
Workshops, end use training courses	$ 45,000.00
Training/Study Tour (Nepal and Philippines)	$ 50,000.00
Training materials, equipment, facilities	$ 20,000.00
Monitoring & Evaluation	$ 30,000.00
Project Management at Sengor	$ 20,000.00
Total	$ 635,000.00

Table 3.5 solar					
Fixed Capital Cost Parts	Specification	Quantity	Unit Cost (Nu)	Total Cost (Nu)	without storage
Solar panel	50 Wp	1	7,875	7,875	7,875
Solar panel stand	Painted steel stand	1	675	675	675
Charge controller	7 Amps	1	990	990	990
Luminaries	3 Watt WLED	3	1,575	4,725	
Night lights	0.5 Watt LED	2	270	540	
Battery	50 AH sealed dry cell	1	8,100	8,100	
M-phone charging socket	Socket & cable	1	450	450	
Wires	2.5 sq mm@40 m	1	1,440	1,440	1,440
Accessories		1	700	700	700
Total fixed capital cost				25,495	11,680
Total labor costs		1	1,500	1,500	1,500
			Total	26,995	13,180

6m3 Biogas				
Price	**Materials**	**Quantity**	**Costs(NU)**	**Source**
940	Stone (m3)	5	4,700	Local market
25	Sands (bag 50 kg)	70	1,750	Local market
35	Aggregate (bag 50 kg)	35	1,225	Local market
250	Cement (bag 50kg)	14	3,500	Local market
70	MS rod (kg 10 mm)	15	1,050	Local market
70	Binding wire (kg)	0.5	35	Local market
250	Dome pipe	1	250	Local market
50	GI Fittings	12	600	Local market
650	Gas pipe (GI 1/2" in pc)	2	1,300	Local market
350	Main gas valve	1	350	Nepal
200	Water drain	1	200	Nepal
200	Gas tap	1	200	Nepal
550	Stove	1	550	Nepal
600	Dung Mixer	1	600	Nepal
40	Hose pipe	1	40	Local market
200	Inlet pipe (mtr)	3	600	Local market
10	Teflon tape	3	30	Local market
150	Emulsion paint	1	150	Local market
300	Mason	11	3,300	Local market
200	Skilled labor	11	2,200	Local market
150	Labors	10	1,500	Local market
LS	Transport etc		900	
	Total costs		**25,030**	

LCOE

LCOE $/kWh			
	solar ($/kWh)	wind($/kWh)	hydro($/kWh)
1%	0.066700808	0.066134487	0.036987635
2%	0.073611465	0.076207574	0.046136388
3%	0.080904386	0.087078629	0.056346094
4%	0.088566892	0.098703231	0.067487163
5%	0.096584228	0.111028459	0.07941376
6%	0.104939951	0.123995677	0.09197973
7%	0.113616325	0.137543226	0.105050238
8%	0.122594713	0.151608847	0.118508482
9%	0.13185594	0.166131694	0.132258131
10%	0.141380626	0.181053892	0.146222775
11%	0.151149488	0.196321633	0.160343652
12%	0.161143591	0.211885856	0.17457667