MSc Program
Environmental Technology & International Affairs

Bhutan's rural electrification by renewable energy sources: Analysis of development policies, technologies, and their socio-economic and environmental impacts

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
em. Univ.-Prof. Dr.-Ing. Günther BRAUNER

Mag. Sarah Elisabeth Maria KÖNIG

01007315

Vienna, 5 June 2018

Affidavit

I, **MAG. SARAH ELISABETH MARIA KÖNIG**, hereby declare

1. that I am the sole author of the present Master's Thesis, "BHUTAN'S RURAL ELECTRIFICATION BY RENEWABLE ENERGY SOURCES: ANALYSIS OF DEVELOPMENT POLICIES, TECHNOLOGIES, AND THEIR SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS", 60 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 05.06.2018

Signature

Abstract

The Kingdom of Bhutan was long counted among the poorest of the least developed countries in the world. However, due to its immense hydropower potential and with considerable foreign technical and financial assistance, Bhutan achieved a rapid development since the late 20th century which is mainly based upon renewable energy harnessing and thus unique. This master thesis examines if Bhutan's increased electricity generation also lead to the inclusive and reliable access to electricity for its largely rural population by analysing the technologies chosen in development policies and their respective socio-economic and environmental impacts through a desk review of available official documents and literature. It is found that Bhutan's rural electrification overall was remarkable and improved the living conditions of the rural population. Furthermore, environmental impacts have been negligible in smaller power projects. However, the latter are increasingly scrutinized with the accelerated development of large (hydro)power projects as relevant processes in the past exhibited substantial shortcomings.

Table of Contents

List of abbreviations

ADB	Asian Development Bank
BEA	Bhutan Electricity Authority
BLSSR	Bhutan Living Standards Survey Report
BPC	Bhutan Power Corporation
BPFFS	Budget Policy and Fiscal Framework Statement
BWSIS	Bhutan Water Security Index System
CEA	Central Electricity Authority India
DGPC	Druk Green Power Corporation
DHPS	Department of Hydropower and Power Systems
DNI	Direct Normal Irradiance
DoE	Department of Energy
DRE	Department of Renewable Energy
DYT	Dzongkhag Yargye Tshogchung (District Development Committee)
EAA	Environmental Assessment Act
EIA	Environmental Impact Assessment
IEA	International Energy Agency
FYP	Five-Year-Plan
GEF	Global Environment Facility
GHG	Green House Gas
GHI	Global Horizontal Irradiance
GLOF	Glacial Lake Outburst Floods
GNH	Gross National Happiness
GNHC	Gross National Happiness Commission
GoA	Government of Austria
GoI	Government of India
GWh	Gigawatt hours
GYT	Gewog Yargye Tshogchung (Block Development Committee)
IUCN	International Union for Conservation of Nature
JICA	Japan International Cooperation Agency
km	Kilometre
kW	Kilowatt
LULCC	land use land cover changes
MoAF	Ministry of Agriculture and Forests
MoEA	Ministry for Economic Affairs

MoH	Ministry of Health
MTI	Ministry of Trade & Industry
MU	Million Unit (1 MU = $1*10^6$ kWh)
MW	Megawatt
NEC	National Environment Commission
NIWRMP	National Integrated Water Resource Management Plan
NMES	National Monitoring and Evaluation System
NSB	National Statistics Bureau
OECD	Organisation for Economic Co-operation and Development
ppp	Purchasing power parity
PPP	Public Private Partnerships
PV	Photovoltaic
RBC	River Basin Committee
RBMP	River Basin Management Plans
RGoB	Royal Government of Bhutan
SDG	Sustainable Development Goal
SRBE	Sustainable Rural Biomass Energy
UN	United Nations
UNDP	United Nations Development Programme
USD	US Dollar
WRBC	Wangchhu River Basin Committee

Acknowledgements

First and foremost, I would like to express my gratitude to my supervisor, em. Univ.-Prof. Dr.-Ing. Günther Brauner, whose expertise and straightforward, timely feedback have given me valuable guidance throughout the past year.

Furthermore, I am thankful for Prof. Puxbaum's and my fellow students' helpful comments and feedback on my work – especially Valerie's.

I would also like to mention the Austrian Development Agency's commitment in the Kingdom of Bhutan which first introduced me to my thesis' topic.

And last but not least, Papa, Mama, Theresa, Eva, Philipp, Sebastian and Nikolas: Thank you for everything!

1. Introduction

"You say we want a revolution
We better get on right away
Well, you get on your feet
And enter the street
Singin', power to the people, power to the people
Power to the people, power to the people, right on"

John Lennon

John Lennon's song "Power to the People" of 1971 surely does not refer to the equivocalness of the English word *power*, however, it identifies the revolutionary potential of both, political and electric power.

In today's globalised world, especially one form of energy is indispensable and will continue to be the paramount source of energy for a variety of applications that make life more convenient as well as safer: Lighting, heating or cooling, electric motors for movement or electricity's use in telecommunications and electronic devices are just a short enumeration of how electricity has become the epitome of *developed*. It is hence not surprising, that access to energy, especially in form of electricity, is a crucial development indicator and thus also integrated in the UN 2030 Agenda for Sustainable Development. The Sustainable Development Goal (SDG) 7 lists *access to clean and affordable energy* as one objective that is also relevant for almost all other development advancements whether they concern the domains of health, education, industrialisation or combatting climate change. Therefore, it is widely acknowledged that energy and the access thereto play an important role in the eradication of poverty (IEA, 2017). Furthermore, the share of renewable energy sources will have to be amplified substantially to not only meet the increasing demand for energy but also in view of the international efforts to put a halt to global warming.

In this context, an analysis of the Kingdom of Bhutan's fairly recent development (hi)story which is mainly based upon the country's hydropower capacity and its increasing harvesting thereof to not only boost the national socio-economic development but also in order to consolidate international relations and fiscal policy, seems adequately interesting.

This master thesis therefore centres around the following questions:

1. To what extent was Bhutan’s rural electrification scheme socio-economically and ecologically successful?
2. Which parameters enabled Bhutan’s rural electrification?

The remainder of this thesis is consequently organised as follows:

The following parts of the introduction will provide general data on Bhutan as a country and its electrification efforts, whilst Chapter 2 will present the policies relevant to the creation of access to electricity, their financing and the institutions involved in the management as well as an overview of the Indian-Bhutanese development partnership based on hydropower. In Chapter 3, the renewable energy technologies that are used in Bhutan will be discussed, with a focus on hydropower. Chapter 4 puts forth an analysis of the impacts on the environment as well as socio-economic indicators in connection to Bhutan’s rural electrification whilst a conclusion is featured in Chapter 5.

1.1 General country information

The Kingdom of Bhutan, also known as the “Land of the Thunder Dragon”, is a small, landlocked country in the Himalayan Hindukush. With a total area of 38’394 km^2 the kingdom is only slightly bigger than the Austrian provinces of Salzburg, Upper Austria and Lower Austria combined. It boards two booming powers, India to its South, South-West and East as well as China (i.e. the Tibet Autonomous Region) to its North and North-West. In 2017, Bhutan presented a total projected population of 779’666 which gives an overall population density of 20.3 people/km^2 (NSB, 2017a). However, the Bhutan Living Standards Survey Report 2017 (BLSSR) compiled by the Royal Government of Bhutan’s (RGoB) National Statistics Bureau (NSB) and the World Bank indicates a total population estimate of 692,895 of which 34% reside in urban areas and 66% in rural areas. The last population and housing census was conducted in 2005 which resulted in 634’982 Bhutanese recorded of whom 30.9% lived in urban areas and 69.1% in rural areas.

Bhutan was long counted among the poorest of the least developed countries in the world (Savada et al., 1993). A strategic opening to development started from the 1960s onwards. However, only since the 21st century, “poverty reduction has been rapid, broad-based, and inclusive” (NSB, 2014, viii) as poverty incidence declined from 31.7% in 2003 to 23.2% in 2007 and halved to 12.0% in 2012 with the most notable decline in rural areas where still 94% of Bhutan’s poor lived (ADB, 2014c, 1). This also corresponds to the latest findings of the BLSSR: “Almost one-fifth (19%) of rural households believe they are poor/very poor, while only about 8% of urban households believe they are poor/very poor." (90).

This upward developing trend is also reflected in the annual growth of Bhutan's Gross Domestic Product which saw a mean growth of 6.08% over the past 27 years:

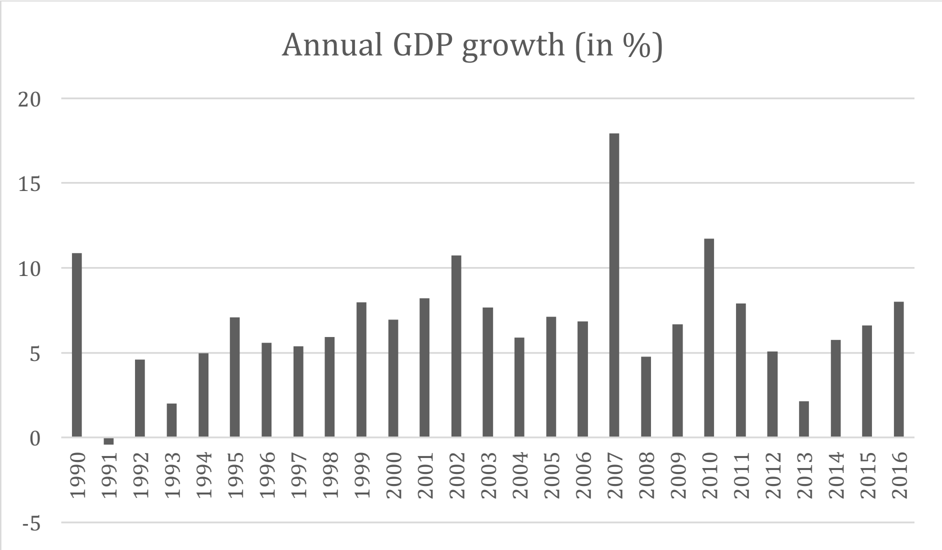

Fig. 1: Annual GDP growth in Bhutan (World Bank).

Nevertheless, Bhutan remains underdeveloped compared globally and has only reached a bit more than half (USD 8,900.80) of the global value of GDP per capita based on purchasing power parity (ppp) (USD 16,216.90) and not even a quarter of the European Union's USD 39,610.90 in 2016:

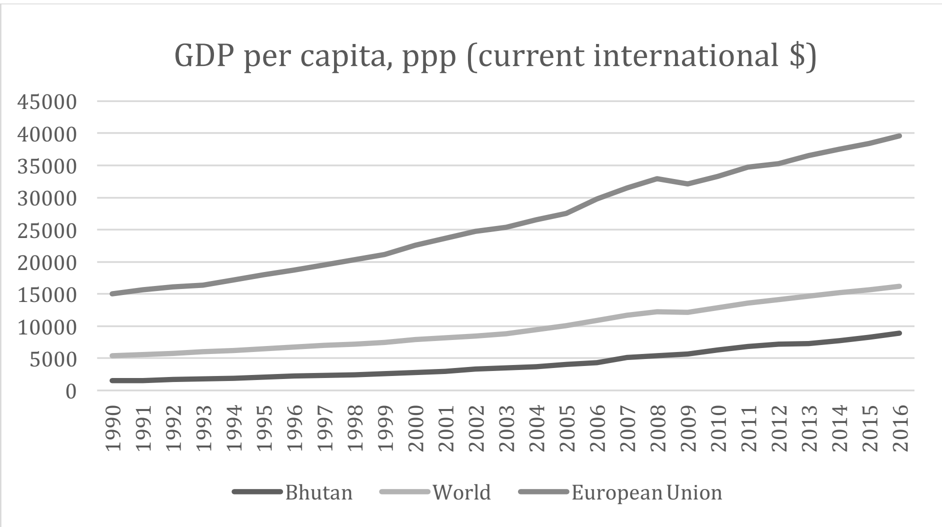

Fig. 2: Comparison in GPD per capita based on purchasing power parity (World Bank).

Sustained planned economic and social development really started with the creation of perennial development plans, i.e. Five-Year Plans (FYP), the first of which was designed in 1961 together with India which always has had considerable interest in protecting and supporting Bhutan given its role as buffer against China. Early in the process, namely in 1972, the then ruling Fourth King His Majesty Jigme Singye Wangchuck introduced the national specific development philosophy of "Gross National Happiness" (GNH) that has ever since served as a reference for all development plans and measures. As to the concept itself, the Eleventh FYP states: "GNH broadly encompasses four pillars, which are namely i) sustainable and equitable socio-economic development, ii) preservation and promotion of culture, iii) conservation and sustainable utilization and management of the environment, and iv) promotion of good governance." (GNHC, 2013a, 29f)

This shift in paradigm has recently also reached the UN whose General Assembly adopted the resolution 65/309 "Happiness: Towards a Holistic Definition of Development" in July 2011 and which held a high-level meeting on "Wellbeing and Happiness: Defining a New Economic Paradigm" in April 2012. For this meeting, also the first World Happiness Report was published. In its most recent edition, the World Happiness Report 2018 which is mainly based on Gallup world polls' data on six key variables (GDP per capita, social support, healthy life expectancy, freedom, perceptions of corruption and generosity), Bhutan ranks 97 out of 156 countries (Helliwell et al., 2018).

Before the planned development started, Bhutan was extremely isolated – politically as well as economically: "Infrastructural facilities were conspicuous by their absence. (…) There were no metalled roads, no motorized vehicles and no electricity." (RGoB, 1971, 3f).

This was also due to Bhutan's general remoteness and its inherently challenging geography: Given its rugged Himalayan mountain terrain with elevations of more than 7'300 meters above sea level in the North and subtropical foothills and plains with altitudes of around 200 meters above sea level in the South, the kingdom's geographic conditions make it extremely difficult and cost-intensive to provide reliable infrastructure throughout the country. Furthermore, the country is thickly forested, and given the steep valleys and fragile mountainous environment, there is little space for large-scale agricultural schemes. A glance at the land cover data reveals that only 0.49% of all land amount to rivers (0.16% to lakes), nevertheless, due to their fast flowing nature, their hydropower potential holds enormous importance for the country's economy and electrification scheme as will be analysed in Chapter 3.

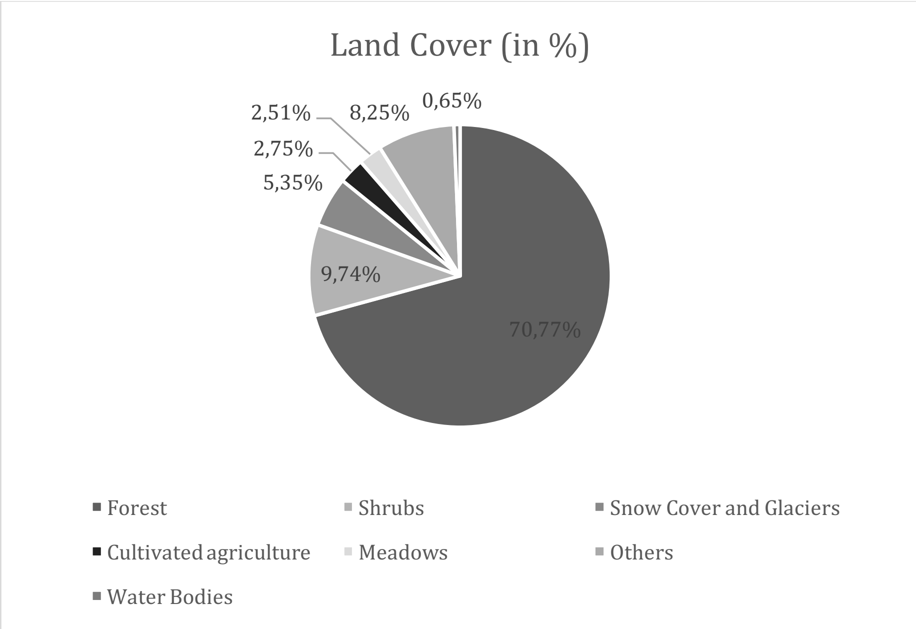

Fig. 3: Bhutan's land cover (in %) (NSB, 2017d).

Administratively, Bhutan is nowadays divided in 20 administrative and judicial districts called dzongkhags (see Fig. 4), that are further divided into 205 gewogs, i.e. a group of villages. Some dzongkhags are further divided into sub-districts ("dungkhags").

After decades of centralisation policies these regional units have been increasingly meaningful for development activities since the formulation of the Fifth FYP in 1981 when Dzongkhag Yargye Tshogchungs (DYTs or District Development Committees) were established and the introduction of the Gewog Yargye Tshogchungs (GYTs or Block Development Committees) in 1991. These steps should also formally stress the local people's and institutions' importance in terms of contributing to the development efforts.

Fig. 4: Administrative districts – “dzongkhags” – of Bhutan (US Central Intelligence Agency).

Internationally, Bhutan’s interests were for a long time represented by others: After the association with the British ended when India became independent in 1947, India took over Britain’s role “as the de facto protector” (Savada et al., 1993, 263) which also meant that India was guiding the external affairs of Bhutan but agreed to not interfere with Bhutan’s internal affairs. This only changed when Bhutan joined the Colombo Plan for Cooperative, Economic, and Social Development in Asia and the Pacific in 1962 and the UN in 1971 after holding an observer-status for three years. Heavily supported by India ever since, Bhutan eventually also worked to improve conditions that would attract not only more foreign aid but also foreign direct investment. This cumulated in the 2010 revision of the Foreign Direct Investment Policy that brought a further liberalisation that also finds its expression in various international rankings.

According to Transparency International’s Corruption Perception Index 2017, which documents and ranks the perceived levels of public sector corruption reported by experts and businesspeople, Bhutan improved one (statistically not significant) rank from its 2016’s 27th place of 176 countries. It now ranks as 26th of the 180 countries assessed, and thus 6th in the Asian Pacific region after New Zealand (1st), Singapore (6th), Australia and Hong Kong (13th) and Japan (20th).

In the World Bank Group's latest (Ease of) Doing Business Ranking 2017 that aggregates data concerning the regulatory environment of starting and operating a local enterprise, Bhutan ranks 75th and hence again before its potent neighbours, China (78th) and India (100th).

Nevertheless, Bhutanese still depend highly on agriculture and forestry which employs around 60% of the population mostly in subsistence farming and the hydropower sector, that as the Eleventh FYP puts it, is "the lynchpin of our economy" (RGoB, 2013a, 191). However, as the hydropower sector does not provide a lot of productive jobs, Bhutan's "economy continues to be aid dependent, import driven and highly vulnerable." (RGoB, 2013a, 38).

1.2 Access to electricity and rural electrification in Bhutan

Given that most of its population lived and – despite the trend of urbanisation – still reside in rural areas, rural electrification became a recognized issue by the RGoB in the early 1990s when projects to electrify rural areas on a large scale were introduced with the government's Sixth FYP 1988-1992 (ADB, 2014a).

Overall, Bhutan has witnessed enormous electrification rates. Whilst in 1990 practically nobody had access to electricity (0.01 % of the population), already by 2016, 100% of the population had access according to the Sustainable Energy for All (SE4ALL) database from the SE4ALL Global Tracking Framework led jointly by the World Bank, the International Energy Agency, and the Energy Sector Management Assistance Program:

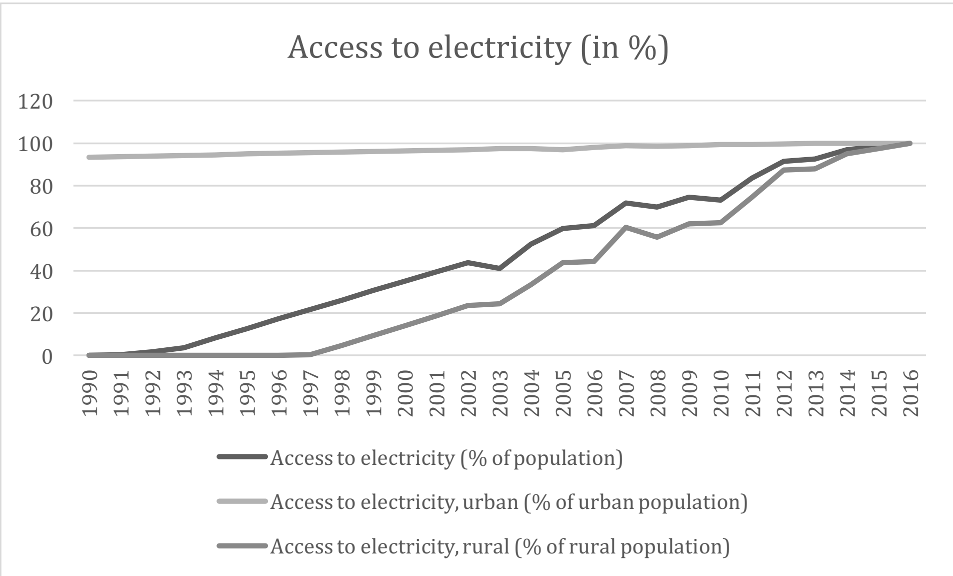

Fig. 5: Access to electricity in Bhutan (World Bank, SE4ALL).

However, a closer look at the 2017 BLSSR's account of access to electricity per dzongkhag compiled by the NSB reveals that not everywhere a 100% household electrification rate has been achieved. This is also supported by the dzongkhags individual statistics given in the NSB series "Dzongkhags at a Glance 2017". But because the reported figures in the latter date from 2016, some dzongkhags did not include information on electrification rates or again other numbers documented do not make sense they are not featured here:

Tab. 1: Bhutanese dzongkhags' population and household electrification rates (NSB).

Dzongkhag	Access to Electricity Services	Major Source		
		Grid	Generator	Solar
Bumthang	99.6%	99.4%	0.2%	-
Chukha	99.6%	99.5%	0.1%	-
Dagana	100%	100%	-	-
Gasa	99.4%	81.2%	-	18.2%
Haa	95.7%	95.7%	-	-
Lhuentse	99.4%	99.4%	-	-
Mongar	99.3%	99.3%	-	-
Paro	99.8%	99.2%	0.6%	-
Pemagatshel	99.6%	99.6%	-	-
Punakha	99.6%	99.6%	-	-
Samdrup Jongkhar	99.4%	99.1	-	0.3%
Samtse	97.6%	96.2	-	1.4%
Sarpang	98.3%	96.7%	0.3%	1.3%
Thimphu	98.7%	97.1%	-	1.6%
Trashigang	99.1%	98.6%	-	0.5%
Trashi Yangtse	99.7%	99.6%	0.1%	-
Trongsa	99.8%	99.1%	-	0.7%
Tsirang	99.6%	97.3%	2.0%	0.3%
Wangdue Phodrang	99.8%	97.6%	-	2.2%
Zhemgang	95.6%	94.5%	0.5%	0.7%
Bhutan	**99.0%**	**98.0%**	**0.2%**	**0.8%**

The BLSSR 2017 outlines the information collected during nationwide data collection in the field during March and April 2017. Access to electricity forms part of the *housing indicator* of living standards and thus features also into one of the domains of GNH. According to the report, 100% of all urban households (99.7%

via grid, 0.1% via generators, 0.2% via solar energy) and 98.5% of all rural households (97.1% via grid, 0.2% via generators, 1.2% via solar energy) have access to electricity (NSB, 2017b). Out of those households lacking access, more than half (55.4%) indicated that access was not available, while 12% said it would be too expensive. The survey also enquired about the reliability of electricity supply and what electric energy is used for:

As could be expected, rural households meet more power interruptions compared to those in urban areas. However, only 18% of all households have experienced no interruption at all during the past 12 months, whilst about 58% have experienced one or more electric interruptions that lasted at least one hour in the last 7 days and 7.6% of all rural households and 2.9% of urban households had faced blackouts of more than one month.

Electricity is mostly used for lighting (98.6% of all households) and cooking (94.9%) while electric heaters (24.2%) are only the third choice in Bhutan: around 30% of households in both, urban and rural areas, have no heating, followed by electrical heaters in urban areas and bukharis or thabs, i.e. traditional space heaters and/or stoves that are typically fuelled by fuel wood or coal, in rural areas. In rural areas, electricity is consumed by 98.3% of households for lighting, by 92.5% of homes for cooking and 9.7% have an electric heater.

2. Regulatory environment concerning electrification technologies, financing, and management in Bhutan

The RGoB's activities for (economic) development are planned in FYPs that starting with the First Development Plan in 1961 have continued to the current Eleventh FYP which includes the years 2013 to 2018. The works for the Twelfth FYP (July 2018 – June 2023) have already started in January 2016. Whilst the first two development plans have been directed by the Development Secretariat, a Planning Commission was established for the formulation of the Third Plan onwards which might also be due to some foreign observers' remarks concerning the failure of the preceding plans in terms of priorities and the achievement of "an economic-sector integration as might be expected of genuine development planning" (Savada et al., 1993, 290).

Nowadays, the FYPs as central development policy formulations are coordinated by the Gross National Happiness Commission (GNHC) which also should ensure the streamlining of the GNH principles in the planning processes and the delivering of results.

However, through the years many other acts and policies that are essential to the energy sector have been established – very often by an impetus during the planning processes of the FYPs. The most important of those being the following:

- Electricity Act, 2001
- Grid Code Regulation 2008
- Operationalization of Grid Code Regulation 2008, 2017
- Tariff Determination Regulation 2007 (updated 2013)
- Domestic Electricity Tariff Policy, 2015
- Bhutan's Rural Electrification Master Plan (REMP; JICA, 2005)
- Bhutan Sustainable Hydropower Development Policy, 2008
- National Transmission Grid Master Plan (NTGMP)
- Integrated Energy Management Master Plan, 2010
- National Strategy and Action Plan for Low Carbon Development, 2012
- Environmental Assessment Guideline for Power Transmission Line Guideline, 2012
- Environmental Assessment Guideline for Hydropower Development, 2012
- Alternative Renewable Energy Policy, 2013
- Economic Development Policy, 2016

- Bhutan Power System Contingency Plan, 2017
- Project on “Power System Master Plan 2040"

Other acts and policies that include essential implications for the (hydro)power sector are:

- Environmental Assessment Act, 2000
- Forest and Nature Conservation Act of Bhutan, 1995
- Forest and Nature Conservation Rules of Bhutan, 2006
- Accounting and Reporting Regulation, 2007
- The Water Act of Bhutan, 2011
- National Integrated Water Resource Management Plan (NIWRMP), 2016
- National Environmental Protection Act, 2007
- Mines and Minerals Management Act, 1995
- Land Act, 1979; and Land Act, 2007

2.1 Electricity and rural electrification in FYPs

The central planning framework of FYPs evidently also included projects in the power and energy sector from the beginning onwards. Over the past decades not only the planning process but also the documentation and reporting standards have continuously improved. This is visible in the plans respective volumes which testify to their level of details but also with regards to their methodology. The Fifth FYP gives an account on the early “evolution of planning”, stating that the first two FYP were “mainly financial budgeting exercises rather than an attempt to work out a framework of priorities (…)” and “evaluation was basically an ex-post audit of expenditures (…)” (RGoB, 1981, 28f). Only for the Third FYP physical and financial targets were formulated and actions measured against them. This was improved further in the Fourth FYP planning which also included the involvement of the local DYT and lastly with the introduction of a new results-based management planning framework in the Tenth FYP.

The *First FYP (1961 – 1966,* RGoB, 1961*)* already highlights India’s initial role in Bhutan’s development also with regards to Bhutan’s electrification: In 1961, the Jaldhaka agreement was signed between the two countries, stipulating that southern Bhutan will receive most of the energy generated at the Jaldhaka hydropower plant in West Bengal, India. This marked the start of a diplomatic and economic cooperation based on hydropower which will be analysed more closely in Chapter 2.4. It was also already during this FYP that first investigations into the Chhukha hydropower project started. Two of the four Chhukha hydropower plant’s units were eventually commissioned in 1986 (the other two in 1988) and propelled access to electricity in Bhutan as well as revenue from hydroelectric exports. Until then, FYPs mainly proposed small hydroelectric (hydel) schemes such as the two < 400kW projects that would serve the country's capital Thimphu and another city Paro. However, the hydel projects for Thimphu and Paro were not concluded until the *Second FYP (1966 – 1971*, RGoB 1966*)*, resulting in delays that can be observed in (almost) all hydropower projects since. The FYP, therefore, only suggested starting one other project, the Sarbhang project, which was not carried out.

During the *Third FYP (1971 – 1976*, RGoB, 1971*),* the progress made so far was summed up by three completed micro-hydel projects at Thimphu, Paro and Wangdiphodrang respectively with a total local generating capacity of 700 kW and works on a 750-kW installed capacity hydel in Tashigang, the first in the eastern region. Especially the capital, Thimphu was already experiencing "acute power shortage" (RGoB, 1971, 32). It also became clear, that the Chhukha hydropower plant would be executed outside the plan due to its financial and technical implications that were enormous given the overall lack of expertise and manpower in Bhutan at that time. The plan, hence, proposed three projects at Gidakom (1,250 kW installed capacity), Mongar (150 kW) and Tongsa to reach a 4000 kW power potential.

For the *Fourth FYP (1976 – 1981,* RGoB, 1976*)*, only the "salient features" are available which do not elaborate on power other than that due attention will be paid to its further development. But given the *Fifth FYP's (1981 – 1986,* RGoB, 1981) account of the previous development performance that are "six small units all over the country" and an installed capacity of 3.45 MW hydropower, it seems no new hydel additions were made during the late 1970s.

With the (partly) commissioning of the Chhukha hydropower plant during the Fifth FYP, however, the dimensions of hydroelectricity generation and use thereof reached new heights in Bhutan. Other than for the micro-hydel projects, a regional 220-kV transmission network of a total 275 km was planned to be installed across western Bhutan for the distribution of the generated electricity. The plan also mentions *rural electrification* for the first time, a thematic that was until then overshadowed by isolated generation schemes and imports from India mainly in southern Bhutan but not recognized as an issue in itself. This also lead to the idea of a 20-year power development "master plan" and the acknowledgement that not only selected areas should be electrified individually (mainly this has been done in urban areas and for a domestic use) but to create a wider reliable electricity supply and also to push ahead with the substitution of non-renewable energy resources and alternative sources. Still, the projects put forward in the plan were orientated along known lines, such as the building of isolated mini-hydel systems (a 5 MW plant at Tangsibi, a 0.5 MW plant at Pemagatshel and one at Tashiyangtshe) and diesel generators.

The Fifth FYP also included a first estimate on the per capita energy consumption (although the numbers have to be consulted with caution as at the time the RGoB grossly overestimated the Bhutanese population): Electricity only accounted for 0.3% of the gross energy consumption and 1.3% of "useful energy" in 1981/82 and thus ranking last, with fuel wood leading the classification with a staggering 94.8% of gross energy consumption and 83.7% of useful energy, followed by coal (3.5%/11.2%) and petroleum products (1.4%/3.8%) (RGoB, 1981, 38).

Power ultimately became a substantially more important development aspect with the *Sixth FYP (1988 – 1992,* RGoB, 1988*)*, specifically under the newly established *rural electrification programme* which included plans for grid extensions, further micro-hydel schemes and the installation of photovoltaic (PV) systems in very remote areas to provide "at least" 10,000 rural households with power (RGoB, 1988, 97f). The need for action was evident as "[t]he achievement in the sphere of rural electrification has been so far disappointing. Only a total of 130 villages have so far been eletrified [sic!]" (RGoB, 1988, 99). Furthermore, the previously unsystematic approach to (rural) electrification was criticised: "The electrification works undertaken in the past were generally carried out in a haphazard way in the absence of town and city maps. The redemarcation of areas and construction of new roads has resulted in continuous need for shifting and re-alignment of power lines, upgradation of substations, erection of new lines and substations etc." (ibid.).

Already operational plants came under spotlight again as refurbishing plans emerged to maximise their efficiency and coincided with development plans for the until-then neglected eastern parts of Bhutan where considerable mining and industrial activities were expected in the future: A medium hydro project (45 MW installed capacity) was proposed at Gyeposhing near Mongar on the Kurichu and four mini hydro schemes with 1 MW each at Radi, Damphu, Shemgang and Dagana. Also, the transmission network was set to be considerably improved and extended but "[a]s of December 1990, 119 km of transmission line had been established" against the planned 320 km (RGoB, 1992, 178). The RGoB was at the time, however, confident that "[i]f all the proposals are put into effect the total hydro generation will rise from the present 3.45 MW to a total of 99.35 MW, excluding Chhukha Hydel Project, at the end of the plan." (RGoB, 1988, 98) This hope did not materialize: At the end of the Sixth FYP, 21 run-of-the-river hydropower plants with a total generating capacity of 355 MW existed, out of which the Chukka Hydro Scheme provided an installed capacity of 336 MW. Works for a Power System Master Plan that commenced in 1990 were also set to be finalised in 1993.

The *Seventh FYP (1992 – 1997,* RGoB, 1992*)* saw the emergence of environmental concerns and thus stipulated the need for mandatory Environmental Impact Assessments "prior to the implementation of any new hydroelectric projects (…)" (RGoB, 1992, 29) but also stated that "the fact that hydroelectric power has been the major source of economic growth has meant that development has had little impact on the environment to date" (RGoB, 1992, 26). Despite the priority that was accorded to the power sector in the past years (and again in this plan), most areas of Bhutan still lacked access to energy which also hampered economic growth and meant that over 90% of Bhutanese have had no access to electricity. The use of alternative forms of energy generation was minimal with 56 small biogas plants (2 to 9 cubic metres capacity per day each) that were mainly used for lighting, a total of 271 solar panels in use that were provided to monasteries, schools etc. in remote areas again for lighting purposes (battery charging), some of which "may no longer be functioning", and the solar electrification of one village with 30 households in Shingkhar (Bumthang) by Indian Assistance in 1991 (RGoB, 1992, 176). Wind energy was also only used in two places, namely "the Swiss Project Farm in Jakar, Bumthang for battery charging and in the Centre for Agriculture Research Development (CARD) in Wangdiphodrang for irrigation." (ibid.). The main objectives set forth in the plan were the increase of government revenue through power exports to India and sale to domestic industries, the fulfilment of energy demand at minimum cost, the balanced regional development of infrastructure and ensuring an "environmentally sustainable use of hydropower resources" (RGoB, 1992, 179). The strategies to achieve those goals were besides new power tariffs for India, the commissioning of further hydropower projects such as the Chhukha Tail Race and Bunakha Reservoir Scheme to maximise efficiency in existing plants but also the implementation of projects like the Kurichu Hydel Project (45 MW), the Tangsibji Hydel Project (45 MW) and the Basachu Hydel

Project (41 MW). Nonetheless, the plan already acknowledges that those "will produce substantial power for export or internal consumption, but only in the early part of the 8FYP." (RGoB, 1992, 179). The main constraints in the hydropower sector were identified as "insufficient number of technical personnel, high costs of casual labour and lack of finance. Because of the rough terrain and scattered population, the per capita cost of transmission and distribution of electricity is extremely high." (RGoB, 1992, 177).

These constraints were again noticeable when projects already mentioned in previous plans also failed to be implemented during the *Eighth FYP (1998 – 2003,* RGoB, 1998*)*, most notably the Kuricho and Basochu projects that eventually were only commissioned in 2003 and 2004. Also, the FYP's remark that "at present 23 hydroelectric generating stations with 344 MW installed capacity (…)" existed, shows that not much progress was achieved (RGoB, 1998, 166f). Still, the consumption pattern of energy changed according to the plan with hydropower assuming "the leading role" although fuel wood, kerosene and liquefied petroleum gas (LPG) were still widely used – fuel wood accounting for more than 75% of the national energy consumption. Due to the improved and extended road infrastructure, also the demand for petrol and diesel products increased. The rural electrification programme that started in the Sixth FYP was set to be finalised during the plan period after only 80% of the Seventh FYP rural electrification targets was reached. The rural electrification scheme was henceforth based on the regional DYT's input and aimed at providing 7,500 households with electricity until 2003.

This path was continued during the *Ninth FYP (2003 – 2008,* RGoB, 2003*)* that envisioned the electrification of 15,000 households via expanding transmission lines that should also promote and facilitate the export of electricity and development of power-intensive industries. At the beginning of the plan, the total installed capacity of the power system amounted to 440 MW of hydropower to which the newly commissioned medium-sized 60 MW Kurichhu plant and 22.2 MW Basochhu Upper Stage added most. Furthermore, with the Tala Hydroelectric Project (1,020 MW) and the Basochhu Lower Stage (38.6 MW) two more large projects were under implementation. The plan stressed the positive spill-over effects of hydropower and stated: "The production and sale of hydropower will provide the main impetus to the growth." (RGoB, 2003, 55)

Domestic electricity consumption "has been growing at an average rate of 9.53 percent over the last five years" (RGoB, 2003, 100). Amongst the objectives of the plan was a 100% rural electrification rate by 2020 which was thus accorded the highest priority. To this extent, the creation of a comprehensive *Rural Electrification Master plan* was decided. This study was eventually carried out by the Japanese International Cooperation Agency (JICA) which presented its final report, “The Integrated Master Plan Study for Dzongkhag-wise Electrification in Bhutan”, in 2005. It was also planned to create a more “enabling environment” meaning to encourage the participation of independent power producers and operators as well as to prepare an Energy Master Plan, a Water Resources Management Master Plan and an update of the Hydropower Master Plan Inventory in order to enable a systematic and sustainable approach to harnessing the renewable energy resources (RGoB, 2003, 102). With the completion of the 1,020 MW Tala hydropower plant the actual hydropower generation potential almost quadrupled to 1,489 MW at the end of the Ninth FYP which subsequently also boosted the export of surplus energy to India.

The Ninth FYP was extended for one year, firstly to conclude all the plan’s activities and secondly, so the *Tenth FYP (2008 – 2013*, GNHC, 2008a and 2008b*)* “could start a fresh with the launching of the Constitution and installation of the new government in 2008” (GNHC, 2008a, 3). The Tsa Thrim Chhenmo formally marked the transition to a democratic constitutional monarchy.

The plan also introduced a new planning framework, i.e. the *results-based management planning framework*, after a critical recommendation by the Good Governance Plus report of 2005. Specifically, the FYP should be “operationalized” by two multi-year plans that allow for annual work plans and furthermore, all infrastructure development (such as rural electrification) underlie “Master Plans” to enhance priorities and the planning process (GNHC, 2008a, 54f). The necessary financial resource allocation (i.e. the distribution of grants) is based on the regional Budget Policy and Fiscal Framework Statements (BPFFSs) which draw on macroeconomic factors whilst a National Monitoring and Evaluation System (NMES) was set up for the systematic evaluation of development plans and activities. The GNH Index (GNHI) serves as the overall yardstick given that GNH is “the ultimate objective of Bhutan’s development” (GNHC, 2008a, 55).

In documenting the designated strategies and visions, the Tenth FYP is divided in two volumes, a “Main Document” and “Programme Profiles”, e.g. of the rural electrification programme.

Given that “[t]he sector has been the proverbial engine of growth for the economy and the catalytical hub around which socio-economic development has been advanced.” (GNHC, 2008*a*, 31) high hopes were allocated to the energy sector again. The Indo-Bhutan umbrella agreement of 2006 for the long-term development of hydropower stipulated that until 2020 an additional minimum 5,000 MW (which was increased to 10,000 MW in the Protocol to the agreement in 2008) shall be generated for the export to India, whilst the overall aim of providing all Bhutanese with electricity by 2013 (an acceleration of the country’s Vision 2020’s deadline of 2020) also meant to find alternative (renewable) energy sources for the 12% of households that would not be connected to the national electricity grid. The plan itself, however, notes that “this [note from the author: i.e. the access to electricity for all by 2013] is likely to be seriously challenged by resource and accessibility constraints” (GNHC, 2008a, 114).

In accordance with the new planning framework, a national transmission master plan and a plan for accelerated hydro-power development were proposed to better cater the objective of accelerated development of (large) hydro-power plants. The plan set forth 10 hydropower projects with a combined installed capacity of 11,576 MW, among them the Sunkosh Reservoir project (4000 MW), the Kuri-Gongri hydropower plant (1800 MW), the Punatsangchhu I and Punatsangchhu-II hydropower plants (1200 MW and 1000 MW respectively), which should be implemented until 2020 (see also Annex II).

In the plan’s second volume, more detailed information on the rural electrification programme is given that relies on the 2005 Rural Electrification Master Plan for reference. Emphasis was given to feasibility studies and the involvement of donor development agencies. According to the plan, only 54% of rural households had access to electricity in 2007. The target for electricity receiving households during the Tenth FYP was therefore set at 40,000 households to reach the aim of electricity for all (RGoB, 2008b).

The ambitious goals that were introduced with the Tenth FYP or during its time, especially the accelerated development of hydropower which was fuelled by the earlier agreement with India sparked concerns that were also formulated in the *Eleventh FYP (2013 – 2018,* RGoB, 2013a and 2013b*)*: “Given the huge revenue gains expected from the hydropower sector, there is also a growing imperative for preventive measures against the phenomenon of ‘Dutch disease”.” (GNHC, 2013a, 96). Such loss of competiveness in other sectors as a result of relying too much on the hydropower sector should be counteracted with the “accelerated green development” strategy that looked to strengthen the diversification by developing sustainable measures in other sectors as well as the continued strategic development of critical infrastructure (GNHC, 2013a, 14f).

Boosted by the agreement with India, the plan envisioned the harnessing of 4,546 MW of hydropower by 2018 which especially relied on the timely commissioning of the previously proposed projects (see Tenth FYP). But also voices that wanted to see an increased productivity in Bhutan were included: The simple export of hydropower should be substituted by the promotion of power-intensive industries that would produce for export and thus more added value could be harnessed from the cheap and abundant hydropower (GNHC, 2013a, 81).

And still, the goal of electricity for all has not been achieved yet: From the 88,642 households, 82,270 households have received access to electricity by 2013, amounting to 92.82%. As part of the *rural electrification programme* also other renewable energy sources were promoted which resulted in 8,000 kW from small hydro power plants, 152 kW of PV technology and 900 biogas plants. The costs for electricity were the lowest in the region, despite increases and rural consumers got free electricity for the first 100 units consumed in three years with the idea of encouraging the use of electricity to reduce the use of fuel wood in favour of a healthier and environmentally friendlier energy source. According to the *Integrated Energy Management Master Plan for Bhutan* fuel wood consumption is reduced by 30 – 35% by access to electrification (DoE, 2010).

The plan increased its transparency with three volumes, covering general information in the “main document” (Vol. I), an overview of the central government programme profiles (eg. the rural electrification programme, Vol. II) and the local government programme profiles (Vol. III).

In the energy sector, three programmes were included, the rural electrification programme being noticeably absent in the central government’s programme profiles. These programmes were “Institutional Reforms and Capacity Building”, “Accelerated Hydropower Development & Transmission Network Strengthening” and “Promotion and Development of Renewable/Alternate Energy Technologies” (GNHC, 2013b, 131ff). Rural electrification can, however, be subsumed under the latter programme.

2.2 Institutional management

With the implementation of the Electricity Act of 2001, the energy sector experienced a major transformation whose preparation fell mainly in the Ninth FYP period. The functions of the Ministry of Trade & Industry’s (MTI) Department of Power were divided along the following substantial lines:

The competence for policy development fell to the Ministry of Economic Affairs (MoEA) which followed the MTI in 2007 and compromises three departments (with further divisions each): The Department of Hydropower and Power Systems (DHPS), the Department of Renewable Energy, and the Department of Hydro Met Services.

The Bhutan Electricity Authority (BEA) was established as the power sector regulator and is thus "responsible for setting tariffs; establishing and enforcing technical, safety, and operational standards; issuing licenses; and monitoring other regulatory functions." (ADB, 2014a, 1). It is an autonomous body since 2010 really when the RGoB forfeited their right to approve of BEA acts, however, the members of the commission are still appointed by the Minister for Economic Affairs.

The transmission and distribution of electricity was accorded to the fully state-owned Bhutan Power Corporation (BPC) as the Bhutan Power System Operator. BPC therefore undertakes the construction and operation of transmission networks under licence from the BEA as well as the construction of generation plants connected to the national grid. It also owns and manages the smaller hydropower plants except for the Lingzhi hydropower plant (e7, 2005, 7).

The export orientated power generation, i.e. the operation of the bigger hydropower plants, falls mainly upon the – again – under the Druk Holding and Investments Limited state-owned Druk Green Power Corporation (DGPC). The DGPC was formed in 2008 as an amalgamation of the previous individual corporations of three hydropower plants, namely Chhukha, Kurichhu and Basochhu and incorporated the Tala Hydropower plant in 2009, too. It also holds shares of the Dagachhu Hydro Power Corporation Limited (59%) and the Tangsibji Hydro Energy Limited as well as investments in some Joint Venture companies, Kholongchhu Hydro Energy Limited (50%), Bhutan Hydropower Services Limited (51%) and the Bhutan Automation & Engineering Limited (51%).

Independent private hydropower projects have not been successful so far, despite that fact that Bhutan's Sustainable Hydropower Policy of 2008 allows private sector companies to participate in projects of less than 25 MW (Premkumar, 2016, 14).

Given Bhutan's energy mix, also other ministries are relevant especially with regards to the still widely used fuel wood. As Art 5 para 3 of the Constitution of Bhutan sets forth that 60% of the land must be covered with forests, the fuel wood supply is regulated by the Forest and Nature Conservation Act of Bhutan (1995) and the thereupon issued Forest and Nature Conservation Rules of Bhutan (2006). Designated forest management units or community forests are established for the industrial or commercial harvesting of fuel wood. Households that lack electricity access are allowed up to 16 m^3 of fuel wood/year from the forest management units, households with electricity half (Siebert and Belsky, 2015).

2.3 Financing of Bhutan's (rural) electrification

The ADB indicated the costs of Bhutan's electrification rate at an average connection cost of 1,500 USD per household (ADB, 2010b).

Bhutan's early energy sector development was – like all development activities – almost exclusively financed by foreign grants (and later loans). This changed only after the commissioning of the Chhukha hydropower plant (1988) whose generation of surplus power also allowed for the generation of revenues from the sale of this excess hydropower as most important export product to India. By 1994, these revenues alone accounted for 11% of all government resources (RGoB, 1998, 13). During the Eighth plan the direct sale of hydropower contributed to as much as 45% of the gross national revenue through taxes and dividends (GRoB, 2003, 100).

The both first FYP were planned in consultation with India's Planning Commission and their entire expenditures (Rs. 1 702 000 000, this would today amount to 25.4 million USD; and Rs. 2 000 000 000, which nowadays would amount to 29.8 million USD respectively) were covered by Indian grants. For the Third FYP, India again provided for 90% of the financial assistance, the remainder being financed from domestic resources (7%) and assistance from the UN (3%) – a trend that was furthered with the Fourth FYP financing (India 77%, UN 17.5% and domestic resources 5.5%) (RGoB, 1981, 28). Only with the Sixth FYP, a "substantial portion of assistance (…) is coming in as loans" (RGoB, 1986, 29), making considerations of repayment liabilities and debt servicing a first issue. The further FYPs do not indicate the share of bilateral and multilateral aid clearly.

According to the ADB Energy Sector evaluation study of 2010, the ADB has been the leading partner in continuously channelling (financial) support for the rural electrification schemes of Bhutan. Its support was rated relevant, the supported rural electrification projects' efficiency was assessed based on the economic internal rate of return (EIRR). The assessed programmes were the following:

1. 1995 – 2000: Rural Electrification Project (6.64 million USD of the 8.21 million USD actual project costs were covered by the Asian Development Fund, EIRR of 12.9%, i.e. efficient project).
2. 1999 – 2006: Sustainable Rural Electrification (9 million USD of the 11.6 million USD actual project costs were covered by the Asian Development Fund, EIRR of 23.0%, i.e. highly efficient).
3. 2003 – 2009: Rural Electrification and Network Expansion (9.7 million USD of the 13.2 million USD actual project costs were covered by the ADB, EIRR of 21.7%, i.e. highly efficient).
4. 2008: Green Power Development Project (EIRR for Dagachhu component of 19.5 – 24.8% and for rural electrification component EIRR 14.3%).

They FYPs respective financial outlays also state the share of total expenditure allocated to the power sector's programmes:

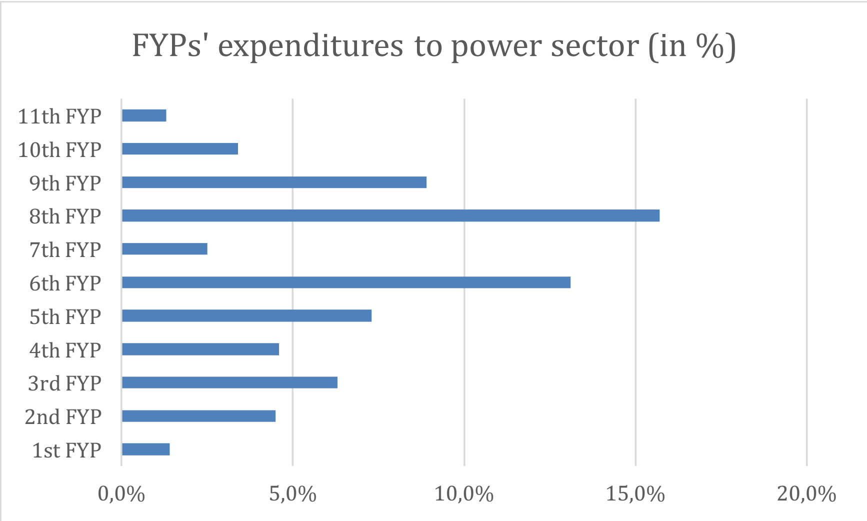

Fig. 6: FYPs' expenditures to power sector in % (RGoB, GNHC).

The above average allocations of the Sixth and Eighth FYP must be consulted with caution as usually delays in the respective programmes' implementation have impeded the full spending on power related projects. The Seventh FYP mentions for instance, that the actual share for power during the Sixth FYP's period was at 9.6%.

Albeit the importance accorded to the (renewable) energy sector can be read into the share of expenditure thereon in the FYPs, the financing of the larger hydropower projects was carried out mostly outside of the FYP frameworks, leading to additional (international) financing which must be considered as it was directly attributed to the development of hydropower plants. The projects were mainly based upon bilateral agreements (with the GoA or the GoI). But with the Dagachhu project the first PPP was conceived and its project also registered under the Clean Development Mechanism (CDM).

Tab. 2: Financing structure of larger hydropower plants.

Power plant	Project cost (Nu. Million)	Grant	Loan	Domes-tic share	Body
Chhukha	2,465	60%	40%	0%	GoI
Kurichu	5,600	60%	40%	0%	GoI
Basochu I	1,440	37.47%	49.14%	13.39%	GoA
Basochu II	1,834	2.51%	95.64%	1.85%	GoA
Tala	41,258.55	60%	40%	0%	GoI
Dagachhu	8,600				PPP (ADB, GoA, GoJ)

These larger hydropower plants were already built with the intention of generating domestic income through the sale of hydropower exclusively to India. However, "[b]efore power exports, DGPC gives 15% of the power it generates as an energy royalty to the government, which sells it to BPC at discount prices. Electricity is supplied to domestic consumers at affordable tariffs that are substantially cross-subsidized by power exports." (ADB, 2014a, 1).

The current electricity tariffs are featured on the BPC's website as well as in the BEA's tariff reports and include the free first 100 kWh for rural consumers to encourage electricity consumption. The tariffs are structured along low, medium and high voltage and within the low voltage range in "blocks". Other charges include the meter security deposit, service cable charge, an installation, inspection and testing charge etc.

Tab. 3: Revised electricity tariffs Bhutan (BPC).

Tariff structure	1 Jul 2017 to 30 Jun 2017	1 Jul 2018 to 30 Jun 2019
Low voltage (LV)		
LV Block-I (Rural) 0-100 kWh	0 Nu./kWh	0 Nu./kWh
LV Block-I(Others) 0 – 100 kWh	1.28 Nu./kWh	1.28 Nu./kWh
LV Block-II (All) >100 – 300 kWh	2.60 Nu./kWh	2.68 Nu./kWh
LV Block-III (All) >300 kWh	3.43 Nu./kWh	3.53 Nu./kWh
LV Bulk	3.90 Nu./kWh	4.02 Nu./kWh

Medium voltage (MV)		
Energy Charge	2.07 Nu./kWh	2.16 Nu./kWh
Demand Charge	275 Nu./kVA/month	300 Nu./kVA/month
High voltage (HV)		
Energy Charge	1.59 Nu./kWh	1.59 Nu./kWh
Demand Charge	262 Nu./kVA/month	262 Nu./kVA/month

Around this, export tariffs are negotiated with India and stipulated in power purchase agreements. Only in February of this year, the export tariff for Chhukha's electricity was revised from Nu 2.25 a unit to Nu 2.55 which will be applied retroactively from 1 Jan 2017 (Dorji, 2018).

When foreign aid was increasingly conveyed in form of loans, the term *hydropower debt* emerged also in Bhutan's fiscal planning. Today, Bhutan's "[h]ydro-power debt is expected to account for 80 percent of the total public debt stock, most of which is denominated in INR." (GNHC, 2013a, 107). This, however, has not led to panic amongst the RGoB which calculates with the self-liquidation and debt servicing of hydropower plants. Still, this means that – however – impressive revenues generated from hydropower plants have to be set against the paybacks and cannot be freely allocated to other development programmes (see Annex III).

For the Chhuka hydropower plant, Dhakal and Jenkins (2013) have provided an extensive insight in the agreement's contractual arrangements and based on a financial and economic benefit calculation highlight the positive aspects of the undertaking for both sides. The stated reasons for this include, for instance, the inflation rate that was higher than the agreed upon interest rate and which therefore eroded the real value of the biannual repayments.

Nevertheless, the surge in capital inflow for hydropower development since 2011 (which relates to the accelerated planning and construction of hydropower plants according to the agreement with India) has – amongst other factors – posed "unprecedented macroeconomic policy challenges" for the RGoB (GNHC, 2013a, 8).

2.4 Hydropower cooperation between India and Bhutan

A closer description of the Indian-Bhutanese electricity development cooperation allows an evaluation of foreign financing and its strings attached. As already mentioned, India basically took over the international representation of Bhutan until the kingdom itself became member of the UN. However, Bhutan and India still cooperate very closely on a variety of policy and economic issues, furthermore, Bhutan's currency (ngultrum, Nu.) is pegged to the Indian rupee. India was donating to Bhutan ever since its own independence in 1949 and its financial (and technical) contributions to the overall development of Bhutan are substantial:

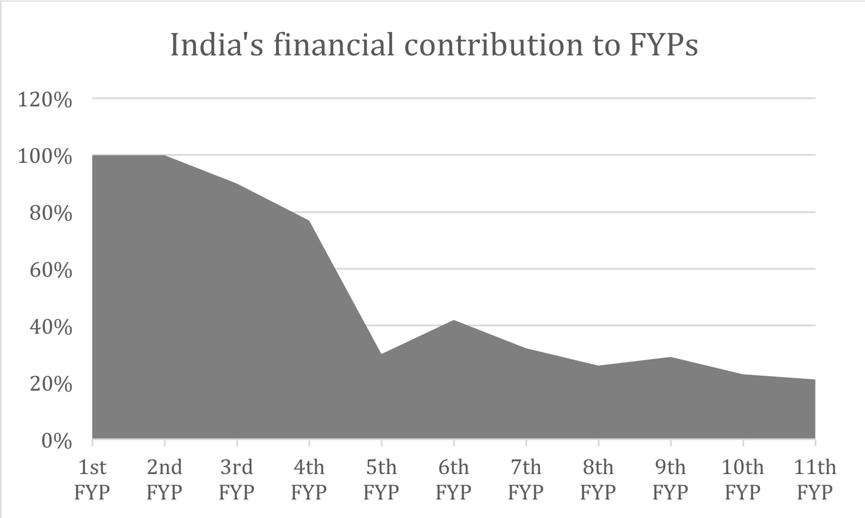

Fig. 7: India's financial contribution to FYPs (Premkumar, 2016).

This special bond between the two countries is valued on both sides and emphasized with regular high-level visits. India's premier Narendra Modi, for instance, visited neighboring Bhutan during his first foreign state visit in 2014, where he laid the foundation stone of the 600 KW Kholongchu hydropower plant site that was agreed upon in a bilateral agreement.

Concerning hydropower, the ever energy-hungry neighbour to the south, relies very much on the abundant energy potential of its developing neighbours Bhutan and Nepal. Since their Friendship Treaty of 1949, documents such as the Jaldhaka Agreement in 1961, or the agreement for the Chhukha hydropower plant in 1974 to the more recent umbrella agreement of 2006 and 2008 had one common goal: The advanced harnessing of Bhutan's hydropower. Although India's share to development activities is declining as multilateral partner, especially the Asian Development Bank and UN agencies, and other bilateral donors (eg. Austria, Japan, Norway) step up, Bhutan is expecting the relationship to mature. However, Bhutan seems to discourage from deviations off the status-quo. When the GoI, for instance, proposed to shift from bilateral inter-governmental project and financing schemes for hydropower development, the RGoB was hesitant at first (Premkumar, 2016).

While at a first glance the Indo-Bhutanese collaboration may seem more profitable for the latter, Tortajada and Saklani (2018) argue that this may hold true in absolute terms, but that the cooperation would be “significant” for India, too. Dhakal and Jenkins argue similarly, stating that “[t]he Chukha Hydel Project is an excellent example of bilateral cooperation in which both countries have gained economically” as Bhutan would not have been able to bear the financial risks alone whilst India received a low-cost reliable hydroelectricity source (2013, 124).

Premkumar (2016), however, notes that the modalities of agreements between India and Bhutan and the thereafter developed hydropower projects lack transparency in comparison to projects with other donors and project authorities are dominated by Indians in decision-making positions as well. As the planning, design and construction of such projects is also mainly handled by Indian agencies or contractors, Premkumar (2016, 26) remarks on the “quality of work of the consultants and contractors” which had come under question after several projects experienced gross problems.

Lean and Smyth (2014) examined the effect of hydropower consumption and trade on the economic growth in Bhutan in an augmented production framework and found, unsurprisingly, that electricity consumption and trade have an overall positive effect on economic growth in the long run.

3. Renewable electricity generating technologies in Bhutan

“Bhutan is amongst a few countries where hydropower is the main source of electricity.” (Dorji et al., 2012, 51). Given its abundant natural endowment with fast flowing rivers this does not surprise, however, the terrain makes it also technically extremely challenging and economically unfeasible to connect all households to a (national) electricity grid. Furthermore, Bhutan – in spite its immense hydropower potential – already faces generation and peak demand shortages during the dry season in winter (December – March) due to low water levels (ADB, 2014a). To achieve a 100% electrification rate and countersteer dependency on electricity imports, Bhutan has – tentatively – started to invest in alternative renewable energy sources.

Electricity has established itself as primary source of energy according to the BLSSR 2017: Even in rural areas, electricity is consumed by 98.3% of households for lighting purposes, in 92.5% of homes for cooking and 9.7% have an electric heater. However, the NSB Statistical Yearbook 2017 remarks that “domestic consumption of electricity has been marginal but should increase with the ongoing emphasis on Rural Electrification Programs” and hinted at the importance of the future exploration of “[o]ther forms of energy such as the solar, wind and biomass energy” (NSB, 2017d, 189). In this context, it is also noteworthy that the domestic electricity consumption per capita has declined from 2015 (2,804.3 kWh) to 2016 (2,673.1 kWh) almost reaching its 2013 level of 2,625.1 kWh (NSB, 2017d, 201). This has certainly also to do with the comparatively distinct decline in energy generation by the mini- and micro-hydels (which feature a drop from 16.014 GWh in 2015 to 11.027 GWh in 2016) although electricity generation by the large hydropower plants increased during the same period, namely from 7,731.14 GWh in 2015 to 7,941.843 GWh in 2016 (NSB, 2017d, 191f). The resulting discrepancy shows the necessity of local, independent electricity generation schemes in Bhutan due to the lack of a nationwide transmission grid.

It is therefore imperative to further diversify the energy supply in order to achieve an overall more reliable supply of electricity in Bhutan. Still, the 2005 Rural Electrification Master Plan “recommends renewable energy technologies (only solar and micro-hydro have been considered) to be used only in places where grid extension is practically impossible” (Dorji et al., 2012, 51). This seems to be outdated to some extent given the programmes included in the Eleventh FYP, especially the programme “Promotion and Development of Renewable/Alternate

Energy Technologies" that includes the promotion of biogas plants and solar water heating, biomass and wind projects – the total number of households connected to the grid, nevertheless, is planned to be increased.

The national peak demand in the first quarter of 2018 was 375.23 MW on 24 Feb 2018 (BPC, 2018b) and the national peak load for the year 2017 was 362.09 MW measured on 14 Nov 2017 (BPC, 2018a).

According to the NSB Statistical Yearbook 2017, a total of 7,953.58 Million Unit (MU) of electricity has been generated throughout the year 2016. The yearbook furthermore contains detailed data sets on the electricity generation and supply in Bhutan for the years 2012 to 2016, the type of electricity consumption and more information on the domestic energy consumption, the individual capacities of the hydropower plants from 2014 to 2016, installed diesel generation sets, the major transmission lines and the monthly revenue from electricity sales from the major hydropower plants, i.e. Chhukha, Tala, Kurichu, Dagachu (noteably absent Basochu I and II).

3.1 Hydropower

Bhutan's hydropower potential relies on five major river systems: the Mangdechhu, the Drangmechhu, the Punatsangchhu, the Wangchhu, and the Amochhu. Each is flowing from the Himalayan North southwards to eventually join India's Brahmaputra river. The year-round snow cover and glaciers in the North provide the rivers with water, however, during the dry period in winters, the water levels are regularly too low for enough hydropower generating, resulting in dependency on electricity imports (from India). Additionally, environmental threats like global warming and the resulting impact on the fresh water reserves endanger the system.

The environmentally and economically important water resources are protected by a series of policies that fall mainly under the supervision of the National Environment Commission (NEC) and are managed – according to the number of river basins – by five River Basin Committees (RBCs) as laid out in the NIWRMP. The committees each shall develop River Basin Management Plans (RBMP) and furthermore encourage community participation and the involvement of local bodies in the protection and use of rivers. So far, only the Wangchhu River Basin Committee's (WRBC) RBMP has been put forward. This is, however, "perhaps the most dynamic of the basins in the country considering the diversity of stakeholders in the use and management of its water resources” and also important for the hydropower sector given that the plants in the river basin, especially Chhukha and Tala, generate 47% of the total national revenues from hydropower (WRBC, 2016, iii).

The economic water security (which is important for agriculture, industries and the hydropower sector) is considered as one of five key dimensions of the Bhutan Water Security Index System (BWSIS) that is also applied on the local level. With scores of (close to) 2 of a scale of 1 (poor) to 5 (very good) in Bhutan and the Wangcchu river basin in 2016, it is obvious that there is much room for improvement. This is also expressed by the plotting of hydrographs against the flow requirements of Chhukha and Tala’s turbines: It was found that during the wet season (June – October) there is enough water to drive all six generators, but starting from November less than three generators can be operated and around February there may not be enough flow to drive even one. The RBMP therefore proposes the construction of hydropower reservoirs in order to storage water for lean periods and adapt to climate change despite being aware of the “negative side effects on the natural environment, such as inundation of land with decomposition of vegetation, interrupting the movement of migratory fish, changing the temperature and silt content of the water” as well as the risk for dams posed by the seismic potential in Bhutan (WRBC, 2016, 73).

All hydropower projects have to be in accordance with the *Bhutan Sustainable Hydropower Policy* of 2008 that stipulates rules concerning investment models, project ownership, mandatory definition and preparatory studies (DPS) by the (then) DoE (now MoEA) or other authorized bodies etc.

The Sustainable Hydropower Policy of 2008 also defines the following project classifications:

1. “micro-/mini projects”, i.e. with an installed capacity $\leq$ 1 MW,
2. “small projects”, i.e. with an installed capacity of $>$ 1 MW and $\leq$ 25 MW,
3. “medium projects”, i.e. with an installed capacity of $>$ 25 MW and $\leq$ 150 MW,
4. “large projects”, i.e. with an installed capacity of $>$ 150 MW and $\leq$ 1000 MW, and
5. “mega projects”, i.e. with an installed capacity of $>$ 1000 MW.

Bhutan’s hydropower potential is regularly indicated as being as high as 30,000 MW of which 23,760 MW are said to be technologically and economically feasible (RGoB, 2008). By the end of 2017, Bhutan’s hydropower plants donned a total installed capacity of 1,614 MW (see Annex I) which is close to 7% of the feasible potential. The projects proposed to be implemented until 2020 amount to a total installed capacity of 12,534 MW, which is more than half of the possible development altogether. Given the current progress (more accurately, delays) on all the projects, it is more than doubtful that Bhutan will have made use of half of its hydropower potential in two years’ time.

3.1.1 Hydropower plants

First hydropower plants established were small (micro- or mini-)hydels with capacities of less than 400 kW that were built to cater the basic need for electricity of urban centres, such as the capital, Thimphu, and other regional hubs.

The first larger hydropower plant planned was the already often mentioned Chhukha plant that commissioned in 1988 set the trend for future investments and plant designs. However, only during the Eighth FYP’s period other large hydropower plants were commissioned, namely the Basochhu I and Kurichhu hydropower plants in 2001 and 2002 respectively. This is mainly due to the long preparatory phases of such projects and the pilot character of the Chhukha plant (Dhakal and Jenkins, 1991).

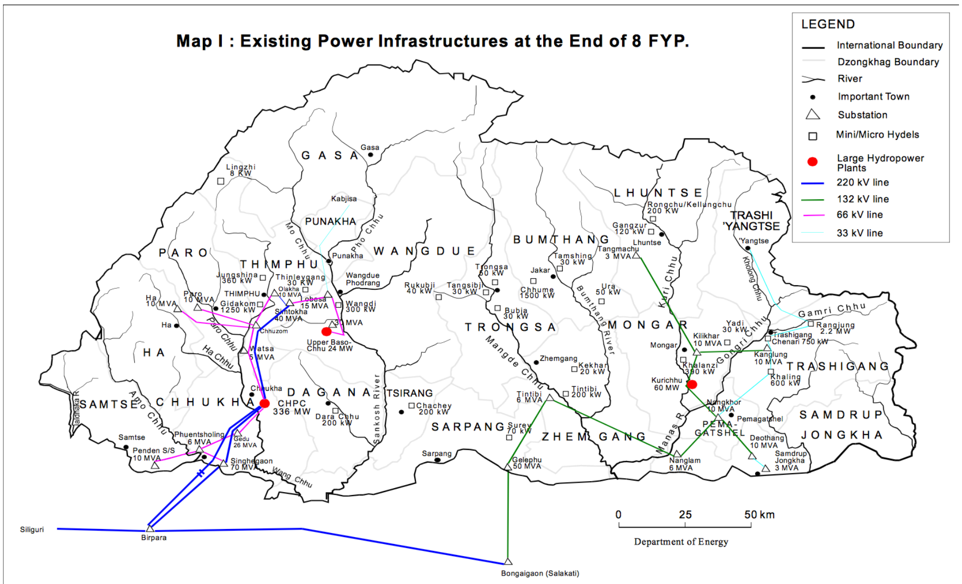

Fig. 8: Bhutan’s power infrastructure at the end of the 8th FYP anno 2003 (DoE).

The mico- and mini-hydels continue to hold high importance especially for the provision of electricity to rural households. This can be deducted by the decrease of domestic electricity consumption from 2015 to 2016 because of a considerable decline of electricity generated by the small hydropower plants (see above).

Furthermore, the micro hydropower plant at Chendebji (commissioned in 2005) was one of late micro-hydropower plant additions in Bhutan and yet one of the first small-scale projects registered under the Clean Development Mechanism (CDM) of the Kyoto Protocol. It was financed by the e7 Fund for Sustainable Development (a group of G7 countries' electricity utilities) which was also responsible for building the plant and providing training to the Trongsa District Administration and the Chendebji villagers who are responsible for the operation and maintenance of the micro-plant (Uddin et al., 2008; e7, 2005).

In the following, selected larger hydropower plants will be analysed as proposed future projects are oriented along those. A total list of all currently installed, operational hydropower plants is given in Annex I.

Chhukha is a run-of-river scheme on the Wangchhu river with a peak load capacity of 336 MW (4 x 84 MW) turbines. At the time of the project's planning, it was not believed that Bhutan would consume the generated electricity by Chhukha "even by the middle of the 21st century" (Dhakal and Jenkins, 1991, 2). This was, firstly, wrong (see also last quarter's peak demand of 375.23 MW) and secondly, not hindering the project – to the contrary. Chhukha was financed by India (60% as a grant and 40% as a 15-year loan carrying an interest of 5%) and built for India "with an energy buy-back arrangement for 99 years" (ibid., 3). However, domestic electricity demand sprung up to the point that power supply from Chhukha to the domestic market had to be capped by 2005 (Dhakal and Jenkins, 2013).

Around this time, the Basochhu plant, whose development was assisted by the GoA was fully commissioned. The Basochhu hydropower plant features two stages, the Upper Stage (Basochhu I) on the river Basochhu and the Lower Stage (Basochhu II) on the Basochhu and Rurichhu. The rivers were already identified as potential hydropower sources in the 1980s with preliminary studies and designs produced in the 1990s. The plant employs a total of 136 people although is fully automated using a micro SCADA (Supervisory Control and Data Acquisition) system from ABB that should, however, be replaced by GE India due to the “obsolescence of SCADA system and owing to the difficulties in obtaining technical support and spares” (DGPC).

Tab. 4: Salient Features of Basochhu I and II (DGPC).

	Basochhu I	Basochhu II
Capacity	2 x 12 MW	2 x 30 MW
Catchment area	162 km2	64 km2
Max. water level	1,788 m	1,443 m
Storage capacity		84,000 m3
Design Energy in 90%	105 MU	186 MU
Commissioning	2001	2005

The Punatsangchhu I plant is going to be the biggest hydropower generation facility (until other mega projects like Kuri-Gongri or the Sunkosh Reservoir are developed). However, the project is a negative example so far: Costs have seen an escalation by tripling, the dam was relocated after unprecedented floods in 2009, where works started before the new site was geologically assessed and found to be not supportive of a dam which led to remedy measures to stop the dam site to slide down. The summary of these financial, geological and technical challenges have led to considerable delays. The commissioning of the plant is now considered for 2022 instead of 2019.

A glance at the other projects planned until 2020 illustrates the eagerness of the RGoB to harness its hydropower potential, however, the complexity and possibility of errors increase correspondingly.

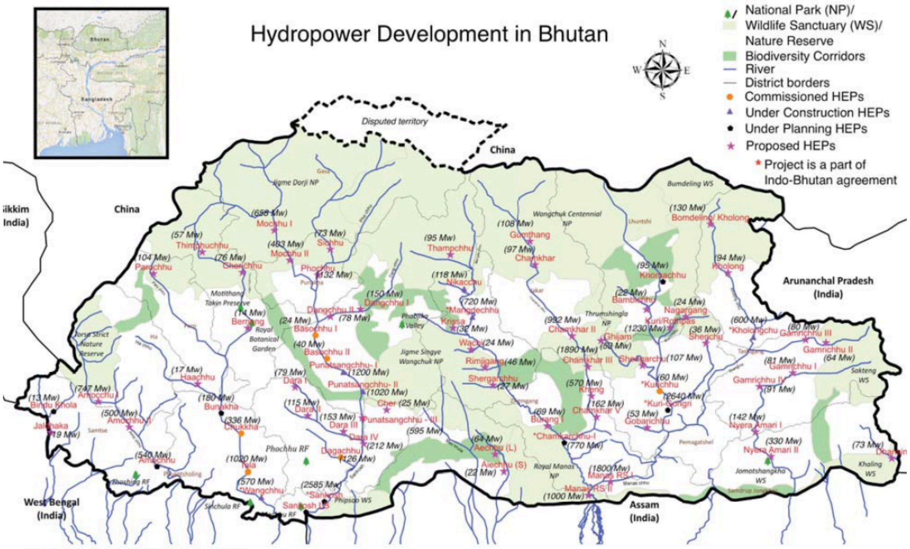

Fig. 9: Hydropower development in Bhutan (Vasudha Foundation; Premkumar, 2016).

3.2 Alternative renewable energy

Given the dimensions of newer hydropower plants as well as energy security and diversification considerations, alternative renewable energy sources have become an increasingly viable power source in Bhutan.

Although some scientific papers (Dorji et al., 2012; Lhendup, 2008) already have investigated the potential of alternative renewable energy generating technologies for Bhutan some years ago as well as the kingdom's development plans (such as the FYPs) and policies (like the *Integrated Energy Management Master Plan for Bhutan, 2010*; the *Economic Development Policy, 2016;* and even an *Alternative Renewable Energy Policy, 2013*) have formulated targets that should enhance the use of those sources, systems that exploit solar power, wind or biomass have not been established on a wider scale so far.

The RGoB has, however, taken sustained interest in alternative renewable energy sources as they, on the one hand, have no negative effects on the GHG balance and on the other, can enhance the energy security in terms of availability of electricity. Especially in most remote areas, where on-grid electrification is uneconomic as well as technologically unfeasible, electrification schemes based on alternative energy sources were introduced – with limited success so far.

3.2.1 Solar power

The first mentioning of solar power was in the Seventh FYP (RGoB, 1992), where it is indicated that its use is minimal and not very fruitful as some of the installed 271 panels on monasteries, schools and basic health units in remote dzongkhags would be non-functional anymore and the other examples, such as one village (Shingkhar in Bumthang) that was provided with solar lighting in 1991 and a trial operation of thermal solar power for heating water, further explain the limited scope.

As rural electrification was, however, a viable interest at the time, the solar power programme was continued and increased with a total of 1,316 solar panels installed by the end of the Seventh FYP (RGoB, 1998). Solar powering was considered an option where grid-connectivity would not be achieved for some time but not as generally applicable technology despite good sunshine hours in Bhutan.

The potential for solar power in Bhutan was scientifically assessed by a group of US scholars only in 2009 after the Rural Electrification Master Plan (JICA, 2005) found that 12% of households (a total of 4,400) would not be connected to the electricity grid but rather be served by micro-hydropower plants and solar home systems. Gilman et al. (2009) identified the annual *direct normal irradiance* (DNI), which is used by concentrating collectors that follow the direct sunlight, ranging between a daily 2.5 and 5.0 kWh/m^2 and the sum of direct solar radiation and diffuse solar radiation, i.e. the *global horizontal irradiance* (GHI), which amounts to 4.0 to 5.5 kWh/m^2 per day in Bhutan.

Therefore, larger solar power farms that would make use of DNI and be connected to a grid would find the best conditions in the high-altitude areas of the far north of Bhutan, which is, however, the most inaccessible and uninhabited part of the country. Furthermore, the authors note that “[a]nalysts generally consider an annual average DNI estimate of less than 6.0 or 7.0 kWh/m^2/day to be insufficient for development of utility-scale, grid-connected, concentrating solar power systems.” (Gilman et al., 2009, 5).

Flat-plate collectors, though, can be used in most areas of Bhutan as they exploit the GHI. Those solar panels are usually installed at latitude tilt (i.e. tilted at an angle equal to the latitude at the collector), the map in Fig. 10 shows the resulting GHI. Again, the northern regions feature the best provisions, but also the surroundings of the western-central towns of Paro and Wangdue keep up.

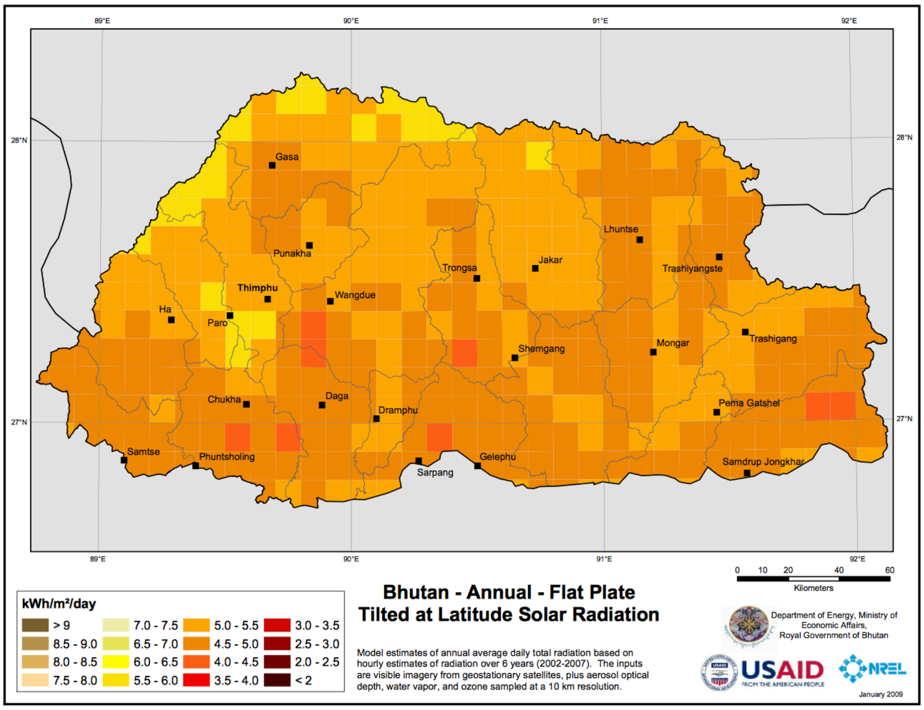

Fig. 10: Annual GHI for flat-plates tilted at latitude (National Renewable Energy Laboratory).

The peak solar season was found to be between May and July, whereas solar resources are low between November and January (ibid., 13). This is somewhat, yet not fully, complimentary to the hydropower season which experiences its lowest in February whilst its peak period commences in June (WRBC, 2016; ADB, 2014a).

Also Dorji et al. (2012) and Lhendup (2008) stress that the success of a solar scheme (but really any renewable energy scheme) is very much dependent on the location, thus site-specific. The previous inadequate data availability was one of the reasons why solar electrification systems often failed, as solar radiation was estimated at a fixed 4 kWh/m^2/day without regard for seasonal and geographical alterations (Dorji et al., 2012, 53).

Other reasons that hampered the effective use of solar power according to Dorji et al. (2012) were the lack of (locally based trained) service and maintenance back-up, excessive use (eg. solar lighting systems being used for entertainment purposes), or also the lack of a systematic solar electrification (eg. on-grid connections established shortly after a solar electrification).

Still, the Eleventh FYP reports that solar PV is contributing 152 kW to the overall renewable electricity generation and states the existence of 10 solar heating systems (GNHC, 2013a, 191f). And according to the director of the MoEA's Department of Renewable Energy, Bhutan plans to generate 5 MW from solar power in the near future by creating a large-scale solar farm at Shingkhar in Bumthang (Palden, 2017). The feasibility of this project is yet to be determined (Gilman et al., 2009, excluded Bumthang as no land there met the development criteria for projects with >1 MW PV production potential), however, it is definitely a reiteration of the *2013 Alternative Renewable Energy Policy's* minimum target for solar electricity generation of 5 MW by 2025 (RGoB, 2013, 6).

3.2.2 Wind power

As with solar power, wind power has long been overshadowed by Bhutan's hydropower development. By 1992, there were only small systems like a Swiss Project Farm in Jakar, Bumthang, where wind power was used for battery charging and in the Centre for Agriculture Research Development in Wangdiphodrang wind power was installed for irrigation (RGoB, 1992).

The study by Gilman et al. (2009) has also assessed the potential wind resources in Bhutan. The study found the Wangdue, the Lhuntse/Mongar, and the Chhukha valleys to be the valleys with the most wind potential. Especially Wangdue valley "is a good candidate for more wind studies". It was, indeed, at Rubessa in the Wangdue valley where the RGoB, with financial assistance by the ADB, planned and developed the "Pilot Wind Power Project". Two wind turbines of 300 kW each, began producing electricity in 2015.

3.2.3 Biomass and –gas

Although priority is given to solar and wind power (RGoB, 2013, 16), the *Alternative Renewable Energy Policy* also names biomass as to be included in the resources mapping process. By 2013, 900 biogas plants were established throughout Bhutan (GNHC, 2013a). The same year, the RGoB and UNDP introduced the *Sustainable Rural Biomass Energy (SRBE) project* with the support of the Global Environment Facility (GEF) that ran until 2015 and aimed at promoting the use of biomass resources for cooking, heating and lighting in rural areas in clean cook stoves and included the education on the maintenance thereof. The target for the energy potential of biomass was indicated with 10 kW in the Eleventh FYP (RGoB, 2013a).

Biomass, particularly fuel wood, is still widely used amongst the rural population which continues to rely on traditional cooking stoves even when access to electricity is given (Wangchuck et al., 2017). The focus has long been on limiting the use of biomass, which apart from fuel wood includes crop residues, animal dung and municipal solid waste, due to inefficient cook stoves' effects on human health and forest conservation concerns. However, now, biomass enters the discussion under the headwords *energy diversification* and *energy security* and is also promoted as viable alternative energy source (Siebert and Belsky, 2015; Namgyel, 2016).

Biogas plants were first established in the 1980s during the Sixth FYP's spotlight on rural electrification projects, however, most have been abandoned due to maintenance and repair issues resulting from poor technical designs (MoAF, 2012). Within the framework of the ADB supported *Rural Renewable Energy Development* (that included also off-grid solar projects and aforementioned wind pilot project), biogas plants were again proposed mainly to dairy or cattle farmers (ADB, 2016).

3.3 Electricity transmission and distribution grid

As indicated above, previous development plans envisioned the use of alternative energy sources only in cases where a connection to the grid was virtually impossible (Dorji et al., 2012; Lhendup, 2008). The continuous extension of the transmission grid was therefore a development priority, at the latest since the development of the Chhukha hydropower plant that needed lines to export surplus electricity to India.

According to the NSB's Statistical Yearbook of 2017, Bhutan had 74.143 km of D/C 440-kV, 182.033 km of S/C 220-kV and 143.005 km of D/C 220-kV, 344.534 km of S/C 132-kV, 301.066 km of S/C 66-kV and 47.769 km of D/C 66-kV of "major transmission lines" at its disposal in 2016 (NSB, 2017d, 195ff). This excludes, however, the 11-kV and 33-kV distribution lines that are more important with respect to rural electrification. These are given in the map below (Fig. 11) that was prepared by the MoEA for the grid-based projects of electricity access in the Tenth FYP.

This BPC's project, R*ural Electrification Project for Clean Energy, Better Living and Sustainable Growth in Bhutan*, which was conducted during the Tenth and Eleventh FYP was also registered under the CDM aimed exclusively at the rural electrification of villages by 11-kV and 33-kV grid extensions. The villages covered were among the 1,268 non-electrified villages identified as targets for grid-based rural electrification by the REMP and had either no access to electricity and therefore used kerosene, diesel, LPG and/or candles for lighting, heating etc. or relied on stand-alone diesel-fired generators (BPC, 2014).

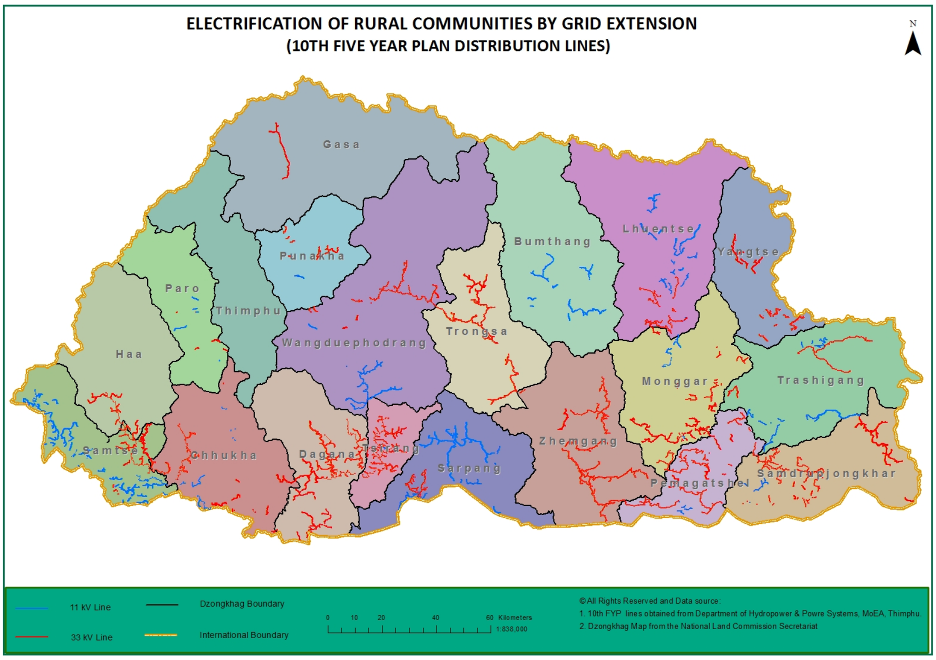

Fig. 11: Rural grid extensions (MoEA).

Corresponding to the NSB’s Statistical Yearbook, the National Transmission Grid Master Plan (NTGMP) which was compiled by India’s Central Electricity Authority (CEA) does not elaborate on distribution lines or the rural electrification programme. But the extension of the national transmission grid naturally also benefits the overall population. The proposed lines are in line with the generation of hydropower for the purpose of export to India and thus strongly orientated versus the south of the country.

To avoid unnecessary environmental impacts, the transmission lines proposed in the NTGMP are directed along already existing corridors, if applicable.

However, as indicated below, some transmission projects enter protected areas or biological corridors which leads to the assumption that the rate of disapproval of certain lines might increase. Already now, objections against transmission lines in protected or scenic areas have been raised and even led to the removal of two transmission lines because they were blocking a scenic view for the Dochula pass and the Jomolhari trek (World Bank Group, 2016).

The current regulations do not explicitly include the necessity of an impact assessment of transmission lines on tourism relevant aspects (scenery, property value of surroundings, habitat or biodiversity). These aspects, however, have become increasingly important as tourism became a substantial source of revenue in Bhutan and thus might become fault lines in future development projects.

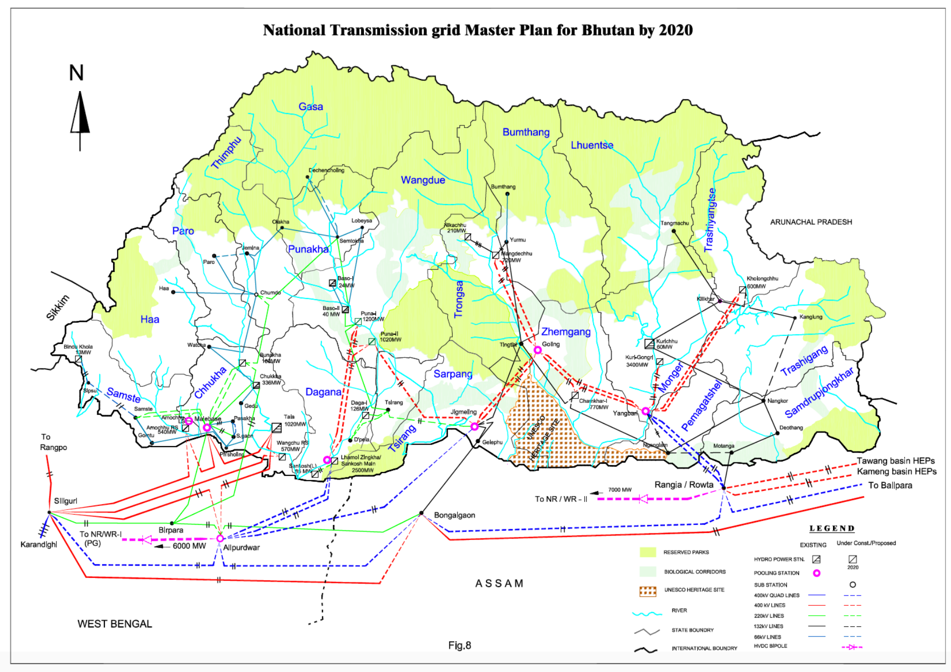

Fig. 12: National Transmission Grid Master Plan for Bhutan by 2020 (CEA, 2012).

4. Impacts of Bhutan's rural electrification

"Energy access is the "golden thread" that weaves together economic growth, human development and environmental sustainability." (IEA, 2017, 11).

Therefore, the socio-economic and environmental impacts of Bhutan's rural electrification are explored in this chapter as the philosophy of GNH conveys considerable weight to both, the Bhutanese's wellbeing and the preservation of nature. To this extent, the current status-quo of access to electricity but also the future development of energy generating schemes are considered, especially respecting large hydropower plants.

4.1 Impacts on the environment

The investigation in impacts on the environment by power projects in Bhutan is predominantly important also with regard to the sustainability of the renewable energy generating schemes themselves, or as the Tenth FYP (2008a, 113) put it: The "country's main watersheds will in the long term determine the sustainability of the hydropower projects. The key challenge will thus be to develop hydropower projects in an environmentally friendly and sustainable manner and doing it efficiently and in a cost effective [sic!] manner." This statement is surely equally true for all other power projects, although one could suspect that with the decade-long experience in hydropower development and their increasing volumes, authorities are more sensitised in this domain.

After the first large hydropower plant, Chhukka was commissioned in 1988, the Seventh FYP (RGoB, 1992) introduced the concept of *Environmental Impact Assessments*. However, only in 2000 the corresponding legislative act, namely the Environmental Assessment Act (EAA), was stipulated which excluded the Kurichhu and Tala hydropower plants from an EIA as the development works there had already started. The EAA requires an Environmental Impact Assessment (EIA) to be conducted for power projects or transmission line projects. The process is regulated by the NEC which has to grant the "environmental clearance" if the "effects of the project on the environment are foreseeable and acceptable (…) [t]he project, alone or in connection with other programs or activities contributes to the sustainable development of the Kingdom and the conservation of its natural and cultural heritage" (RGoB, 2000, 6). However, the individual environmental clearances, i.e. for land acquisition, road development or widening, for quarries, or the removal of vegetation, are to be obtained from the respective responsible authorities, i.e. the National Land Commission Secretariat in the first case, the

Department of Roads in the second, the Department of Geology and Mines in the third, and the Ministry of Agriculture and Forests (MoAF) in the last. Furthermore, “concerned people” have the right to due process of law as adequate attention has to be paid to their interests.

No environmental clearance was needed for projects like the initiative for *Solar Home Lighting Systems* (SHLS) assisted by the ADB as there were no significant environmental impacts during construction or operation to be expected (DRE, 2016). Nor can EIA reports be found on the micro- and mini-hydel development as most of those smaller hydropower plants were constructed before the implementation of the EAA.

The meaningfulness of EIAs is, however, doubted by some including the World Bank Group (2016). Premkumar (2016), for instance, too, criticises that the environmental (and social) impacts’ screening happens only after the signing of hydropower implementation agreements with India. This would “reduce (…) regulatory processes, impact analysis, and consents and clearances from ministries to become inconsequential proceedings.” (Premkumar, 2016, 31). He furthermore puts forth substantial critique on the EIA’s content (for hydropower projects under Indio-Bhutan agreements), stating that “Indian organizations such as the South Asia Network on Dams, Rivers and People (SANDARP) have critiqued WAPCOS [note from the author: an Indian consultancy agency] for substandard work, manipulation of information and underassessment of impacts.” (ibid.).

This argument is also supported by the finding that most EIAs of hydropower projects take simple approaches concerning the hydrology of the concerned water body instead of a multilayer approach which was also laid down in the Environmental Assessment Guidelines for Hydropower Projects of 2012 (World Bank Group, 2016).

Additionally, and departing from international good practices, EIAs are often not made publicly available after the environmental clearance was obtained (World Bank, 2016; Premkumar, 2016) which impedes the participation of interest groups or individuals. Furthermore, there are no regulations on the modalities of these disclosures (i.e. on the language, location or medium) (World Bank Group, 2016).

One reason for these concerns surrounding the EIA that is also found by the World Bank (2016) could be that the NEC lacks the institutional capacity to monitor and enforce mitigating measures for adverse environmental impacts given the scale of planned hydropower development in Bhutan according to the ADB's Energy Sector evaluation study of 2010 (ADB, 2010b).

Generally, environmental impacts of power projects can be classified according to their *timely occurrence* (during construction and/or operation), according to the *affected habitat* (aquatic or terrestrial ecosystems, flora and fauna, etc.) and according to the *type of infrastructure* (auxiliary infrastructure such as roads, sanitation etc., transmission lines, and the power plant itself).

Another aspect that must be considered is the resilience towards natural disasters, especially ones related to climate change such as Glacial Lake Outburst Floods (GLOF), floods, landslides and droughts. As the ADB states it: “In Bhutan, climate adaptation and climate-resilient development are more important than meeting climate mitigation commitments.” (ADB, 2014b, 3). Interestingly enough, Bhutan's hydropower plant authorities make use of its hydropower under the CDM's provisions and applies for certified emission reduction credits – with mixed success (Premkumar, 2016). Nevertheless, a total of 4 projects have been included, among them the Dagachhu plant which the world's first cross-border project to receive carbon credits under the Clean Development Mechanism in February 2010, as well as a micro-hydropower plant project (Chendebji), the grid-based rural electrification programmes of the Tenth and Eleventh FYP and the Punatsangchhu-I project.

The Ninth FYP put the RGoB assessment of environmental stressors like this:

> *“With the rapid pace of economic development, pressures on the natural environment continue to increase and are fuelled by a complex array of forces. They include population pressures, agricultural modernization, hydropower and mineral development, industrialization, urbanization, and infrastructure development.”* (RGoB, 2003, 30).

Power related activities contribute to land use land cover changes (LULCC) as infrastructure (“built-up areas”) increases, land degradation as soil and water bodies erode which could have effects on the GHG inventory and air quality as forests, typical GHG sinks, decrease. Furthermore, power infrastructure could hinder fish migration or curtail animals' habitat through river and land fragmentation. And especially during construction periods, heavy dust and noise pollution from increased transport and building activities affect humans as well as the flora and fauna. These will be assessed in the following.

4.1.1 Land use change, land degradation

Bhutan is heavily forested which is also due to the constitutional stipulation that two thirds of the country shall be covered with forests (cf. Art 5 para 3 Constitution of the Kingdom of Bhutan). This benchmark is currently even over exceeded (see above), however, Yangchen et al. (2015) who have analysed the LULCC in Bhutan from 2000 to 2013 based on (low resolution) remote satellite imaginary from Landsat found that during the evaluated period built-up areas had increased from 4% to 14% and vegetation and agricultural areas have also increased to the expense of bare land until 2006 but then started to decline. These changes are attributed to increased urbanization and expansion of infrastructure whereas the share of lakes stayed the same. Also Gilani et al. (2015) support these findings, stating that forest areas increased over the evaluated period of 1990 – 2010 at an equivalent average annual growth rate of 59 km^2/year (0.22%). However, they find the change in built-up area "negligible" with an increase of 0.18%, and information on water bodies, barren areas and snow and glacier covers highly seasonal (Gilani et al., 2015, 96f). It is indicated that increased use of alternative energy resources in lieu of fuel wood from the woods may have contributed to this effect, however, they also mention that hydropower projects "post a threat to flora, fauna and habitat (…), as well as to the surrounding LCLU." (Gilani et al., 2015, 97).

Of the larger hydropower projects implemented till date, only the 60 MW Kurichhu plant features a reservoir based scheme. Yet, four projects planned under the 2006 umbrella agreement with India are large or even mega reservoir-based projects that will result in large LULCC (i.e. the 180 MW Bunakha, the 2560 MW Sunkosh, the 2640 MW Kuri-Gongri and the 540 MW Amochcu plants) that together with the other projects in the pipeline will increasingly encroach protected areas and biological corridors (World Bank Group, 2016).

And as a LULCC assessment of Premkumar (2016) shows, already established run-of-river hydropower plants have severe impacts though not so much on LULCC but on land degradation: "In the case of the River Wangchhu, the land-use change map reveals that a 10 km stretch from the Chhukha headrace tunnel and another

25 km stretch from the Tala headrace tunnel are practically dry with very limited water flow." (Premkumar, 2016, 35).

4.1.2 Land and river habitat fragmentation or loss

Any new power project except for the installation of solar systems that are mostly attached to already existing buildings, includes the erection of infrastructure. In the case of hydropower plants this immediately concerns the respective rivers and river banks but has also implications up- and downstream and thus on the potential habitat of aquatic organisms through the fragmentation or destruction of their habitats.

Therefore, hydropower plant designs usually include fish ladders that should enable the migration of fish over concrete structures to the other side of the dam site. The Water Regulation of Bhutan of 2014 requires fish passages or other measures that allow the migration of fish. However, so far, fish ladders have not been successfully implemented in Bhutan's larger hydropower plants: "The fish ladders constructed at the Kurichhu and Dagachhu dams failed to transport fish across the dams. The height of the dam is too high (…). The designs for Punatsangchhu I, Mangdechhu and Punatsangchhu II do not even include fish ladders." (Premkumar, 2016, 32).

Premkumar (2016) states further that the – IUCN Red List listed – critically endangered White-bellied Heron (Ardeainsignis) is under threat of extinction in Bhutan because of the Punatsangchhu I and II hydropower plants' development, which are in close proximity to their habitat, the rivers Dikchhu and Hararongchu, as well as reiterating concerns about the breeding and migration of the golden mahseer and Deccan mahseer. Furthermore, "[i]n 2013, *International Rivers* reported that illegal riverbed mining for the construction of the Punatsangchhu HEP has affected [the] breeding of Ruddy Shelduck." (Premkumar, 2016, 32).

The current praxis was to rather create fish nurseries and thus base the protection on quantity than to invest in the maintenance of fish migration (World Bank, 2016).

The World Bank Group (2016) estimates that if all projects at the prefeasibility and reconnaissance stage from Bhutan's Power Master Plan are realised, the free-flowing river network of Bhutan that currently stands at 90% could be reduced to 50%.

To analyse the water quality, i.e. the degree of (organic) pollution, eutrophication, land use of the floodplain or the hydromorphological degradation to which hydropower development can contribute, it is common to use benthic invertebrates which are highly sensitive to changes. For Bhutan, Korte et al. (2010) and Giri and Singh (2013) conducted such surveys. However, only Korte et al. (2010) referred to the hydromorphological status whilst Giri and Singh (2013) concentrated their research on the physical, chemical and biological parameters and LULCC.

However, given the “[l]ack of baseline data to properly assess the impacts on natural habitats, especially aquatic ecosystems” (World Bank, 2016, 27) more information is needed for a meaningful assessment of hydropower projects’ effects on the water (body) quality.

On land, the development of surrounding infrastructure such as roads, but also transmission and distribution lines can lead to the fragmentation or destruction of habitat. Whilst transmission and distribution lines as such are neither polluting the air, water or land, considerable impacts on the environment occur especially during the construction phase of such infrastructure.

Due to Bhutan’s geographical prerequisites, especially its steep valleys, the terrestrial footprint of hydropower plants, also large reservoir-based ones, “is likely to be small” (World Bank, 2016, 33).

4.2 Socio-economic and political aspects of the rural electrification

Given that by 2005 still 69% of all Bhutanese lived in rural areas, rural electrification can be considered a key policy to provide large portions of the population with a basic modern amenity.

By the late 1990s, fuel wood was the first and often only available or affordable energy “choice” for more than 75% of the people. The collection of fuel wood is not only time-consuming but also a tedious yet strenuous task for humans and can be a stress factor for forests if carried out unmanaged. Although voices have emerged that urge for the increased forest utilization and coordinated management of fuel wood sources by promoting the clean and green character of wood as a source of energy (Siebert and Belsky, 2015; Namgyel, 2016) and some that even promote domestic charcoal production (Feuerbach et al., 2016), the focus of the RGoB has been on increasing the share of electricity also for rural consumers.

An assessment by the ADB, investigating the impact of two of its projects under the question whether electrification would improve the quality of life, found that “electrified households enjoy a better quality of life”, however, impacts would be modest as household consumption of energy is low (ADB, 2010a, iii).

Electricity is a multiplier with regards to development and has various spill-over effects like the creation of roads. In the following, aspects like health, education, prosperity and self-determination as well as displacement and the competition facets of Bhutan's rural electrification schemes are discussed.

4.2.1 Health

As pointed out above, the main source of energy for most Bhutanese was fuel wood. And although most villages have nowadays access to electricity via one or the other renewable energy based scheme, the use of traditional stoves powered by fuel wood is still high in rural areas as some of the primary cooking activities cannot be carried out on a modern electrical stove (Wangchuck et al., 2017).
However, Wangchuck et al. (2017) have conducted a pilot study based on four typical stove types (i.e. a metal chimney stove called "bukharī", two mud stoves and an open stone tripod stove) and measured pollutants' concentrations and emission rates of indoor biomass cooking and heating. They found that "[i]n all the houses, concentrations of all the pollutants [note from the author: i.e. $PM_{2.5}$, particle number, CO_2 and CO] were significantly higher during the activity than the background levels (on average by a factor 40 and 18 for PM2.5 and CO, respectively) and after activities have ceased (…)." (Wangchuck, 2017, 164).

Exposure to these pollutants is higher among women and children who spend more time inside kitchens. The findings of the pilot study highlight the serious health issue that consumers of traditional stoves face. Apart from the promotion of other energy sources, improved cooking stove designs and the education on proper maintenance as well as adaptation of household practices could help in reducing risks for respiratory diseases. The Ministry of Health (MoH) records common colds, acute pharyngitis/tonsillitis, pneumonia, asthma and other respiratory & nose diseases under the header respiratory diseases. The numbers have stayed pretty much constant over the past 10 years (see Fig. 13).

However, life expectancy rose considerably having reached 70 years for males and 71 years for females (WHO), indicating the improvements in quality of life (see Fig. 14).

Yangka and Diesendorf (2016) have gone a bit further and conducted "the first ever integrated long-term energy system modelling in Bhutan" (494) that quantified the benefits of electrical cooking's expansion at the expense of kerosene and fuel wood in quantitative terms and reductions in CO_2 (- 17%), SO_2 (- 12 %) and NO_x (-

8%). They identified the following limitations to the use of electricity for cooking though: higher costs for cookers and energy source.

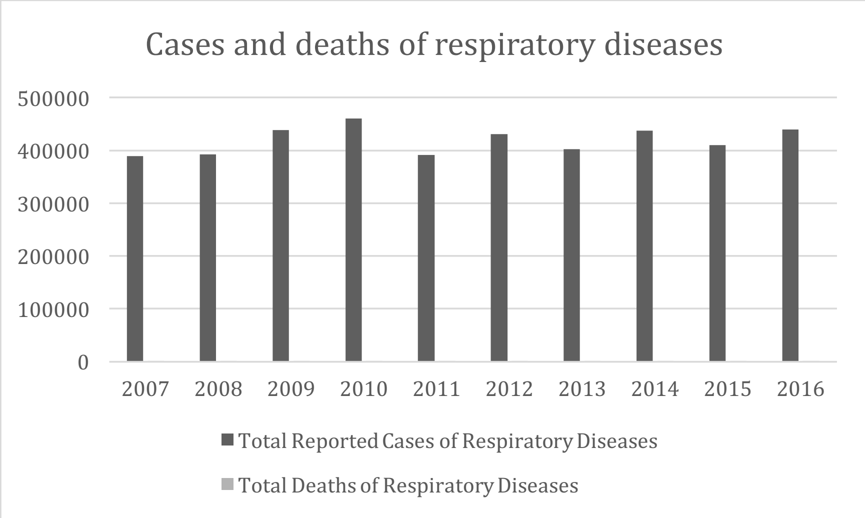

Fig. 13: Cases and deaths of respiratory diseases (MoH).

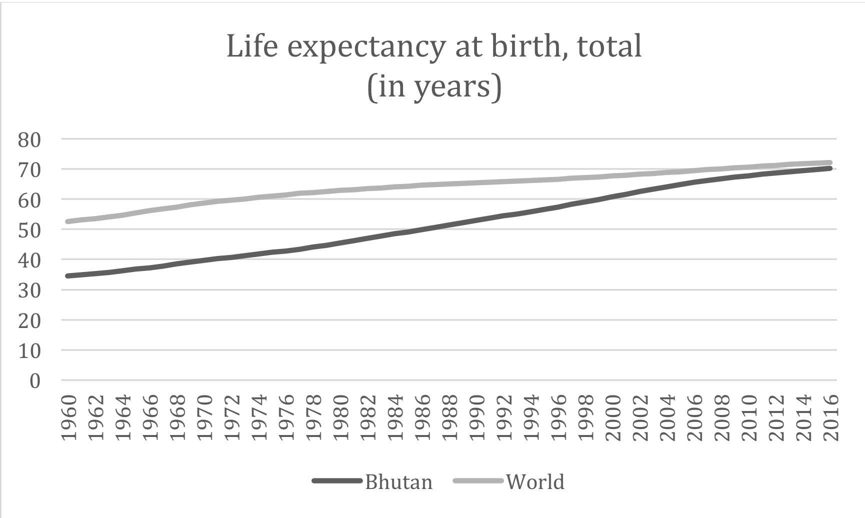

Fig. 14: Life expectancy at birth in Bhutan and worldwide (World Bank).

Other improvements in the health sector by rural electrification was the access to electricity of basic health units which can be consulted free of charge by all Bhutanese by virtue of the Constitution's Article 9 Section 21. Both, modern and traditional medicine treatments are compromised. Accompanying the first, vaccines and medicine are now kept refrigerated in these local health units making trips to central hospitals unnecessary as well as the extended opening hours of health centres due to electric lighting do (ADB, 2010a).

4.2.2 Education, income and prosperity

The inherent challenge of impact assessments is to overcome selection bias which in the case of electricity access are the “endogeneity of program placement and household adoption of electricity” (ADB, 2010a). The ADB impact assessment study’s authors have analysed selected quality-of-life indicators in three ways: comparison of means, regression, and propensity score matching (PSM). The results suggest that electrified households reap higher percentage increases in income, children from electrified households attend school longer and women in electrified households hold more significant roles concerning the decision-making (ADB, 2010a). Considering the higher household income, however, only non-farm income achieved statistically significant increments and as most of Bhutan’s rural population depends on farming activities, the impact can be “considered modest” at best (ADB, 2010a, 11).

An analysis the other way around was conducted by Rahut et al. (2016) who have analysed the household energy choice and consumption intensity for Bhutan and found empirical evidence that the households’ choice of energy is driven by the following factors: income level and household wealth, age, gender and education, access to electricity, and location.

These findings imply that with increased income and accessibility, more people will choose electricity as an energy source which in turn has policy implications itself. Furthermore, it is suggested that households with female or older heads are more likely to choose clean energy sources instead of fuel wood (Rahut et al., 2016, 1008). However, more fuel wood is used if children under 15 years are living in a household which hints at children’s role in collecting fuel wood or cow dung.

On the bigger picture, policies like the *Economic Development Policy 2016* stipulate the mandatory engagement of local firms by foreign contractors if the latter want to participate in the construction of hydropower plants to ensure the transfer of technology and skills and indicate preference to local experts and women in technical capacities. Furthermore, “[t]he Royal Government shall promote the development of hydropower related activities such as consultancy and construction services, manufacture, repair and maintenance of hydropower components. Linkages shall be developed between the energy sector employers and tertiary and vocational institutes to build local capacities." (RGoB, 2016, 17)

So far, the implemented larger hydropower plants resulted in the regular employment of 1,581 people according to the DGPC plants' profiles and the Dagacchu directory which are both accessible online. Premkumar (2016) states that the Kuricchu and Tala hydropower plant respectively employ "predominantly Bhutanese citizens". In the case of the smaller micro- and mini-hydropower projects, direct employment is extremely limited. The e7 financed 70-kW plant in Chendebji for instance is operated by just one local villager and assisted by the BPC (e7, 2005, 7). Overall, 4,260 people were employed in the electricity & gas supply sector in 2016, out of which Bhutanese nationals (3,788) outweighed foreign workers (472) significantly (NSB, 2017d).

According to the World Bank Group (2016, 45), however, most of the construction jobs due to hydropower projects "have gone to foreign workers (over 22,000 foreign laborers in the hydropower construction sector)."

Given the positive association of several socio-economic factors and the choice of energy source, it is imperative to increase the possibility of access to electricity as well as opportunities for economic activities. Still, the rural electrification schemes so far featured only limited evidence of the direct link between rural electrification and an increase in production. Only small-scale microenterprises such as shops have been established. As most of rural Bhutanese depend on the sale of agricultural and livestock products, very few households use electricity directly for income-generating purposes (ADB, 2010a).

4.2.3 Displacement and multi-purpose conflicts

The current rural electrification schemes were mainly based upon small-scale power projects for which no resettlements were necessary. This aspect is therefore mostly relevant with regard to the large and especially upcoming mega hydropower projects – which themselves were not explicitly part of Bhutan's rural electrification programmes, can, however, be seen as drivers for the extension and creation of national transmission grids that feed into the grid-based access to electricity in rural areas.

The World Bank Group (2016) gives an account of land and households affected by currently developed or planned hydropower plants, including the Punatsangchhu I for which 5 households must relocate. Premkumar (2016) did not have access to this data and further states that, information concerning the social impacts of Chhukha and Kurichhu hydropower plants is nearly non-existent.

The 5 households identified during the Punatsangchhu I EIA are furthermore identified as a “vulnerable” group as they not only would lose their land but also their houses. Premkumar (2016) based his finding of 116 families that are likely to lose cultivated land for Punatsangchhu I on the focus group discussions held in field in September 2015. During those “the people from the project-affected areas asserted that the district authorities did not seek their consent before acquiring their land for the hydropower projects” (Premkumar, 2016, 37).

For those affected of displacement, the Land Act of 2007 gives a choice between monetary compensation and substitution land in return for the land acquired from them, however, only if more than 0.01 acre or <0.004 ha of land are lost, otherwise the only option is monetary compensation (World Bank Group, 2016). In praxis, the private land affected by development projects is acquired by the RGoB which then leases it to the project authority. In case of substitution land awarded, the often challenging terrain thereof necessitated land preparation and implied production delays that – not compensated – led to losses in the past (World Bank Group, 2016; Premkumar, 2016). Furthermore, the compensation rates granted according to the Property Assessment and Valuation Agency (PAVA) are “considered low given that the market value of land has increased significantly since 2009” when the current rates were set (World Bank Group, 2016, 41).

Additionally to the compensation in land or money, the respective hydropower projects have implemented different direct livelihood support measures, such as free units of power for land acquired, community development by roads and other infrastructure etc. (World Bank Group, 2016).

Whilst the overall number of relocations and resettlements have been minimal so far, the upcoming mega hydropower projects and their cascading effects will increase the dislocation of people.

The use of water resources for power generation generally evoked management issues especially as the natural resource is also covering other basic needs notably drinking water but affects also other economic sectors like agriculture and industries (“multi-purpose conflicts”).

Premkumar (2016, 32f), who conducted interviews in the field, for instance, reports that affected communities in the case study areas (i.e. Chhukha, Kurichhu, Tala, Punatsangchhu I and II as well as Mangdechhu – the latter three as construction areas) indicated “that spring waters, which were traditionally used for household and agricultural purposes, are gradually reducing while surface sources such as ponds are drying up at rates much faster than recharge of water sources is taking place.”

To avoid conflicting interests, water management has become an increasingly important tool in Bhutan (as analysed above). With regards to multi-purpose conflicts, the idea that reservoirs could be used for several purposes was rejected in the water management plan of 2003, however, the NIWRMP of 2016, “found four locations that may have potential for building a (multi-purpose) reservoirs (Haa, Burichhu, Yunari, and Nikachhu)” (NEC, 2016, 32).

5. Conclusion

This master thesis aimed at tracing Bhutan's path of rural electrification based on its development policies and an analyse thereof in terms of socio-economic and environmental impacts as to evaluate if the programmes were successful and which parameters enabled this in order to implement strategies of rural electrification by renewables elsewhere in the world.

Generally, it can be said that the rural electrification efforts by the RGoB are remarkable and follow a sustainable vision by having focused on the electrification by renewable energy sources from early on. In this context, the degree of the RGoB's ownership in terms of strategy development and implementation measures is worth mentioning as particularly outstanding. This was further facilitated by long-term financial and technical support from bilateral donors, especially India, and other multilateral institutions, particularly, the ADB. Their support's continuity and predictability enabled the RGoB to formulate concise rural electrification targets.

On a closer examination, however, inefficiencies were detected. These were to a large extent conditional on the lack of skilled and educated workforce in almost all sectors and capacities involved in rural electrification, notably in the early years. The structural prerequisites that have been forged over the decades, have led to largely foreign contractors, agencies and workers being employed, especially in projects developed with India. Other socio-economic benefits such as increased income have not materialized abundantly from access to electricity as most of the rural population still depends on (subsistence) farming.

The impact assessment on the ecology and environment is seriously hampered by the lack of baseline data concerning biodiversity and habitats. Furthermore, the process of the EIA is worthy of improvement and must be complied with more stringently, especially with regard to the assessment of the provided information's quality and adherence to international standards, calculations and best-practises.

Also, the involvement of the affected population by increasing the transparency of projects could be augmented.

Given the excessive and accelerated development of large and mega hydropower plants in the future, the cumulative socio-economic and environmental effects are yet to be seen. However, based on the analysis of Bhutan's rural electrification progress in this master thesis the following policy recommendations seem adequate:

In light of the anticipated increased hydropower plant development's necessity of resettlement of rural population and the concomitant increase in their land's value, the relevant legislative acts and policies should be updated to reflect a fairer compensation of people that lose their land and/or homes.

Whilst current visions include the maximisation of power plants in terms of installed capacity, investment volume etc., the RGoB should also reiterate the successful implementation of smaller, decentralised or even off-grid solutions especially in the solar PV and solar thermal sector where Bhutan achieves the necessary sun hours as well as considering biomass and biogas technologies. This is imperative, as rural electrification is also seen as one way of reducing the rate of urbanisation because modern amenities thus become available in rural areas enhancing the living conditions and granting opportunity for increased societal interaction. Excessive grid extensions could, however, be rendered in vain, given the continued trend of urbanisation. The RGoB should therefore, concentrate electrification efforts on off-grid solutions and stand-alone systems in the most remote parts of the country.

In order to convince the rural population of the numerous benefits of electrical energy in comparison to other energy sources, the awareness amongst people has to be increased. The studies analysed here, suggest that women are more likely to agree with the profits that access to electricity brings. The RGoB's strategy should therefore emphasise the role of women in decision-making processes and positions in households and society.

Lastly, India has proven to be a very reliable development partner in the past, still, Bhutan also needs to become increasingly independent from foreign aid and should not develop its largest power projects with the exclusive purpose of generating electricity for India (although globally, the supply with clean energy for India is essential). Therefore, the acceptance and promotion of private undertakings in the power sector as well as (private) development of industries will become crucial for the enhanced socio-economic materialisation of electricity's benefits.

References

ADB. 2010a. *Asian Development Bank's Assistance for Rural Electrification in Bhutan—Does Electrification Improve the Quality of Rural Life?* Aug 2010. Available from: http://www.oecd.org/countries/bhutan/46757667.pdf [Last accessed on 3 Jun 2018]

ADB. 2010b. *Bhutan: Energy Sector*, Aug 2010. ADB Evaluation Study. Available from: https://www.adb.org/sites/default/files/evaluation-document/35383/files/sap-bhu-2010-21.pdf [Last accessed on 3 Jun 2018]

ADB. 2014a. *Country Partnership Strategy: Bhutan, 2014—2018 SECTOR ASSESSMENT (SUMMARY): ENERGY.* Jun 2014. Available from: https://www.adb.org/sites/default/files/linked-documents/cps-bhu-2014-2018-ssa-01.pdf [Last accessed on 3 Jun 2018]

ADB. 2014b. *Country Partnership Strategy: Bhutan, 2014—2018 ENVIRONMENT ASSESSMENT (SUMMARY).* Jun 2014. Available from: https://www.adb.org/sites/default/files/linked-documents/cps-bhu-2014-2018-ena.pdf [Last accessed 3 Jun 2018]

ADB. 2014c. *Country Partnership Strategy: Bhutan, 2014—2018 POVERTY ANALYSIS (SUMMARY).* Available from: https://www.adb.org/sites/default/files/linked-documents/cps-bhu-2014-2018-pa.pdf [Last accessed on 3 Jun 2018]

ADB. 2016. *Environmental Monitoring Report, Bhutan: Rural Renewable Energy Development Project (Part D – Biogas Plants)*, Nov 2016. Available from: https://www.adb.org/sites/default/files/project-documents/42252/42252-022-emr-en_1.pdf [Last accessed on 3 Jun 2018]

BPC. 2014. *Rural Electrification Project for Clean Energy, Better Living and Sustainable Growth in Bhutan, Project design document form for small-scale CDM project activities*. Available from: https://cdm.unfccc.int/filestorage/J/1/T/J1TNK9275YIZ3W0LRMD8X4AUVCG6BP/Untitled%20%28uploaded%2013%20Nov%2014%2010%3A43%3A59%29.pdf?t=Tll8cDl1YnpvfDDo562KtHD826SrVn0gZez1 [Last accessed on 3 Jun 2018]

BPC. 2018a. *ANNUAL TRANSMISSION SYSTEM PERFORMANCE REPORT FOR THE YEAR 2017*, Jan 2018. Available from: http://bpso.bpc.bt/wp-content/uploads/2018/02/Annual-Report-2017.pdf [Last accessed on 3 Jun 2018]

BPC. 2018b. *Transmission System Performance Report First Quarterly Report – January to March, 2018.* Available from: http://bpso.bpc.bt/wp-content/uploads/2018/04/First-Quarterly-Report-2018.pdf [Last accessed on 3 Jun 2018]

CEA. 2012. *National Transmission Grid Master Plan (NTGMP) for Bhutan*, Apr 2012. Available from: http://www.cea.nic.in/reports/others/ps/pspa1/ntgmp_voll.pdf [Last accessed on 3 Jun 2018]

DGPC. *BASOCHHU HYDROPOWER PLANT.* Available from:

https://www.drukgreen.bt/images/yootheme/Publication/Plant%20Profile/Basochhu%20Hydropower%20Plant.pdf [Last accessed on 3 Jun 2018]

Dhakal, D. N. S. and Jenkins, G. P. 1991. *International Trade in Energy: The Chukha Hydroelectric Project in Bhutan*, Nov 1991. Development Discussion Paper No. 412. Available from: https://cri-world.com/publications/qed_dp_82.pdf [Last accessed on 3 Jun 2018]

Dhakal, D. N. S. and Jenkins, G. P. 2013. Risk sharing in hydropower development: case study of the Chukha Hydel Project in Bhutan. *Water Policy* 15, 109–125. DOI:10.2166/wp.2013.001

DoE. 2010. *Integrated Energy Management Master Plan for Bhutan*. Available from: http://www.nec.gov.bt/nec1/wp-content/uploads/2012/11/energymasterplan2010.pdf [Last accessed on 3 Jun 2018]

Dorji, Tshering; Urmee, Tania; Jennings, Philip. 2012. Options for off-grid electrification in the Kingdom of Bhutan. *Renewable Energy* 45, 51 – 58. DOI:10.1016/j.renene.2012.02.012

Dorji, Tshering. 2018. *Chukha export tariff revised by 30 Cheltrum a unit*, Feb 2018. Available from: http://www.kuenselonline.com/chukha-export-tariff-revised-by-30-cheltrum-a-unit/ [Last accessed on 3 Jun 2018]

DRE. 2016. *Environmental Safeguard Monitoring Report - Bhutan: Rural Renewable Energy Development Project (Part B – Off-grid Rural Electrification)*, Nov 2016. Available from: https://www.adb.org/sites/default/files/project-documents/42252/42252-022-emr-en.pdf [Last accessed on 3 Jun 2018]

e7. 2005. *e7 Bhutan Micro Hydro Power CDM Project Project Design Document*, Mar 2005. Available from: https://cdm.unfccc.int/filestorage/F/S/_/FS_201499534/BhutanPDD_Rev2.pdf?t=TUN8cDl1YXg3fDBCJS63vWb0OBGKERuSEWra [Last accessed on 3 Jun 2018]

Feuerbacher, Arndt; Siebold, Matthias; Chhetri, Ashit; Lippert, Christian and Sander, Klas. 2016. Increasing forest utilization within Bhutan's forest conservation framework: The economic benefits of charcoal production. *Forest Policy and Economics* 73, 99-111. DOI: 10.1016/j.forpol.2016.08.007

Gilani, Hammad; Shrestha, Him Lal; Murthy, M.S.R; Phuntso, Phuntso; Pradhan, Sudip; Bajracharya, Birendra and Shrestha, Basanta. 2015. Decadal land cover change dynamics in Bhutan, *Journal of Environmental Management* 148, 91-100. DOI:10.1016/j.jenvman.2014.02.014

Gilman, P.; Cowlin, S.; and Heimiller, D. 2009. *Potential for Development of Solar and Wind Resource in Bhutan*. United States: National Renewable Energy Laboratory, US Department of Energy. DOI:10.2172/964607

Giri, Nandu and Singh, O. P. 2013. URBAN GROWTH AND WATER QUALITY IN THIMPHU, BHUTAN, *Journal of Urban and Environmental Engineering* 7(1) 82-95. DOI: 10.4090/juee.2013.v7n1.082095

GNHC. 2008a. *TENTH FIVE YEAR PLAN 2008 – 2013 Volume I: Main Document.* Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/Tenth-Plan_Vol1_Web.pdf [Last accessed on 3 Jun 2018]

GNHC. 2008b. *TENTH FIVE YEAR PLAN 2008 – 2013 Volume II: Programme Profile*. Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/TenthPlan_Vol2_Web.pdf [Last accessed on 3 Jun 2018]

GNHC. 2013a. *ELEVENTH FIVE YEAR PLAN 2013 – 2018 Volume I – Main Document*. Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/Eleventh-Five-Year-Plan.pdf [Last accessed 3 Jun 2018]

GNHC. 2013b. *ELEVENTH FIVE YEAR PLAN 2013 – 2018 Volume II : Programme Profile.* Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/11th-Plan-Vol-2.pdf [Last accessed 3 Jun 2018]

Helliwell, J., Layard, R., & Sachs, J. 2018. *World Happiness Report 2018*, New York: Sustainable Development Solutions Network. Available from: http://worldhappiness.report/ed/2018/ [Last accessed on 3 Jun 2018]

IEA. 2017. Energy Access Outlook 2017 – World Energy Outlook Special Report, Oct 2017. Available from: https://webstore.iea.org/weo-2017-special-report-energy-access-outlook [Last accessed on 3 Jun 2018]

JICA. 2005. *The Integrated Master Plan Study for Dzongkhag-wise Electrification in Bhutan*, Oct 2005. Available from: http://open_jicareport.jica.go.jp/pdf/11803582_01.pdf [Last accessed on 3 Jun 2018]

Korte, Thomas; Baki, Abul; Ofenböck, Thomas; Moog, Otto; Sharma, Subodh; Hering, Daniel. 2010. Assessing river ecological quality using benthic macroinvertebrates in the Hindu Kush-Himalayan region. *Hydrobiologia* 651(1) 59-76. DOI:10.1007/s10750-010-0290-z

Lean, Hooi Hooi and Smyth, Russel. 2014. *ELECTRICITY CONSUMPTION, OUTPUT, AND TRADE IN BHUTAN*, Dec 2014. ADB South Asia Working Paper Series No. 34. Available from: https://www.adb.org/sites/default/files/publication/152765/south-asia-wp-034.pdf [Last accessed on 3 Jun 2018]

Lhendup, Tshewang. 2008. Rural electrification in Bhutan and a methodology for evaluation of distributed generation system as an alternative option for rural electrification. *Energy for Sustainable Development* 12(3) 13 – 24. DOI: 10.1016/S0973-0826(08)60434-2

MoAF. 2012. *First Annual Progress Report: Bhutan Biogas Project (BBP)*, Mar 2012. Available from: http://www.build-a-biogas-plant.com/PDF/bhutan_biogas_project_first_annual_progress_report_2012.pdf [Last accessed on 3 Jun 2018]

Namgyel, Phuntsho. 2016. *Wood: Dirty to Clean Fuel and National Energy Security*, Aug 2016. Available from: http://www.kuenselonline.com/wood-dirty-to-clean-fuel-and-national-energy-security/ [Last accessed on 3 Jun 2018]

NEC. 2016. *NATIONAL INTEGRATED WATER RESOURCES MANAGEMENT PLAN 2016*, Mar 2016. Available from: http://www.nec.gov.bt/nec1/wp-content/uploads/2016/03/Draft-Final-NIWRMP.pdf [Last accessed on 3 Jun 2018]

NSB. 2014. *Bhutan Poverty Assessment 2014*, Sept 2014. Available from: http://documents.worldbank.org/curated/en/914381468013483608/pdf/905320WP0Bhuta00Box385319B00PUBLIC0.pdf [Last accessed on 3 Jun 2018]

NSB. 2017a. *Bhutan at a Glance*, Sept 2017. Available from: http://www.nsb.gov.bt/publication/files/pub9wt9959wh.pdf [Last accessed on 3 Jun 2018]

NSB. 2017b. *BHUTAN LIVING STANDARDS SURVEY REPORT 2017*. Available from: http://www.nsb.gov.bt/publication/files/pub2yo10667rb.pdf [Last accessed on 3 Jun 2018]

NSB. 2017c. *Dzongkhags at a Glance 2017.* Available from: http://www.nsb.gov.bt/publication/publications.php?id=18 [Last accessed on 3 Jun 2018]

NSB. 2017d. *Statistical Yearbook of Bhutan 2017*, Sept 2017. Available from: http://www.nsb.gov.bt/publication/files/pub10ss7733bo.pdf [Last accessed on 3 Jun 2018]

Palden, Tshering. 2017. *Bhutan to generate 6.5MW renewable energy*, Oct 2017. Available from: http://www.kuenselonline.com/bhutan-to-generate-6-5mw-renewable-energy/ [Last accessed on 3 Jun 2018]

Premkumar, Lakshmi. 2016. *A Study of the India-Bhutan Energy Cooperation Agreements AND THE IMPLEMENTATION OF HYDROPOWER PROJECTS IN BHUTAN*, Jan 2016. Vasudha Foundation, New Delhi. Available from: http://www.vasudha-foundation.org/wp-content/uploads/Final-Bhutan-Report_30th-Mar-2016-1.pdf [Last accessed on 3 Jun 2018]

Rahut, Dil Bahadur; Behera, Bhagirath and Ali, Akhter. 2016. Household energy choice and consumption intensity: Empirical evidence from Bhutan. *Renewable and Sustainable Energy Reviews* 53, 993–1009. DOI: 10.1016/j.rser.2015.09.019

RGoB. 1961. *1st Five Year Plan 1961 – 1966*. Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/1stFYP.pdf [Last accessed on 3 Jun 2018]

RGoB. 1967. *2nd FIVE YEAR PLAN*. Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/02fyp.pdf [Last accessed on 3 Jun 2018]

RGoB. 1971. *Third Five Year Plan 1971 – 76*. Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/3FYP-1971-76.pdf [Last accessed on 3 Jun 2018]

RGoB. 1976. SALIENT FEATURES OF THE FOURTH FIVE YEAR PLAN (1976-81). Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/4FYP-1976-81-Salient-Features.pdf [Last accessed on 3 Jun 2018]

RGoB. 1981. *Fifth Plan 1981 – 1987 MAIN DOCUMENT*. Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/5FYP-1981-86.pdf [Last accessed on 3 Jun 2018]

RGoB. 1988. *6th Five Year Plan*. Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/06fyp.pdf [Last accessed on 3 Jun 2018]

RGoB. 1992. *7th Five Year Plan*. Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/07fyp.pdf [Last accessed on 3 Jun 2018]

RGoB. 1998. *8th Five Year Plan (1998 – 2003)*. Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/08fyp.pdf [Last accessed on 3 Jun 2018]

RGoB. 2000. *Environmental Assessment Act*. Available from: http://www.nec.gov.bt/nec1/wp-content/uploads/2012/10/EA-Act-2000.pdf [Last accessed on 3 Jun 2018]

RGoB. 2003. *9th Five Year Plan (2003 – 2008).* Available from: https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/5yp09_main.pdf [Last accessed on 3 Jun 2018]

RGoB. 2008. *Bhutan Sustainable Hydropower Policy*. Available from: http://www.moea.gov.bt/wp-content/uploads/2017/07/dhps1.pdf [Last accessed on 3 Jun 2018]

RGoB. 2013. *Alternative Renewable Energy Policy.* Available from: http://img.teebweb.org/wp-content/uploads/2015/06/alternative-renewable-energy-policy-2013.pdf [Last accessed on 3 Jun 2018]

RGoB. 2016. *Economic Development Policy*, Dec 2016. Available from: http://www.moea.gov.bt/wp-content/uploads/2017/07/Economic-Development-Policy-2016.pdf [Last accessed on 3 Jun 2018]

Savada, Andrea Matles; George Lawrence Harris and Library Of Congress. 1993. Federal Research Division. *Nepal and Bhutan: country studies*. Washington, D.C.: Federal Research Division, Library of Congress: For sale by the Supt. of Docs., U.S. Govt. Print. Office, 1993.

Siebert, Stephen F. and Belsky, Jill M. 2015. Managed fuelwood harvesting for energy, income and conservation: An opportunity for Bhutan. *biomass and bioenergy* 74, 220 – 223. DOI:10.1016/j.biombioe.2015.01.013

Tortajada, Cecilia and Saklani, Udisha. 2018. Hydropower-based collaboration in South Asia: The case of India and Bhutan. *Energy Policy* 117, 316 – 325. DOI: 10.1016/j.enpol.2018.02.046

Transparency International. 2017. *Corruption Perception Index 2017*. Available from: https://www.transparency.org/news/feature/corruption_perceptions_index_2017 [Last accessed on 3 Jun 2018]

Uddin, Sk Noim; Taplin, Ros and Yu, Xiaojiang. 2007. Energy, environment and development in Bhutan, *Renewable and Sustainable Energy Reviews* 11, 2083 – 2103. DOI:10.1016/j.rser.2006.03.008

Wangchuk, T.; He, C., Knibbs, L.D.; Mazaheri, M. and Morawska, L. 2017. A pilot study of traditional indoor biomass cooking and heating in rural Bhutan: gas and particle concentrations and emission rates. *Indoor Air* 27(1), 160–168. DOI:10.1111/ina.12291

World Bank Group. 2016. *Managing Environmental and Social Impacts of Hydropower in Bhutan*, Jun 2016. Available from: http://documents.worldbank.org/curated/en/254821470402939614/pdf/107462-REVISED-PUBLIC-HydropowerforBhutanWebCORRECTED.pdf [Last accessed on 3 Jun 2018]

World Bank Group. 2017. *Doing Business 2018 - Reforming to Create Jobs*, Oct 2017. Available from: http://www.doingbusiness.org/~/media/WBG/DoingBusiness/Documents/Annual-Reports/English/DB2018-Full-Report.pdf [Last accessed on 3 Jun 2018]

WRBC. 2016. WANGCHHU BASIN MANAGEMENT PLAN 2016. Available from: http://www.nec.gov.bt/nec1/wp-content/uploads/2017/09/Wangchhu-Basin-management-Plan-2016.pdf [Last accessed on 3 Jun 2018]

Yangchen, Ugyen; Thinley, Ugyen and Wallentin, Gudrun. 2015. Land Use Land Cover Changes in Bhutan: 2000-2013, Sept 2015. *Occasional Publication No. 1 Centre for Rural Development Studies, College of Natural Resources, Lobesa, Royal University of Bhutan*. Available from: http://www.cnr.edu.bt/CCED/04_UgyenY-UgyenT-GudrunW_LULCinBhutan_P-37-46.pdf [Last accessed on 3 Jun 2018]

List of Tables

List of Figures

Appendices

Appendix I: List of all operational hydropower plants in Bhutan

Nr.	Plant name	Dzongkhag	Installed capacity (MW)	Energy generation 2016 (GWh)	Type	Commissioning (/Re-Commission-ing)	Project information
Medium, large and mega hydropower plants							
1	Chhukha		336 (4 x 84)	1.930	RoR	1986-88	Bilateral, GoI
2	Kurichu	Mongar	60 (4 x 15)	391	R	2001	Bilateral, GoI
3	Basochu I	Wangdue Phodrang	24 (2 x 12)	117	RoR	2002	JV, GoA
4	Basochu II	Wangdue Phodrang	40 (2 x 20)	206	R	2004	JV, GoA
5	Tala	Chukha	1,020 (6 x 170)	4.925	RoR	2006-07	Bilateral, GoI
6	Dagachhu	Dagana	126 (2 x 63)	374	RoR	2015	PPP (ADB, GoA, GoJ)
TOTAL:			***1606***	***7.942***			
Nr.	**Plant name**	**Dzongkhag**	**Installed capacity (kW)**	**Energy generation 2016 (GWh)**	**Type**	**Commissioning (/Re-Commission-ing)**	**Project information**
Mico- ,mini- and small local hydropower plants							
1	Jushina	Thimphu	360 (4 x 90)	1,273		1967/1998	1st FYP, GoI
2	Hesothangkha	Wangdue Phodrang	300 (3 x 100)	0,093		1972	2nd FYP, GoI
3	Chenari	Tashigang	750 (3 x 250)	0		1972	2nd FYP, GoI
4	Gidakom	Thimphu	1250 (5 x 250)	4,738		1973/2001	3rd FYP

5	Khalanzi	Mongar	390 (3 x 130)	0		1976	
6	Chumey	Bumthang	1500 (3 x 500)	0		1988	
7	Gangzur	Lhuentse	120 (2 x 60)	0,018		2000	
8	Rukubji	Wangdue Phodrang	40 (1 x 40)	0,016		1986-87	
9	Tangsibji	Trongsa	30 (1 x 30)	0,047		n/a	
10	Sherabling	Trongsa	50 (1 x 50)	0		n/a	
11	Bubja	Trongsa	30 (1 x 30)	0		n/a	
12	Tamzhing	Bumthang	30 (1 x 30)	0,015		n/a	
13	Ura	Bumthang	50 (1 x 50)	0,265		n/a	
14	Surey	Sarpang	Dismentled	0		n/a	
15	Kekhar	Zhemgang	20 (1 x 20)	0		n/a	
16	Changchey	Tsirang	200 (2 x 100)	0,252		1991	
17	Tingtibi	Zhemgang	200 (2 x 100)	0,117		1992	
18	Darachhu	Dagana	200 (2 x 100)	0,385		1992	
19	Lingzhi	Thimphu	8 (1 x 8)	n/a		1999	
20	Rangjung	Tashigang	2200 (2 x 1100)	2,81		1996	GoA
21	Rongchu	Lhuentse	200 (2 x 100)	0,765		2001	
22	Chendebji	Trongsa	70 (1 x 70)	0,185		2005	
23	Sengor	Mongar	100 (1 x 100)	0,049		2007	
TOTAL:			***8098***	***11***			

(ADB = Asian Development Bank; GoA = Government of Austria; GoI = Government of India; GoJ = Government of Japan; RoR = Run-of-River; R = Reservoir; JV = Joint Venture; PPP = Public Private Partnership; n/a = not available)

Appendix II: List of proposed hydropower projects until 2020

Nr.	Proposed plant	Dzongkhag	Installed capacity (MW)	Type	Commissioning (/Re-Commissioning)	Project information
1	Phunatsangchhu I	Wangdue Phodrang	1200	RoR	under construction	Bilateral, GoI
2	Phunatsangchhu II	Wangdue Phodrang	1020	RoR	under construction	Bilateral, GoI
3	Mangdechhu	Trongsa	720	RoR	set for Sept/Oct '18	Bilateral, GoI
4	Bunakha	Chukha	180	R	planning	JV, DGPC & THDC India
5	Sunkosh Reservoir	Dagana	2560	R	planning	Bilateral, GoI
6	Sunkosh Left Bank	Dagana	35	RoR	planning	Bilateral, GoI
7	Chamkarchhu	Zhemgang	770	RoR	planning	JV, DGPC & NHPC India
8	Kuri-Gongri	Mongar	2640	R	planning	Bilateral, GoI
9	Kholongchhu	Trashi Yangtse	600	RoR	early construction	JV, DGPC & Satlui Jal Vidyut Nigam Ltd.
10	Wangchhu	Chukha	570	RoR	planning	JV, DGPC & Satlui Jal Vidyut Nigam Ltd.
11	Amocchu	Samste	540	R	planning	Bilateral, GoI
12	Nikachhu	Trongsa	120	RoR	planning	PPP (DGPC, ADB)
13	Khomachhu	Mongar	336	RoR	planning	PPP (DGPC, n/a)
14	Rotpashong	Mongar	1230	RoR	planning	PPP (DGPC, n/a)
15	BinduKhola	Samste	13	RoR	planning	n/a
TOTAL:			***12534***			

(ADB = Asian Development Bank; DGPC = Druk Green Power Corporation; GoI = Government of India; RoR = Run-of-River; R = Reservoir; JV = Joint Venture; PPP = Public Private Partnership; n/a = not available)

Appendix III: Revenues from large hydropower plants and their debt servicing terms

Plant	Commissioning	Electricity sale revenues (Nu. Millions)				Debt servicing		
		2013	2014	2015	2016	Project cost (Nu. Million)	Loan	Repayment terms
Chukkha	1986-88	3698,67	3815,44	4307,15	5137,92	2465	40%	3 years after completion, 15 years of equal bi-annual instalments, 5% interest rate/year, loan was liquidated on 31 Dec 2007
Kurichu	2001	560,68	592,4	542,11	321,37	5600	40%	12 years, 10.75% interest, loan was liquidated in 2016
Basochu I	2002	n/a	n/a	n/a	n/a	1440	49.14%	15 years, 0% interest
Basochu II	2004	n/a	n/a	n/a	n/a	1834	95.64%	12 years, 2.8% interest
Tala	2006-07	7459,45	7470,14	7468,87	6995,51	41258,55	40%	12 equated annual instalments at 9% interest rate/year
Dagachhu	2015	0	0	988,59	1189,42	8600	ADB; RZB (AT) & NPPF	Shareholders: DGPC (59%), Tata Power Company Limited of India (26%) and the National Pension and Provident Fund of Bhutan (NPPF, 15%)

(Source: NSB, 2017b; World Bank, 2016)