Investigating the Impact of Hydropower Investment on Economic Growth and Development: Bhutan's Experience from the 1980s to 2017

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Contents

Abstract

This thesis comprises two interrelated papers that examine the impact of hydropower investment and rural electrification on economic growth and household non-farming income diversification in Bhutan.

Chapter 3 examines the impact of hydropower development on Bhutan's GDP growth for the period from 1980 until 2017. The study employs a two-stage least squares regression analysis. The estimation results indicate that domestic investments, domestic labour and hydropower investments foster economic growth in Bhutan, whereas foreign labour and the Hicks neutral technological change has no significant impact on economic growth for the study period. The main contribution of this chapter to the field of study is to provide empirical evidence for the impact of hydropower investment during the construction phase on Bhutan's economic growth.

Chapter 4 investigates the impact of rural electrification on household non-farming income activities in rural Bhutan. Two identification strategies are used to ascertain the impact: the panel fixed-effect using logit regression, and the difference-in-differences approach using a linear probability model. The findings generated from both strategies indicate that rural electrification has had a positive effect on improving household non-farming income diversification. Concerning the timing of access to the grid and its impact on the outcome variables, households that are connected at an earlier stage (i.e., 2007) are better off than households connected to the grid at the midway stage (i.e., 2012). However, the benefits erode over time, and by 2017 household access to the grid is no longer considered a key driver for non-farming income diversification. Overall, households that are connected to the grid are better off than the households not connected in terms of non-farming income diversification. The main contribution of this chapter to the literature is to provides empirical evidence for the positive impact of access to the grid in the case of a small, developing country like Bhutan. It also provides evidence of the effects of the timing of gaining access to the grid on household income diversification.

Declaration

This thesis is an original work of my research and contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Signature

Name: Sonam Tobgye

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List of Figures

ADB	:	Asian Development Bank
BLSS	:	Bhutan Living Standard Survey
CLM	:	Conditional Logit Model
DiD	:	Difference in Differences
FYP	:	Five Year Plan
GDP	:	Gross Domestic Product
GNH	:	Gross National Happiness
GoI	:	Government of India
GWh	:	Giga Watt Hour
IMF	:	International Monetary Fund
KWh	:	KiloWatt Hour
MW	:	Mega Watt
NSB	:	National Statistics Bureau
Nu.	:	Ngultrum
OLS	:	Ordinary Least Squares
RGoB	:	Royal Government of Bhutan
RMAB	:	Royal Monetary Authority of Bhutan
TSLS	:	Two Stage Least Squares
UNDP	:	United Nation Development Programme

1.1 Background

Access to clean, safe and affordable sources of energy is a crucial driver for social, physical and economic development (Rathi & Vermaak, 2018; Samanta, 2015). South Asia,[1] which is home to some of the world's most populated developing countries, is confronted with challenges of rapid urbanisation and industrialisation leading to an unprecedented surge in the demand for electricity (Singh, 2013). Electricity demand in the region is expected to increase by 9% per annum between 2010 and 2020 and has already surpassed the installation capacity (Tortajada & Saklani, 2018). As a result, there has been growing collaboration amongst countries for energy trading to address the demands and to diversify energy sources. One example of such cooperation is the India–Bhutan hydropower cooperation. The Government of India is assisting Bhutan in building hydropower projects through technical and financial support in return for import electricity after the completion of the project.

Bhutan is a small and developing nation with a population of 735,553 (National Statistics Bureau, 2018a) sandwiched between China to the north and India to the south. It is driven by a unique development philosophy of Gross National Happiness[2], which accentuates four key pillars: good governance, sustainable socio-economic development, preservation and the promotion of culture and environmental conservation (Laczniak & Santos, 2018). As of 2017, due to a firm policy to conserve its environment, 71% of the country's landscape remains covered by forest (Palden, 2017), which serves as a catchment for the perennial flow of rivers. With high mountainous terrain and a gradient of rivers flowing through steep rocky terrain and gorges, Bhutan is naturally endowed with ideal conditions for the development of hydropower. As outlined in the Bhutan Power System Master Plan (2003 to 2022), Bhutan has about 30,000 MW of hydropower potential,

[1] South Asian countries include Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka.

[2] Gross National Happiness is a holistic and multi-dimensional development approach to public policy in Bhutan that seeks to achieve a harmonious balance between material wellbeing and the spiritual, emotional and cultural needs of the society (Baral & Holmgren, 2015).

of which 23,765 MW is found to be techno-economically feasible to access (Uddin, Taplin, & Yu, 2007). With limited natural resources and challenging terrain for economic development, the tapping of the country’s hydropower potential has been a core development strategy pursued by the Bhutanese government since the 1980s (Gross National Happiness Commission, 2013).

India is one of the fastest developing countries in the world, with an expanding population base and a continuously increasing demand for electricity (Bowen et al., 2010; Ganguly, 2018). The Government of India has set ambitious economic and social development objectives, including financial reforms and an expanding provision for electricity that has a tremendous impact on future energy demands and the nation’s economic outlook (Buckley & Shah, 2017; Energy Information Administration, 2018). In 2017, India’s total electricity generation came from thermal power (80.1%), hydroelectricity (9.9%), non-hydro renewable energy (6.6%), and the remainder from nuclear power projects (Buckley & Shah, 2017). India’s over-dependence on thermal power for electricity has produced financial as well as environmental burdens, and hydropower cooperation with Bhutan has become a centrepiece of India’s energy development. The cooperation between Bhutan and India in the hydropower sector is a win-win situation for both of the countries. Hydropower projects have benefitted Bhutan in terms of revenue generated through the sale of electricity that is used locally for social and developmental programs (International Monetary Fund, 2007; Santini, Trang, & Beath, 2017; Tortajada & Saklani, 2018). For instance, in 2018 only 6.79% (1,614 MW) of the total hydropower capacity in Bhutan was being tapped, but electricity accounts for almost 36.96% of the nation’s total export (Royal Monetary Authority, 2018). Hydropower has also benefitted Bhutan in establishing various electricity-intensive industries and intensifying its rural electrification projects (International Monetary Fund, 2018).

On the other hand, cheap and renewable energy has benefitted India (in the north-eastern states) in terms of meeting its increasing energy demands and reducing its carbon dioxide emissions from other sources of energy production (Bisht, 2012). Currently power exports from Bhutan meet approximately 8.4 % of the peak power demand in the north eastern states of India (Central Electricity Authority, 2018). A study has found that the hydroelectric power supply from Bhutan saw a reduction of about 4.4 million tons of carbon dioxide emissions (approximately 0.176%) in India for the year 2015 (National Environment Commission, 2015). With the full commissioning of Bhutan’s ongoing hydropower construction projects, annual CO_2 emissions in India could be reduced by as much as 40 million tons annually by 2020 and 2021 (Wijayatunga, Chattopadhyay, & Fernando, 2015).

1.2 Statement of the problem

Following the successful cooperation between India and Bhutan on past hydropower projects, a protocol was signed between the countries in March 2009 for the development and production of 10,000 MW of hydroelectricity by the year 2020 (Royal Government of Bhutan & Government of India, 2009). Pursuing this protocol, four projects of various sizes with a total capacity of 2,938 MW have been under construction as of 2020.

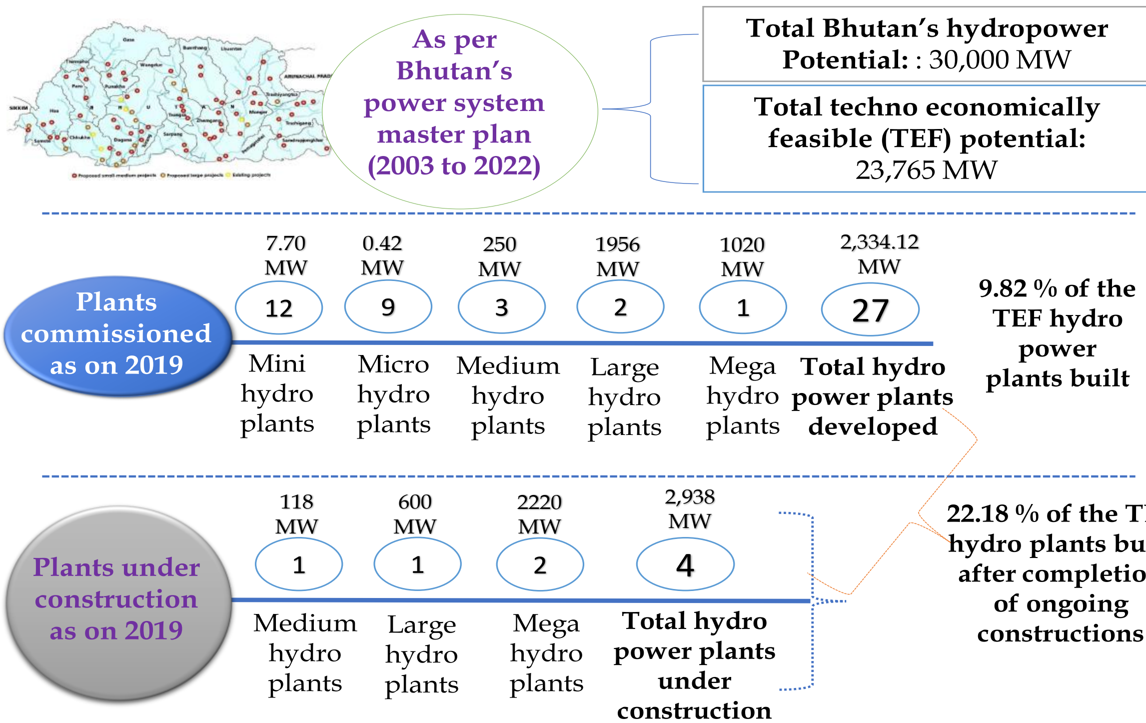

Figure 1: Summary of hydropower investment in Bhutan as on February 2020

Source: (Alam et al., 2017; Druk Green Power Corporation Limited, 2018b; National Statistics Bureau, 2018c).

While the expansion of hydropower projects has brought significant benefits to Bhutan, there are contextual concerns related to an over-concentration of investment, soaring national debt, the balance of payment issues, fund management, environmental and social issues, and the problem of Dutch diseases. The construction of hydropower requires enormous investment, which leads to excess liquidity, appreciation of the real exchange rate, and macroeconomic instability in Bhutan

(G. Boyreau & M. Rama, 2015; Kojo, 2005; World Bank, 2019). For the 2016/17 fiscal year, hydropower debt quadrupled to Nu.123.85[3] billion, which was a drastic increase from Nu.31.45 billion in the 2010/11 fiscal year. This forms about 83.30% of the GDP, constituting more than 76% of the total external debt (Royal Monetary Authority, 2018).

The World Bank indicated that small developing countries like Bhutan that rely specifically on a limited amount of natural resources for growth might potentially be affected by 'resource curse'[4] symptoms in the future (Santini, Trang, et al., 2017) if proper mechanisms are not instituted to diversify the economy. The United Nations Development Programme (UNDP) highlighted Bhutan's heavy dependence on hydropower exports, which are highly vulnerable to hydrological and climatic risk, further heightened by India being a monopsony buyer (Marshall, 2013). The International Monetary Fund (IMF) also stated that Bhutan's exports are characterised by a lack of diversification relying specifically on the sale of electricity as a significant share of exports (International Monetary Fund, 2014, 2016). From the literature review, a host of studies have also observed that large dams are risky investments that involve substantial social costs (Tilt, Braun, & He, 2009) and increasing cases of cost and time overrun, thereby placing emerging economies in risk of debt unless suitable risk-management measures are taken into account (Ansar, Flyvbjerg, Budzier, & Lunn, 2014; Awojobi & Jenkins, 2015; Cernea, 2004).

Despite the concerns and issues that have been raised, Bhutan is still committed to investment in hydropower projects. Most of the empirical evidence on the impact of Bhutan's hydropower investment relates to the export of electricity after the commissioning of projects. Therefore, this research investigates the overall impact of hydropower investment during the construction phase at a macro level on Bhutan's economic growth since the 1980s.

With the development of hydropower, Bhutan has also embarked on an ambitious program to provide electricity to all residents by 2020. When the project started in 1980, only 5% of Bhutanese rural households had access to the grid. This increased to 20% by 1995 (Kumar & Rauniyar, 2018)

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[3] USD1.8 billion (based on the exchange rate as of 20 January 2020, i.e., 1 USD equals Nu.70). Since all hydropower plants are constructed with loans and grants from India, the debt constitutes the loan repayable to India which includes principal and interest.

[4] Resource curse is a term used to explain the ill effect of a country's natural resources on its economic, social and political wellbeing in the long run (Morrison, 2012; Ross, 2015)

and almost 99% by 2019. One of the objectives of such a program is to raise the income and employment opportunities of the rural population and to reduce poverty. However, 8.2% of the Bhutanese population were still defined as poor in 2017 (National Statistics Bureau, 2018c). Critically, poverty in rural areas accounts for 11.9% of the population, which is significantly higher than the urban areas at 0.8%. This discrepancy motivated the current study to investigate how the rural electrification program has an effect on non-farming income diversification among the households of rural Bhutan.

1.3 Aims and objectives of the study

Overall the study is aimed at ascertaining and evaluating the performance of Bhutan's economy from the 1980s,[5] when the first hydropower plant was constructed, until 2017. Currently, Bhutan has built 12 mini-hydropower plants, nine micro plants, three medium-sized plants, two large plants and one mega plant with an installed capacity of 2,334.12 MW, as summarised in Figure 1. The study has identified the economic implications of increasing investment in Bhutan's hydropower with a focus on the following sub-objectives:

i. Investigating the macroeconomic impact of hydropower investments and other related structural variables on Bhutan's economic growth since the construction of the first hydropower project in 1980.

ii. Exploring the links between the development of hydropower, rural electrification and its impact on household income diversification in rural Bhutan.

iii. Proposing recommendations for policy-makers and future research directions based on the above findings.

1.4 Research methodology

The study applies a quantitative analysis based on secondary data sourced from various relevant agencies.

The theoretical framework for the first objective is based on the new endogenous growth theory by Romer (1994), where the driving force for the country's economic growth is through the

[5] Based on the availability of data after the construction of the first mega hydropower plant in Bhutan in 1980.

accumulation of physical capital, human capital, labour and technological change. The study employs a Cobb–Douglas production function to capture the relationship between potential output and its structural determinants such as domestic investment, domestic labour, foreign investments, foreign labour and Hicks neutral technical change. Due to a simultaneous causality and omitted variable bias in the structural equation, the study uses the two-stage least squares (TSLS) estimation as proposed by Wright (1928) and Theil (1961).

For the second objective, the study uses the panel data for the years 2007, 2012 and 2017 to ascertain the impact of household access to the grid on income diversification in rural Bhutan. The study uses a conditional logistic fixed-effect regression as proposed by McFadden (1973) on a balanced panel across the three survey waves. The study also applies the linear probability model and the difference-in-differences design to estimate how the outcome variables change with household access to the electricity grid at different periods.

1.5 Research significance

Hydropower has been Bhutan's main engine of growth for the last two and half decades since full commissioning of the first mega project in 1988 (International Monetary Fund, 2018; Mitra, Carrington, & Baluga, 2014; Royal Monetary Authority, 2018). Despite its importance to the national economy, few empirical studies have been conducted so far to ascertain the actual impact created by hydropower development on the Bhutanese economy. The identification of the relationship between hydropower investments and economic growth is complex in Bhutan's case, particularly with limited time-series data. With the problem of simultaneity bias between economic growth and the x variable chosen in the proposed model, conclusions that can be drawn from the single OLS regression equation for the growth rate in GDP are questionable. However, in this study, I address the problem of simultaneity bias by applying a two-stage least squares estimation procedure.

The findings from this study contribute to the limited literature on the contribution of hydropower to economic growth, trade, investment, budgetary issues, government expenditure and economic diversification in Bhutan. So far, there is scarce literature on the impact of hydropower projects in Bhutan during its construction phase. Although a few studies by international donor agencies, such as the World Bank (2005; 2009), Asian Development Bank (2008), and the United Nations Development Programme (2006), have looked at the impact of hydropower on Bhutanese economy, none have used the time-series data since the inception of the first hydropower projects. Furthermore, most analyses focused on the export of electricity after the commissioning of the project. There is no identifiable research that has empirically investigated the overall impact of hydropower during its construction phase on Bhutan's economic growth since the 1980s.

Chapter four addresses the impact of access to electricity on household non-farming income activities, which has not been studied much in the case of Bhutan. While a few studies have looked at the impact of rural electrification on health, education and employment using cross-sectional data, none has used the panel data for three waves of Bhutan Living Standard Survey (2007, 2012 and 2017). In addition, the global literature on the timing of access to the grid and its impact on non-farming income diversification is scant. This is especially the case for Bhutan, for which there is not a single study that has examined the effects of the timing of access to the grid on household income diversification activities. Therefore, the findings from this research will contribute significantly to the existing literature on rural electrification and its impact on household income diversification activities. Furthermore, it can serve as a reference for future researchers interested in studying the impact of rural electrification on consumption, welfare and happiness in rural Bhutan, or a similar developing country.

1.6 Thesis outline

In order to fulfil the research objective, the study was divided into five chapters.

Following this introductory chapter, the second chapter describes the economic conditions in Bhutan over the last four decades. This chapter provides an overall summary of the recent macroeconomic development trends in Bhutan. It also highlights the key economic indicators and performance in the real and external sectors for the study period.

The third chapter provides an extensive discussion on the macroeconomic impact of hydropower development in Bhutan. This section highlights the impact of hydropower development in Bhutan on Bhutan's economic growth from the period 1980 to 2017. Following this, an econometric model is developed to ascertain how key variables such as hydropower investment, domestic and foreign capital and labour, affect the overall economic growth of the country.

The fourth chapter provides an extensive discussion on the rural electrification and its impact on income diversification in rural Bhutan. Similarly, to chapter three, it also offers two econometric models to explain how access to electricity affects the nonfarm income activities of the individual household.

The last chapter provides concluding comments alongside some potential avenues for related future research.

2.1 Country background and its macroeconomic indicators

Bhutan is a small country landlocked between two of the world's most populous nations, China and India. It remains one of the smallest economies in the world, with a population base mainly dependent on natural resources for its economic growth. In terms of geographical features, the land rises from an elevation of 200 metres above sea level in the south to over 7,550 metres in the north resulting in extreme variation in climate, agroecology and biodiversity (Ministry of Economic Affairs, 2010). Despite facing challenges in its geographical location and limited connectivity to the rest of the world, Bhutan has sought to open up its economy and transform itself from being an underdeveloped, pastoral and subsistence economy, to a middle-income nation by the year 2022.

The World Bank (2017) stated that for the last two decades Bhutan has maintained robust economic growth and macroeconomic stability. However, it is also reported that delays in the completion of some hydropower projects scheduled in the coming years could impact Bhutan's macroeconomic stability due to accumulated debt. Thus, given the nation's reliance on an investment portfolio in hydropower and its importance to the economy, any obstacles or delays in this sector could have a significant negative impact on growth, revenues and exports (World Bank, 2018a). The overall macroeconomic developments in Bhutan, particularly in the real and external sector, are briefly summarised below:

2.1.1 Key economic indicators and performance in the real sector

Despite various challenges faced in the aftermath of the rupee crisis[6] in 2013 (Ura, 2015) and delays in hydropower construction, Bhutan's economic growth and the overall macroeconomic situation has improved considerably in recent years. The Royal Monetary Authority (2018) states

[6] India is the major trading partner of Bhutan accounting approximately 74% of the overall trade. Therefore, importing goods and services from India including debt servicing necessitates rapid conversion of ngultrum (Bhutanese currency) to Indian rupees. In 2011, due to huge pressure and demand on the Indian rupee, which extended to levels unable to be matched by official rupee holdings and reserves, liquidity crunch and Indian rupee crisis occurred in Bhutan.

that the real GDP growth for Bhutan has been positive, with an increase of 7.99% for the 2016/17 fiscal year compared to an increase of 6.60% for the 2015/16 fiscal year. The key achievement is that such an increase has been at its highest during the last five years. The major thrust for economic growth was from the tertiary sector, which was recorded at 10.48% against 5.45% growth in the previous fiscal year of 2015/2016. This was the result of impressive growth and recovery in the transport and finance sub-sectors, which grew by 11.20% and 10.70%, respectively. Amongst the three key sectors, the tertiary sector (consisting of services such as transport, finance, trade, etc.,) continuously recorded the highest share in the economy with 42.02% in 2016, followed by the secondary sector (concerned with manufacturing of goods) at 41.46%, and the primary sector (concerned with the extraction of raw materials, such as agriculture and mining) at 16.52% (Ministry of Finance, 2018). In terms of real GDP growth, the service sector contributed the highest, accounting at 4.55 percentage point followed by the secondary sector at 2.98 percentage and the primary sector at 0.46 percentage point. The primary sector contribution has been the lowest as it mainly affected by the forestry and logging sub-sector, which has recorded minimal and negative contribution to growth.

Table 1: Overall balance of trade for the fiscal year 2012 to 2017 (Figures in a billion Nu.)

Trade	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017
Total Exports	**28.60**	**31.85**	**35.58**	**35.23**	**35.26**
Export to India	26.63	28.98	31.80	31.80	32.05
Export to Third Countries	1.97	2.87	3.78	3.43	3.21
Total Imports	**53.09**	**53.28**	**56.88**	**68.04**	**67.36**
Import from India	41.83	43.89	47.85	53.74	52.29
Import from Third Countries	11.26	9.39	9.04	14.30	12.08
Overall balance of trade	**(24.67)**	**(21.42)**	**(21.30)**	**(32.81)**	**(32.10)**
Balance of trade with India	(15.21)	(14.91)	(16.05)	(21.94)	(23.23)
Balance of trade with Third Countries	(9.46)	(6.51)	(5.25)	(10.87)	(8.87)

Source: (Chewang, Tobgye, & Dorji P, 2018; National Statistics Bureau, 2017)

2.1.2 Key economic indicators and performance in the external sector (balance of payment)

The current account deficit for the years 2007 to 2017 has worsened with the onset of the construction of four large hydropower projects in 2007 (World Bank, 2019). The deficit has occurred due to the massive demand for import of capital-intensive goods and services related to hydropower and its ancillary economic activities. However, there has been an improvement in the balance of payment since 2016. The Royal Monetary Authority (2018) indicates that the current account deficit has decreased from 33.13% of the GDP in the fiscal year 2015/2016 to 24.44% of GDP in the fiscal year 2016/2017. This is due to slight improvements in the trade deficit, which has decreased to Nu.3.1 billion from Nu.3.7 billion in the previous year. It was driven primarily by higher electricity exports to India and an increase in exports of other minerals and metals to third countries.

With proximity of geographical linkages and friendly cooperation between the two countries, India is the Bhutan's largest trading partner. The overall balance of payment for the fiscal years 2012 to 2017 is depicted in Table 1. It can be observed from Table 1 that the balance of trade has worsened since 2012. The trade deficit increased from Nu.24.67 billion in the year 2012 to Nu.32.10 billion in the 2016/17 fiscal year. As per the latest figures for the period 1st April to 30th June 2019 (Ministry of Finance, 2019), the trade deficit has reached more than Nu.11.28 billion (excluding electricity) and Nu.9.09 billion (including electricity) as summarised in Table 2

Table 2: Summary of balance of trade situation for the period 1st April 2019 to 30th June 2019 (Figures in billion Nu.)

Trade	Overall Balance of Trade		Trade with India		Trade with countries other than India
	Trade excluding electricity	Trade including electricity	Trade excluding electricity	Trade including electricity	
Import (A)	17.54	17.67	14.46	14.59	3.08
Export (B)	6.26	8.59	4.76	7.10	1.50
Balance (B-A)	(11.28)	(9.09)	(9.70)	(7.50)	(1.59)

Source: (Ministry of Finance, 2019)

2.2 Key merchandise trade analysis of Bhutan

While Bhutan's economy is one of the smallest in the world, it has been growing consistently in recent years. Despite this, the economy remains undiversified with manufacturing accounting for a minuscule portion of the industries sectors. The top ten commodities Bhutan exported to its trading partner for the year 2018 is summarised in Table 3.

Table 3: Top ten exports of Bhutan in the year 2018 (Figures in billion Nu.)

Sl. No.	Commodities	Export Value	% share of total export
1	Electricity	11.98	41.09
2	Ferrosilicon	9.66	33.13
3	Cardamom	1.33	4.56
4	Cement	1.25	4.27
5	Base metal	1.05	3.61
6	Dolomite	1.05	3.60
7	Calcium carbide	0.86	2.95
8	Silicon carbide	0.70	2.42
9	Boulders	0.69	2.37
10	Ordinary Portland cement	0.59	2.02

Source: (National Statistics Bureau, 2017; Royal Monetary Authority, 2018)

Similarly, the top ten commodities Bhutan imported from its trading partners for the year 2018 is summarised in Table 4

Table 4: Top ten imports of Bhutan in the year 2018 (Figures in billion Nu.)

Sl. No.	Commodities	Import value	% share of total import
1	Light oils and preparations (HSD)	7.94	33.71
2	Ferrous products (obtained by direct reduction of iron ore)	2.56	10.88
3	Moro Spirit (gasoline including aviation spirit)	2.33	9.90
4	Wood Charcoal	2.22	9.45
5	Dumper designed for off-highway use	1.92	8.13
6	Coke and semi coke	1.80	7.62
7	Semi milled or wholly milled rice	1.69	7.17

Sl. No.	Commodities	Import value	% share of total import
8	Electric Conductors (Voltage exceeding 1,000 Volts)	1.25	5.32
9	Gross vehicle weight not exceeding 5 tonnes	0.99	4.21
10	Petroleum bitumen	0.85	3.62

Source: (National Statistics Bureau, 2017; Royal Monetary Authority, 2018)

In terms of trading partners, India is the largest for both exports and imports of goods and services. The top ten trading partners for Bhutan for the year 2018, in terms of both exports and imports, are outlined in Table 5.

Table 5: Top ten trading partner country of Bhutan in regard to export and import (Figures in billion Nu.)

Sl. No.	Top ten import trading partner		Top ten export trading partner	
	Country Name	Value	Country Name	Value
1	India	59.82	India	21.59
2	South Korea	1.67	Bangladesh	5.95
3	China	1.61	Italy	0.92
4	Singapore	1.49	Netherlands	0.55
5	Thailand	1.05	Nepal	0.53
6	Japan	0.78	Germany	0.42
7	Bangladesh	0.45	Spain	0.13
8	United Arab Emirates	0.40	Hongkong	0.10
9	Germany	0.34	Turkey	0.10
10	United States of America	0.25	Singapore	0.99

Source: Royal Monetary Authority (2018) and National Statistical Bureau (2017)

2.3 Hydropower and its contribution to the Bhutanese economy: Ex-post analysis

Hydropower has been Bhutan's main engine for growth over the past two and a half decades since the commissioning of the first hydropower project in 1986. The World Bank (2018b) states that the fiscal revenue from electricity exportation has played a vital role in the improvement of physical and human capital in Bhutan, leading to a drastic reduction in poverty at the national level. The latest report by the Central Bank indicates that with a decline in investment in hydropower, the country's economic growth has declined to 4.6% against 8% growth in 2016 (Royal Monetary Authority, 2018). This impact indicates how vital the hydropower sector is to the Bhutanese economy.

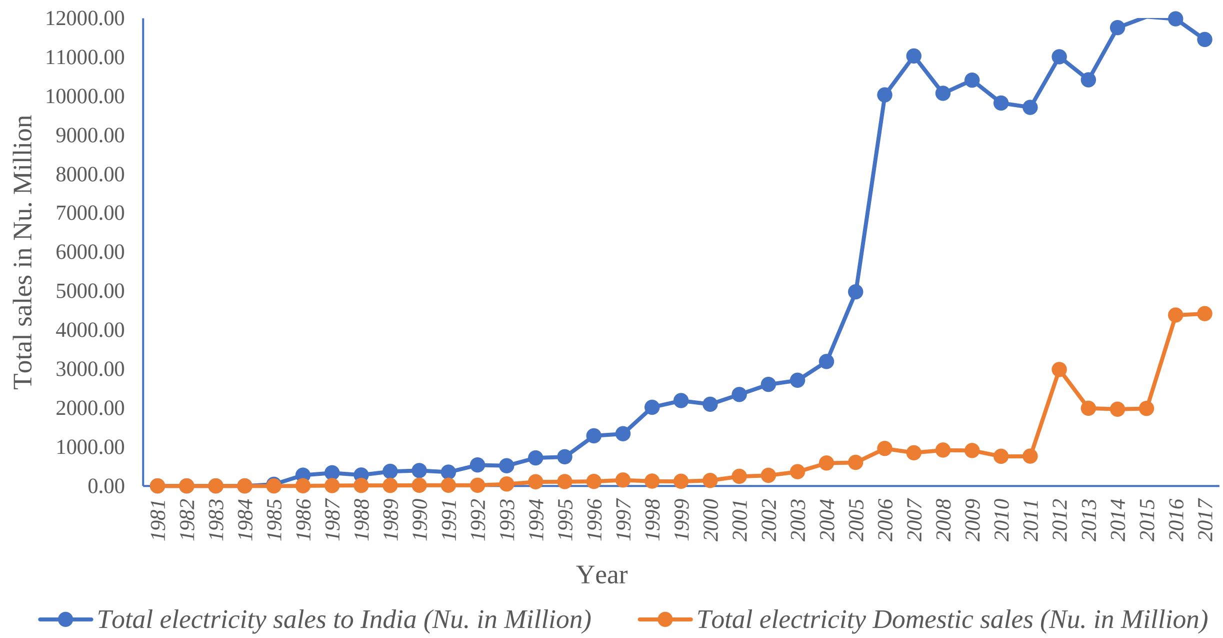

Figure 2: Export of electricity to India and the sale of electricity to the domestic market (1981 to 2017)

Source: (Royal Monetary Authority, 2018; National Statistical Bureau, 2017)

Figure 2 depicts the summary of electricity sales for export and also for domestic consumption between 1984 and 2017. It can be observed that the export of electricity to India has been increasing since 1985. In 2017 alone, Bhutan exported power worth Nu.11.9 billion to India, which accounts for 41% of the overall trade (Royal Monetary Authority, 2018).

In terms of its share to the GDP, the electricity sector is still one of the most significant contributors to economic growth, as depicted in Figure 3.

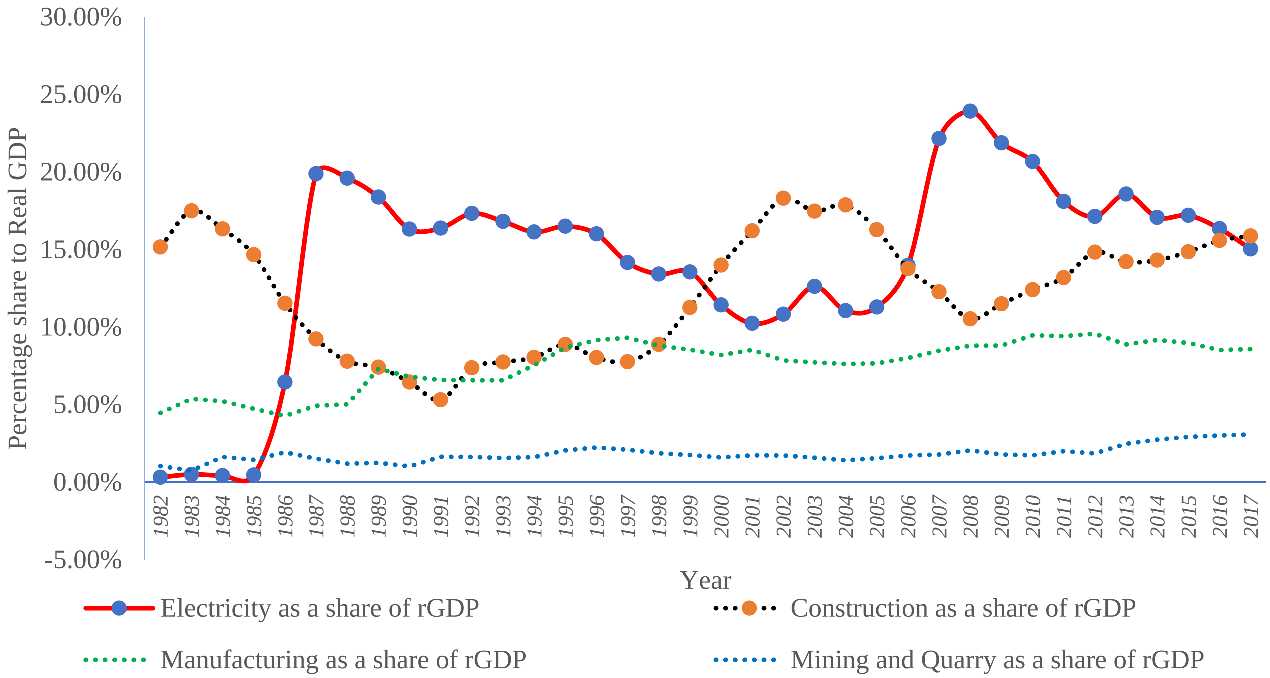

Figure 3: Percentage of sectors share to real GDP (electricity, construction, manufacturing, mining, and quarry)

Source: (Royal Monetary Authority, 2018; National Statistical Bureau, 2017)

2.4 Financing modality and summary of the project

Hydropower is highly capital-intensive, involving long preparation and construction periods. Therefore, securing favourable financing options for hydropower development is a crucial challenge faced by Bhutan. There are currently three models for project financing, which are inter-governmental, joint venture, and public-private partnership models. These financing modalities have been briefly explained below with their project summary.

I. Inter-governmental (IG) projects

The intergovernmental financing model is based on the bilateral agreement signed between two countries. The two different IG models implemented so far are between Bhutan and India and between Bhutan and Austria.

i. Between Bhutan and India

Under this IG model, a detailed project report has to be prepared by the public sector organization or company designated by the Government of India (GoI). During the construction period, the project is managed by an independent project authority comprising the two governments. After completion of the project, the generating plants are handed over to the Druk Green Power Corporation (DGPC), a wholly state-owned company of Bhutan. The project cost has to be met through loans and grants provided by the GoI. The loan portion has to be repaid to GoI on an annual basis at an agreed interest rate for a specified period. The key feature of this model is that all electricity, which is in surplus to domestic consumption after the commissioning of the project, will be purchased by India. Also, as goodwill and friendship, India will guarantee a net financial return of 15 per cent above the debt repayment and the project operating cost to the Bhutanese government (World Bank, 2016).

The following are the projects developed or in the process of construction through IG arrangement between Bhutan and India.

a. Chhukha Hydroelectric Project (336 MW)

The Chhukha hydroelectric project is located in the Wangchhu river basin in western Bhutan. It is the first large run-off river project jointly constructed by the GoI and RGoB. Construction commenced in 1978 and was fully commissioned in 1986. It was financed with a 60 per cent grant and a 40 per cent loan from GoI (Druk Green Power Corporation Limited, 2018a). The loan was repaid over 15 years from 1986 to 2007 at an annual interest rate of 5%. The project was completed at the cost of Nu.2.5 billion, which has increased from Nu.0.83 billion of the initially sanctioned cost (PremKumar, 2016). The tariff was revised from Nu.2 to Nu.2.25 per unit in 2013. All power generated from this plant is exported to India.

b. Kurrichhu Hydroelectric Project (60 MW)

The Kurichhu Hydropower Plant is a run-of-river scheme located at Gyalpozhing, Mongar, on the bank of Kurichhu river in eastern Bhutan. The project was constructed from the year 1995 and was commissioned in 2002. It was financed with a 60 per cent grant and a 40 per cent loan from the GoI. The loan was repaid from the year 2004 till 2015 at a simple interest rate of 10.75 per cent per annum. The final cost of the project on completion was Nu.5.6 billion, which has increased from Nu. 3.13 billion of the estimated amount (Bhutan Electricity Authority, 2017). The RGoB further funded Nu.40 million towards the acquisition of land, the establishment of a communication network, and other infrastructure not covered under the scope of the project. Almost 65% of the power produced from the plant is exported to India at a rate of Nu.1.98 per unit.

c. Tala Hydroelectric Project (1020 MW)

The Tala hydropower plant is located downstream on the Wangchhu from the Chhukha hydropower plant. This run-of-the-river project commenced its construction in 1997 and was commissioned in 2007. The project was financed with a 60 per cent grant and a 40 per cent loan from GoI, which was repaid for the past 12 years at an interest rate of 9% per annum. The cost of the project during the DPR stage was Nu.14 billion, which has increased to Nu.41.26 billion on completion in 2007 (Chewang & Tobgye, 2015). The export tariff for the project was fixed at Nu.1.80 per unit, and all its power is being exported to India.

d. Mangdechhu Hydroelectric Project (720 MW)

The Mangdechhu hydropower project is a run-of-the-river scheme constructed in central Bhutan. The construction started in April 2010 and was recently commissioned in May 2019. The cost of the project was Nu.52.71 billion, which has increased from an initial estimate of Nu.33.82 billion (Bhutan Electricity Authority, 2017). GoI funded the project with a 30 per cent grant and 70 per cent loan repayable for 12 years at a rate of 10 per cent per annum. The tariff for the power was fixed at Nu. 4.12 per unit, which will be increased by 10 per cent every five years (Palden, 2019).

e. Punatshangchhu I Hydroelectric Project (1200 MW)

The Punatshangchhu I hydroelectric project is the largest run-of-the-river project to be undertaken by the GoI and RGoB. It is located in Punatshangchhu river basin in the western part of Bhutan. The agreement for the project was signed on 28 July 2007 and is scheduled to complete by the year 2021. The GoI funds the project with a 40 per cent grant and a 60 per cent loan. The loan has to be repaid within 12 years after completion of the project at an interest rate of 10 per cent per annum. The project has faced a significant setback in terms of cost and time overrun. The DPR cost of the project was Nu.35.13 billion in 2007, which has increased to Nu.99.60 billion as of the year 2015 (Bhutan Electricity Authority, 2017). The project is still under construction.

f. Punatshangchhu II Hydroelectric Project (1020 MW)

The Punatshangchhu II hydroelectric project is a run-of-the-river project located 20 Kms downstream of the Punatshangchhu I project. The agreement for the construction was signed in April 2010 and is scheduled for completion in 2021. The GoI funds the project with a 30 per cent grant and 70 per cent loan, repayable within ten years after commissioning of the project. The interest on the loan is agreed to be paid at a rate of 10 per cent per annum. The initial cost of the project was Nu. 37.77 billion, which has increased to Nu. 72.90 billion as of December 2016 (Bhutan Electricity Authority, 2017). The project is still under construction.

ii. Between Government of Austria (GoA) and Bhutan

Besides India, the RGOB had carried out an IG project with the Government of Austria for the construction of 64 MW run-of-the-river Basochhu hydropower project. The project was started in 1997 and was commissioned in 2001. It was funded with 28 per cent as grant and 72 per cent as a loan, repayable at an interest rate of 2.79 per cent per annum (Druk Green Power Corporation Limited, 2018b). The project supplies all its power for domestic consumption.

2.3.2 Joint Venture Projects

Under the joint venture model, the hydropower project has to be developed by the state-owned enterprise of Bhutan and India. After the agreement was signed, the project will be registered as a company under the Companies Act of the Kingdom of Bhutan, 2000. It was agreed that the project would be developed under the debt-equity ratio of 70 to 30. The GoI will provide the equity of 30 per cent as a grant.

The Kholongchu hydropower project, which is currently under construction, is being implemented through the joint venture model. The project was executed between the Druk Green Power Corporation (Bhutan) and the Satluj Jal Vidyut Nigam Limited (India). The project is located at the lower course of the Kholongchu river in eastern Bhutan. It is a run-of-the-river scheme project with a capacity to produce 600 MW of energy. The project is estimated to cost Nu.37.36 billion, including Nu.31.22 billion as hard cost and Nu.5.9 billion as interest during the construction period (Younten, 2018). The construction for the project started in 2014 and is scheduled to complete by 2023.

2.3.3 Public-Private Partnership projects

In the Public-Private Partnership (PPP) model, the projects have to be developed by the Druk Green Power Corporation, with some equity stakes from private companies both within and outside of the country. The following are the two PPP projects completed and under construction as of 2019:

a. Dagachhu Hydropower Project (114 MW)

The Dagachhu hydropower project is a run-of-the-river scheme located on the left bank of Dagachhu in the south-western part of Bhutan. It is the first project in Bhutan, which is executed through the PPP model. It is also the only project in Bhutan registered with the CDM Executive Board, which allows the project to earn carbon credits that can be traded in international carbon markets. The project was constructed at the cost of Nu. 12,516.00 million, which has increased from Nu. 8,208.00 as per the initial estimates (Bhutan Electricity Authority, 2017). It is jointly owned by DGPC (Bhutan) with 59% shareholding, Tata Power Company Limited (India) with 26% shareholdings, and National Pension and Provident Fund (Bhutan) with 15% shareholdings. The project started its construction in 2009 and was commissioned in 2015.

b. Tangsibji Hydro Energy Project (118 MW)

The Tangsibji hydropower project is a run-of-the-river scheme located in Tangsibji in central Bhutan. It is scheduled to be completed in 48 months from the year 2016, which includes six months of initial infrastructure development & mobilization and 42 months of the construction period. The ADB funds the project with a debt-equity ratio of 65 is to 35. It is estimated to cost around Nu.11.96 billion, which includes the cost for escalation, interest during construction, and the fixed costs (Palden, 2016). The project is still under construction.

CHAPTER THREE: Macroeconomic effects of hydropower development in Bhutan

3.1 Background

Bhutan is rich in water resources and has one of the highest per capita availability of water in the world (Dorji, 2016). With four major rivers flowing from the Himalayan highlands to the lowlands of the Indian plains, Bhutan has strong potential to develop hydropower. Apart from being a source of clean and sustainable energy, hydropower has far-reaching implications for the overall wellbeing and prosperity of the Bhutanese people (Ogino, Dash, & Nakayama, 2019; Veerabhadrappa & Prasad, 2015). The hydropower sector provides enormous potential for socio-economic development in terms of increasing export revenue, sustaining economic growth and eradicating poverty in Bhutan (Boyreau & Rama, 2015). Its main contribution results from the ancillary increase in aggregate demand during the construction phase, followed by additional revenues generated after the commissioning of the projects.

Bhutan's GDP growth rate over the decade to 2017 has averaged around 7.5% per annum, driven primarily by investment in hydropower and the subsequent export of electricity to India (Balasubramanian & Cashin, 2019; World Bank, 2018b). With such consistent economic growth, the poverty rate in Bhutan has declined from 23.2% in 2007 to 12% in 2012, with a further reduction to 8.2% in 2017 (Gross National Happiness Commission, 2013; International Monetary Fund, 2018; Ishihara & Lhaden, 2017). Given the importance of hydropower investment for the Bhutanese economy and the achievement of national development objectives, the expansion of this sector has become one of the highest priorities for the Bhutanese government.

As per the Bhutan Hydropower Development Policy (2008), the Bhutanese hydropower projects are classified into five main categories:

i. Micro or mini power projects: installed power capacity of up to 1 MW;
ii. Small power projects: installed power capacity from 1 MW to 25 MW;
iii. Medium power projects: installed power capacity from 25 MW to 150 MW;
iv. Large power projects: installed power capacity from 150 MW to 1000 MW; and
v. Mega power projects: installed power capacity of more than 1000 MW.

Table 6: Status of the hydropower development in Bhutan as of January 2020

Sl. No.	Category of hydropower plants	Tariff Nu/kWh	Total completed	Capacity in MW (as per category)	Area serviced in Indian and Bhutan States
1	Mini hydropower plants	1.59	12	7.70	*Western and eastern Bhutanese district*
2	Micro hydropower plants	1.59	9	0.42	*Western and eastern Bhutanese district*
3	Medium hydropower plants a) *Kurichhu (60 MW)* b) *Basochhu (64 MW)* c) *Dagachhu (126 MW)*	2.12 2.12 2.90	3	250.00	*a. Eight eastern districts of Bhutan* *b. West Bengal, India* *c. Bihar, India*
4	Large hydropower plants *a. Chhukha Hydropower plant (336 MW)* b. *Mangdechhu Hydropower plant (720 MW)*	2.25 4.12	2	1,056.00	*a. West Bengal, India* *b. Bihar, India* *c. Orrissa, India* *d. Jharkand, India*
5	Mega hydropower plant *(Tala)*	2.12	1	1,020.00	*a. West Bengal, India* *b. Bihar, India* *c. Orrissa, India* *d. Jharkand, India*
	Total		**27**	**2,334.12**	

Source: (Alam et al., 2017; Druk Green Power Corporation Limited, 2018b; National Statistics Bureau, 2018c)

Before 1960, the electricity demand in the country was met through diesel generating sets, which are set up in two major towns, Phuntsholing and Samtse (Ministry of Economic Affairs, 2010). To complement the diesel generating power, some mini and micro hydropower plants were installed in the early 1960s with assistance from various bilateral and multilateral donor agencies. As of 2020, there are 21 mini and micro hydropower plants with a combined installed capacity of 8.12

MW. These mini plants are built with assistance from the governments of India, Norway and Austria. Additionally, a few plants are supported by the United Nations Development Programme.

The turning point for the development of large hydropower projects started after an agreement was signed between the Government of India (GoI) and Bhutan for the construction of the 336 MW Chhukha Hydropower Project. The project was initiated in 1978 with full technical and financial support from India and commissioned in 1988.

The total installed capacity for hydropower in Bhutan is 2,334.12 MW, as detailed in Table 6. As can be observed in the Table 6, in 2020 Bhutan has harnessed around 9.82% of the total techno-economically feasible potential of 23,765 MW. This figure indicates that Bhutan has just developed a minuscule portion of its realisable hydropower potential.

Based on the success of the previous hydropower projects, Bhutan has been investing heavily in the hydropower sector. The future action plan is outlined in the Bhutan Power System Master Plan (2003), Bhutan Sustainable Hydropower Development Policy (2008) and the Bhutan Economic Development Policy (2010). Given the significant impact of the hydropower sector to the local economy, Bhutan has embarked on a plan to generate 10,000 MW of hydroelectricity by 2020 which has been postponed to 2025.

As part of a plan to increase the hydropower capacity to 10,000 MW, projects of various sizes are currently under construction (Table 7).

Table 7: Power plants under construction as of January 2020

Sl. No.	Category of hydropower plants	Total	Capacity in MW	Construction start date	Project completion date
1	Medium hydropower plants *(Nikachu)*	1	118	February 2016	April 2021
2	Large hydropower plants *(Kholongchu)*	1	600	September 2015	February 2022
3	Mega hydropower plants	2	2,220		
a	*Punatshangchhu I (1200 MW)*			November 2008	July 2022
b	*Punatshangchhu II (1020 MW)*			December 2010	December 2021
	Total	**4**	**2,938**		

Source: (Druk Green Power Corporation Limited, 2018b; Tortajada & Saklani, 2018)

Additional projects are also in the pipeline (Table 8), upon the completion of pre-feasibility studies. These projects are proposed to be constructed through a joint venture and public-private partnership model.

Table 8: Details of proposed hydropower project to be developed through the joint venture and public private partnership model

Sl. No.	Hydropower plant	Capacity	Mode of funding		Project period (year)		Project costs in billions (Nu)
		Power (MW)	Debt	Grant	Start	Expected Completion	DPR costs
1	Bunakha	180	70	30	2017	2023	31.68
2	Wangchuk Reservoir	570	70	30	2017	2025	44.70
3	Chamkharchhu – 1	770	70	30	2016	2025	52.12
	Total	**1,520**					

Source: (Druk Green Power Corporation Limited, 2018b)

Bhutan is also actively pursuing investments in three additional mega hydropower projects, with a total of 5,740 MW with GoI financing (Table 9). The detailed feasibility studies on these projects are at a fairly advanced stage, while decisions for the actual investment are being deferred for varying reasons.

Table 9: Details of proposed mega hydropower projects to be financed by the GoI in next five years

Sl. No.	Hydropower plant	Capacity	Mode of funding		Project costs in billions (Nu)
		Power (MW)	Debt	Grant	DPR costs
1	Sankosh Reservoir	2,560	70	30	129.05
2	Kuri-Gongri	2,640	70	30	211.68
3	Amochhu Reservoir	540	70	30	43.78
	Total	**5,740**			**384.51**

Source: (Druk Green Power Corporation Limited, 2018b)

In its effort to further upsurge the hydropower capacity, Bhutan has also identified 11 additional projects as techno-economically feasible (Table 10). These projects, which are currently at various stages of planning, envisage stepping up Bhutan's hydropower capacity by over 2,057 MW in addition to the 10,000 MW. Preliminary concepts have already been shared with the GoI as a development partner and also as a beneficiary of the hydropower projects.

Table 10: Details of eleven additional projects as techno-economically feasible to be planned in future

Sl. No.	Hydropower plant	Capacity Power (MW)	Status of the project
1	Nyera Amari – 1	125	DPR under progress stage
2	Nyera Amari – 2	317	DPR under progress stage
2	Gamri – 1	45	DPR in the planning stage
4	Gamri – 2	85	DPR in the planning stage
5	Chamkharchhu – 1	590	DPR under progress stage
6	Chamkharchhu – 2	364	DPR in the planning stage
7	Dangchhu - 1	170	DPR in the planning stage
8	Jomori (Dhansari)	107	DPR in the planning stage
9	Dagachhu - 2	135	DPR in the planning stage
10	Shongarchhu 1, 2	107	DPR in the planning stage
11	Druk Bindu	12	DPR in the planning stage
	Total	**2,057**	

Source: (Chewang & Tobgye, 2015; Druk Green Power Corporation Limited, 2018b)

While the expansion of hydropower projects has brought significant benefits to Bhutan, there have been various concerns and issues raised in recent times related to an over-concentration of investment, the soaring national debt and the balance of payment issues as discussed earlier. Most of the research carried out on the impact of the hydropower projects has so far ignored the actual impact on Bhutan's GDP growth during the investment phase and mostly focused on the results from after commissioning of the project. Therefore, this research has investigated the overall impact of hydropower development on the Bhutanese economy at a macro level on its economic growth during the construction phase. The study also attempted to ascertain how domestic investment, domestic labour and foreign labour have contributed to GDP growth in Bhutan.

In the following section, the study discusses the contribution of hydropower to the Bhutanese economy, reviews the literature on global debates concerning hydropower, and outlines the research methodology and econometric process, research data, results and discussions, and the conclusions from the analysis.

3.2 Literature review: Global debates on hydropower, energy security, and economic development

Hydropower represents an essential source of renewable energy with multiple benefits. It is the only source of energy that is renewable and viable at a large scale (Killingtveit, 2019; Y. Li, Li, Ji, & Yang, 2015) and a symbol of economic development along with serving as a mitigating factor for climate change (Cole, Elliott, & Strobl, 2014; Nordensvard, Urban, & Mang, 2015). The critical advantage of hydropower is that the energy output from it can be adjusted to demand by the customers. With the flexibility of being able to supply electricity when in need and absorbing it when in surplus, it is seen as an efficient source of renewable energy compared to solar and wind power (Gürbüz, 2006; International Hydropower Association, 2018).

The world's first hydropower plant was built in 1882 in Appleton, Wisconsin, USA (Breeze, 2018; Shortridge, 1988). By 1899, the United States alone had 500 hydroelectric plants generating more than 150 MW of energy. The turning point for the utilisation of large dams for hydropower began in the early 20th century with the construction of first mega dams such as Aswan Low Dam in Egypt, built-in 1902, and the colossal Hoover Dam in the United States built in 1932 (Department of Energy, 2016). In recent years, with 186 of the 195 countries being a signatory to the 21st Conference of Parties (COP 21), hydropower investment has become a priority for many countries (Berga, 2016; Tan-Mullins, Urban, & Mang, 2017). It is perceived that hydropower can serve as a tool to cater to a growing demand for power while fulfilling commitments to climate change.

In terms of the installed capacity and global investment portfolio, hydropower remains the largest source of renewable energy (Sovacool & Walter, 2018). The International Hydropower Association (2018) specified that the total capacity for hydropower worldwide had increased to 1,267 gigawatts by 2017, with a record of 4,185 terawatt-hours (TWh) of electricity generated in that year. With its contribution to the global energy supply, hydropower plays a critical role in terms of sustainable energy security in the longer run. If well planned and constructed responsibly, the cost of electricity production from hydropower is stated to be one of the cheapest in the world

(Kaunda, Kimambo, & Nielsen, 2012). This is one of the reasons why hydroelectricity is popular amongst the utility companies.

The International Hydropower Association (2018), in its report, stated that by replacing coal and thermal power plants with hydropower plants has prevented approximately four billion tons of greenhouse gas emissions globally. In 2017 alone, the use of hydropower electricity avoided the dispersal of 148 million tons of air polluting particles, 62 million tons of sulphur dioxide, and eight million tons of nitrogen oxide. From this, it can be stated that hydropower is critical for long-term energy security and sustainable economic development. In fact, electricity usage is so essential that some countries' level of development is strongly correlated to this energy source (Solarin & Shahbaz, 2013). For instance, in 2009, 81.41% of the population residing in middle-income countries had access to electricity. This figure is comparatively higher than the 24.84% of the population who had access to electricity in the least developed countries, indicating a considerable gap between the two groups of countries. In the same year, despite African countries having a larger population than that of the European Union (EU), the electricity consumption in the EU was eleven times greater than the total consumption of sub-Saharan African countries.

The empirical evidence indicates a positive relationship between electricity consumption and a country's economic growth. Thus, hydropower as a source of non-renewable energy can play a critical role in the long-term socio-economic development of both developed and developing countries. Shiu and Lam (2004) examined the causal relationship between electricity consumption and real GDP in China for the period 1971 to 2000 using the error-correction model. It was found that there is a positive correlation between electricity consumption and an increase in real GDP, showing a unidirectional Granger causality running from electricity to GDP. The study stated that any shock in electricity consumption would adversely affect industrial growth, as growth in electricity triggers GDP through industrial demand for electricity. Narayan and Smyth (2009), while investigating the causal relationship between electricity consumption, exports and gross domestic product for a panel of middle eastern countries, observed that a unit increase in the percentage of electricity consumption increases GDP by 0.04%. On the other hand, a one per cent increase in GDP generates an increase of 0.95% of electricity consumption. In a similar study using time series data for the period 1971 to 2003, Chandran, Sharma, and Madhavan (2010) examined the relationship between electricity consumption and GDP for Malaysia. The authors observed the existence of a long-run relationship between electricity consumption and the GDP growth rate. The autoregressive distributed lag result for the electricity consumption on GDP was found to be 0.7 and statistically significant. Even in the short run, the result from the causality test indicated the existence of a uni-directional causal flow from electricity consumption to economic growth rate for that period.

Besides its environmental and social benefits, the construction of a hydropower project has a spillover economic benefit both during its development and in the post-commissioning of the project. Like any other public infrastructure project, hydropower projects involve substantial civil engineering works with high labour, material and startup costs. As a result, such projects have the potential to increase economic activity and tax revenues in the surrounding regions. International organisations, such as the United Nations Development Programme, World Bank, and the Asian Development Bank, emphasise the critical role played by hydropower and its dams in terms of achieving the sustainable development goals set for the new millennium in developing countries. If pursued sensibly, the construction of hydropower dams has the potential to reduce poverty, while increasing irrigation and electricity (De Faria, Davis, Severnini, & Jaramillo, 2017; Duflo & Pande, 2005, 2007). Awojobi and Jenkins (2015) have investigated 58 hydropower dams financed by the World Bank between the period 1976 and 2005 to ascertain the net economic benefits. It was found that the net contribution from these dams to the economy was positive and substantial. The average ex-ante rate of return from the project was estimated to be around 24.3%, while the ex-post average real rate of return was more than 17% with a net economic present value of approximately US$913 billion.

Hanseen, Lowe and Xu (2014) investigated the long-term impact of large dams in 44 Idaho counties focusing on crop mixes, agriculture productivity and land values. Most of the dams in the counties were used for multipurpose activities such as the generation of electricity, flood protection, drinking water and irrigation. The study was carried out between 1920 and 2002 using a country-level repeated cross-sectional dataset. It was found that the presence of dams has a significant positive impact on agricultural productivity, particularly in those counties where farmers have predominantly marginal water rights.

Despite the apparent benefits that can be derived from the construction of large dams, their merit has been widely contested in the literature on economic development and growth. The primary concerns from the construction of hydropower projects are their social and environmental costs, which sometimes outweigh their benefits. There are also widespread criticisms in regards to the displacement of settlements, resettlement and migration issues, ecological and environmental damages, adverse impact on cultural and social cohesion, and loss of fertile land and watershed destructions (Cernea, 2004; Hilmarsson, 2017; Magee, 2015).

A study by Salazar (2000) on the impact of Three Gorges Dam in China revealed that the social costs from such projects can be high with substantial adverse effects on the local communities. Due to the rise in water level by 175 metres, many archaeological, historical and cultural sites are now lost along the river basin. For instance, the dam has submerged three gorges, 13 cities, 140 towns, more than 1,300 villages, 955 business, and 115,000 acres of arable land, along with displacing 1.9 million people. Overall, the study found that the negative economic ramification from the large-scale dam construction is so significant that, even for a large economy like China, it could hinder its economic viability if inherent risks for the projects are not well managed. A similar study by Jackson and Sleigh (2000) on the socio-economic impact of Three Gorges Dam revealed that the economic cost of submerging farmland due to the project was extremely high. The project has flooded nearly 34,000 ha of agricultural land, of which 50% was used as rice fields, 22% garden plots, 1 % fishponds, and 10% was forest, all impacting the local communities.

Altinbilek (2002) stated that most of the developing countries lack capital and have to rely on external financing to implement large megaprojects. Therefore, executing mega-dam projects results in increased risks of debt and may undermine the country’s future sustainability.

Middleton et al. (2009) reported that dam construction along the Mekong River has resulted in local communities becoming impoverishment. A specific case was given for the Hoa Binh Dam project in Vietnam, where 50,000 to 60,000 people were resettled without any compensation. Similarly, the Nam Song Diversion Dam in Laos has affected around 13 villages through the deterioration of the surrounding natural resources, a decline in fishery production, erosion and flooding of the agricultural land along the river basin.

Ansar (2014) and his team from Oxford University have investigated 245 large dams from 65 countries built between 1934 to 2007 using the “outside view” or “reference class forecasting” method. They have found that three of every four large dams have experienced cost overruns, which were estimated to be 96% higher than the estimated original cost. Increases in the investment costs of large dams due to time and cost overruns have resulted in the explosive growth of debt in most of the developing countries. The study recommended that to minimise the risk of economic uncertainties, countries with a lower level of economic development should devise strategies to implement alternative energy sources that have shorter implementation spans and smaller budgets.

The econometric result from this study supplements the findings from the literature to indicate that hydropower project has positively benefitted the economic growth in Bhutan. It has a spillover benefit to the Bhutanese economy during the construction phase and a direct impact after the project commissioning. This study contributes to the literature on the impact of hydropower project on economic growth in three ways. First, the findings will provide empirical evidence to demonstrate how hydropower during its construction period has impacted Bhutan's economic growth during the last four decades. Few studies have been conducted by the international donor agencies, such as the World Bank (2005, 2009), Asian Development Bank (2008), and the United Nations Development Programme (2006), on the impact of hydropower on the Bhutanese economy. But most of the analysis is focused on the export of electricity after the commissioning of the project. There is no identifiable research that has empirically investigated the overall impact of hydropower during its construction phase on Bhutan's economic growth. Second, the study will show whether any shocks in the GDP growth during a certain period as a result of hydropower investment has any spillover impact on the remaining GDP growth rate in Bhutan. Third, the results obtained from this study are policy relevant as several mega hydropower projects are already planned for the near future. Therefore, any key findings from this study can be used to guide policy decision for future hydropower investment in Bhutan.

3.3 Research methodology and econometric process

The theoretical framework for the study is based on the endogenous growth theory by Romer (1994), where the driving force behind a country's economic growth is the accumulation of knowledge. This indicates that the economic growth of a country is dependent on the accumulation of physical capital, human capital, labour and technological change. Though there is a possibility that the neoclassical trade model with FDI can be used in the study, I have chosen the endogenous growth model for three reasons. First, in the long run, the economic growth of the country will largely depend on technological progress and growth in the labour force growth. Second, due to diminishing returns to capital, FDI affects growth in the short run. The conventional neo-classical growth model with FDI may not provide a realistic explanation or interpretation of these implications. Third, there is a growing literature on using endogenous growth theory to determine the impact of FDI on economic growth in the long run (Asheghian, 2016; De Mello, 1999; De Mello & Fukasaku, 2000; Ericsson & Irandoust, 2001).

3.3.1 The model setup

The study is an extension to a similar idea developed by De Mello (1997), where the economy is based on the production of a single consumption good. The critical difference between the model developed by De Mello and the current study concerns the function of human capital stock *'L'*. As per the De Mello (1997; 1999) formula, the total stock of knowledge 'L' in the economy depends on domestic as well as foreign-owned physical capital stock. It is assumed that with an inflow of FDI to the economy, the recipient economy might experience increasing returns to scale that will ultimately have an impact on faster economic growth. However, in this model, it is assumed that the human capital stock consists of foreign and domestic-owned labour.

Let us consider the following simple AK production function, which produces single consumption goods electricity:

$$y = Ef(K, L, H) \tag{1}$$

Where y denotes real GDP, E is the economy's total productivity level, K is the physical capital, while L and H are the labour and investment in hydropower. The economy productivity level *'E'* in this model will depend on various policy and organisational support frameworks instituted by the government as well as other factors, which will have an impact on the change in productivity.

Let us also assume that investment in hydropower requires labour and physical capital. With this assumption, equation (1) can be rewritten by the following Cobb-Douglas production function:

$$y = EK^{a} L^{1-a} \tag{2}$$

Here a is the share of physical capital, which is assumed to be diminishing returns to scale (i.e., a is less than 1). The physical capital consists of domestic capital (K_d) and the foreign-owned capital (K_f) as a result of the inflow of FDI for the construction of hydropower. Likewise, human capital also consists of domestic as well as foreign human capital. The Cobb-Douglas production function for the physical capital is represented as:

$$K = K_d K_f^{\theta} \tag{3}$$

The θ in equation (3) is the marginal elasticity of substitution between foreign and domestic-owned capital. It is the elasticity of the ratio of foreign and domestic owned capital with respect to the ratio of their marginal products.

Similarly, the Cobb-Douglas production function for human capital is as represented below:

$$L = L_d L_f^{\lambda} \tag{4}$$

Where λ is the marginal elasticity of substitution between foreign and domestic human capital.

Combining equations (2), (3), and (4) results in the following equation:

$$y = E(K_d H_f^{\theta})^a (L_d L_f^{\lambda})^{1-a} \tag{5}$$

$$y = EK_d^a K_f^{\theta a} L_d^{1-a} L_f^{\lambda\, 1-a} \tag{6}$$

After taking the natural logs on both sides of equation (6), the following equation is obtained:

$$Lny = LnE + aLnK_d + \theta aLnK_f + (1-a)LnL_d + \lambda(1-a)LnL_f \tag{7}$$

Finally, by taking the time derivative on equation (7), equation (8) is obtained:

$$\frac{1}{y}\frac{dy}{dt} = \frac{1}{E}\frac{dE}{dt} + a\frac{1}{k}\frac{dK_d}{dt} + \theta a\frac{1}{k_f}\frac{dk_f}{dt} + (1-a)\frac{1}{L_d}\frac{dL_d}{dt} + \lambda(1-a)\frac{1}{L_f}\frac{dL_f}{dt} \tag{8}$$

The growth rate of efficiency or technology in equation (8) is determined as:

Let $E(t) = \mathrm{e}^{a_0 + a_1 t + 0.5 a_2 t^2}$

Then $\dfrac{dE(t)}{dt} = (a_1 + a_2 t)\ e^{a_0 + a_1 t + 0.5 a_2 t^2}$

$$= (a_1 + a_2 t)E(t)$$

$$\frac{(dE(t)/dt)}{E(t)} = a_1 + a_2 t \tag{9}$$

Combining equations (8) and (9) yields the following equation:

$$\frac{1}{y}\frac{dy}{dt} = a_1 + a_2 t + a\frac{1}{k_d}\frac{dk_d}{dt} + \theta a\frac{1}{k_f}\frac{dk_f}{dt} + (1-a)\frac{1}{L_d}\frac{dL_d}{dt} + \lambda(1-a)\frac{1}{L_f}\frac{dL_f}{dt} + u(t) \tag{10}$$

The key variables in the above equation can be written in terms of rates of change, or equivalently, as log derivatives over time as in equation (11) below:

$$\begin{aligned}\frac{d\ln GDP_t}{dt} &= a_1 + a_2 t + a_3\frac{d\ln GDI_t}{dt} + a_4\frac{d\ln GDL_t}{dt} + a_5\frac{d\ln GFI_t}{dt} + a_6\frac{d\ln GFL_t}{dt} + u_t \\ &= a_1 + a_2 t + a_3\frac{dGDI_t/dt}{GDI_t} + a_4\frac{dGDL_t/dt}{GDL_t} + a_5\frac{dGFI_t/dt}{GFI_t} + a_6\frac{dGFL_t/dt}{GFL_t} + u_{1t} \qquad (11) \\ &= \frac{dGDP_t/dt}{GDP_t}\end{aligned}$$

In practice, the continuous-time derivatives are replaced with discrete approximations as below: $(GDP_t - GDP_{t-1})/GDP_{t-1}$, or midyear equivalents $(GDP_t - GDP_{t-1})/½(GDP_t + GDP_{t-1})$, etc.

By taking the anti-derivate of equation (10) is equivalent to a Cobb-Douglas model in levels,

$$GDP_t = \exp\left\{a_0 + a_1 t + ½a_2 t^2\right\} GDI_t^{a_3} GFI_t^{a_4} GDL_t^{a_5} GFL_t^{a_6} e^{t\cdot u_{1t}}$$

In equation (11), $\frac{d\ln GDP_t}{dt}$ is the log derivative of real per capita GDP, *t* is the time trend, which measures the growth rate of efficiency or technology, $\frac{d\ln GDI_t}{dt}$ is the log derivative of the gross domestic investment, $\frac{d\ln GDL_t}{dt}$ is the log derivative of the total domestic labour, $\frac{d\ln GFI_t}{dt}$ is the log derivative of the total hydropower investment, which is in the form of FDI, and $\frac{d\ln GFL_t}{dt}$ is the log derivative of the total foreign labour.

3.3.2 Econometric model

Studies have suggested that there is a positive relationship between domestic investment and access to finance in most developing countries (Asimakopulos, 1986; Ndikumana, 2000, 2005; Wai & Wong, 1982). The neoclassical theory shows that high-interest rates raise the cost of capital, which can affect domestic investment (Drobyshevsky, Trunin, Bogachkova, & Sinelnikova-Muryleva, 2016; Ndikumana, 2000). In Bhutan, several studies have indicated that the availability of cheap electricity has resulted in the establishment of several energy-intensive industries in the south (Ogino, Nakayama, & Sasaki, 2019; Royal Monetary Authority, 2018; World Bank, 2018a).

Without the availability of cheap electricity, Bhutan will not be able to set up domestic industries that are all energy intensive. The International Monetary Fund (2016; 2018) and the Ministry of Finance (2018; 2019) have highlighted that the increased growth of Bhutan's construction sector in the last decade has resulted in significant the growth of domestic investments. The labour supply in a country depends on the size of the population, which is determined by its history of fertility, mortality and migration patterns (Bloom & Freeman, 1986; Schmidt, 1984). Intuitively, higher unemployment rates in a country means there is a larger pool of workers willing to work (who are not currently working).

The GDI and GDL in equation 11 are determined by other variables, where:

$$\frac{d\ln GDI_t}{dt} = f\left(\frac{d\ln ElxDom_t}{dt}, \frac{d\ln Credit_t}{dt}, \frac{d\ln Rate_t}{dt}, \frac{d\ln rCons_t}{dt}, \frac{d\ln ElxExport_t}{dt}\right) + \varepsilon_{GDI,t}$$

and $\frac{d\ln GDL_t}{dt} = f\left(\frac{d\ln Poprate_t}{dt}, \frac{d\ln Unemprate_t}{dt}\right) + \varepsilon_{GDL,t}$.

These errors are likely to be correlated with the error in the regression equation for $d\ln GDP_t/dt$ resulting in an endogeneity problem and simultaneous equations bias.

In order for the OLS estimation to yield a reliable result, all dependent variables on the right-hand side of equation 11 should be independent of all current, past and future values of the error term. However as discussed earlier, $\frac{d\ln GDI_t}{dt}$ and $\frac{d\ln GDL_t}{dt}$ are jointly determined, and thus the OLS estimation of equation 11 will result in simultaneous equations which will be biased and inconsistent (Wooldridge, 2012).

To overcome the problem of endogeneity and to produce a valid and consistent outcome, the study uses two-stage least square (TSLS) or the instrumental variable estimation approach. Poi (2006) stated that the TSLS is the most common instrumental variable estimator to address endogeneity problem in the structural equations. In the TSLS estimation, the independent variables that are endogenous are predicted by a list of instruments, which checks the relationships without being correlated with the disturbances.

Steps to calculate the TSLS:

For simplification, let's relabel the structural equation (11) as below:

$$y_{1t} = x_{0t}\beta_{10} + x_{1t}\beta_{11} + x_{2t}\beta_{12} + x_{3t}\beta_{13} + y_{2t}\gamma_{12} + y_{3t}\gamma_{13} + u_{1t} \tag{12}$$

where $u_{1t} = \rho_1 u_{1t-1} + \varepsilon_{1t}$ with ε_{1t} $i.i.d.\ (0,\ \sigma_1^2),\ \ t = 1,\ldots..T$

The endogenous and exogenous variables from equation (11) are as identified below:

The ***endogenous variables*** are: $y_{1t} = \dfrac{d \ln GDP_t}{dt},\ \ y_{2t} = \dfrac{d \ln GDI_t}{dt},\ \ y_{3t} = \dfrac{d \ln GDL_t}{dt}.$

The ***exogenous variables*** are:

$$x_{0t} = 1,\ x_{1t} = t,\ x_{2t} = \frac{d \ln GFI_t}{dt},\ x_{3t} = \frac{d \ln GFL_t}{dt}$$

As any exogenous regressors can serve as its own instrument, the study will use the following instruments for $y_{2t} = \dfrac{d \ln GDI_t}{dt}$, and $y_{3t} = \dfrac{d \ln GDL_t}{dt}$ as below:

For y_{2t}, the instruments are (refer Table 11 for an explanation of these variable):

$$z_1 = \frac{d \ln ElxDom_t}{dt},\ z_2 = \frac{d \ln \text{Credit}_t}{dt},\ z_3 = \frac{d \ln Rate_t}{dt},\ z_4 = \frac{d \ln rCons_t}{dt} \text{ and } \mathrm{z}_5 = \frac{d \ln ElxExport_t}{dt}$$

Similarly, for y_{3t}, the instruments are: $z_6 = Poprate\ and\ z_7 = Unemprate$

Using annual time series data with finite samples may result in serial correlation issues, which may lead to biased statistical inferences that need to be corrected. For this, first used OLS to estimate $\hat{\boldsymbol{\Pi}}_{OLS}$ structural equation. The consistency of the OLS estimator implied that each equation's $T \times 1$ vector of OLS estimated residuals also is consistent,

$\hat{\boldsymbol{v}}_i = \boldsymbol{y}_i - \boldsymbol{X}(\boldsymbol{X}'\boldsymbol{X})^{-1}\boldsymbol{X}'\boldsymbol{y}_i = \boldsymbol{y}_i - \boldsymbol{X}\boldsymbol{b}_i \xrightarrow{P} \boldsymbol{y}_i - \boldsymbol{X}\boldsymbol{\pi}_i = \boldsymbol{v}_i,\ i = 1, 2, 3.$ Tests for the first-order serial correlation on the structural equation with the Durbin-Watson test statistic are undertaken using the $\hat{\boldsymbol{v}}_i$ error terms. Since serial correlation is absent, the OLS estimators are fully efficient for the estimation.

The TSLS is being estimated as below:

a. First estimate the reduced form equation for $y_{2t} = \frac{d \ln GDI_t}{dt}$ and $y_{3t} = \frac{d \ln GDL_t}{dt}$:

$$y_{2t} = \delta_0 + \delta_1 x_{2t} + \delta_2 x_{3t} + \delta_3 z_1 + \delta_4 z_2 + \delta_5 z_3 + \delta_6 z_4 + \delta_7 z_5 + \delta_8 z_6 + \delta_9 z_7 + u_{2t}$$

$$y_{3t} = \pi_0 + \pi_1 x_{2t} + \pi_2 x_{3t} + \pi_3 z_1 + \pi_4 z_2 + \pi_5 z_3 + \pi_6 z_4 + \pi_7 z_5 + \pi_8 z_6 + \pi_9 z_7 + u_{3t}$$

By OLS estimation, obtain the fitted value for y_{2t} and y_{3t} as below:

$$\hat{y}_{2t} = \hat{\delta}_0 + \hat{\delta}_1 x_{2t} + \hat{\delta}_2 x_{3t} + \hat{\delta}_3 z_1 + \hat{\delta}_4 z_2 + \hat{\delta}_5 z_3 + \hat{\delta}_6 z_4 + \hat{\delta}_7 z_5 + \hat{\delta}_8 z_6 + \hat{\delta}_9 z_7 + u_{2t}$$

$$\hat{y}_{3t} = \hat{\pi}_0 + \hat{\pi}_1 x_{2t} + \hat{\pi}_2 x_{3t} + \hat{\pi}_3 z_1 + \hat{\pi}_4 z_2 + \hat{\pi}_5 z_3 + \hat{\pi}_6 z_4 + \hat{\pi}_7 z_5 + \hat{\pi}_8 z_6 + \hat{\pi}_9 z_7 + u_{3t}$$

b. Replace y_{2t} and y_{3t} in the structural equation by $\hat{y}_{2t}$ and $\hat{y}_{3t}$; and then estimate the new regression equation:

$$y_{1t} = x_{0t}\beta_{10} + x_{1t}\beta_{11} + x_{2t}\beta_{12} + x_{3t}\beta_{13} + \hat{y}_{2t}\gamma_{12} + \hat{y}_{3t}\gamma_{13} + \varepsilon_t$$

After the TSLS, Durbin-Wu-Hausman tests were performed to test for the presence of an endogenous regressor and confirm the exogeneity of the instrument used in the model.

3.4 Research data

The study has used annual time series data maintained by the National Statistical Bureau (NSB), Royal Monetary Authority of Bhutan (RMAB), World Bank, International Monetary Fund (IMF) and the United Nations Development Programme (UNDP) for the period of 1980 to 2018. This period was chosen for two main reasons. Firstly, there is a lack of reliable data before 1980, since Bhutan had just opened its economy to the outside world after its accession to the United Nations in 1971. With support from the UNDP, Bhutan was able to maintain statistics after the year 1980. Secondly, the first hydropower plant was constructed in 1978 and commissioned in 1987. Therefore, the inflow of capital, as well as physical resources pertaining to the hydropower investment, started only from 1979 onwards.

3.4.1 Key variables used for the analysis

For this study the following key variables (Table 11) have been used to estimate the systems of equations:

Table 11: Key variables used for the study

Variable	Description	Source
GDP	Log of real per capita gross domestic product	WB, NSB, RMA, IMF, and UNDP
GDI	Log of real gross domestic investment	RMA, NSB, and MoF
GFI	Log of real gross foreign investment, which is in the form of hydropower investments	RMA, NSB, and MoF
GDL	Log of gross domestic labor	MoLHR and ILO
GFL	Log of gross foreign labor	MoLHR and ILO
t	The growth rate of efficiency/technology	Computed from the data
ElxDom	Log of the sale of electricity for domestic consumption	RMA, NSB, and MoF
Poprate	Annual population growth rate	RMA, NSB, and MoF
Credit	Domestic credit provided by the financial sector (% of GDP)	RMA and WB
Rate	Average lending rate by the bank (in %)	RMA
ElxExport	Log of export of electricity to India	RMA and NSB
Unemploymentrate	Annual unemployment rate (in %)	WB and NSB
rCons	Log of real construction shares to real GDP	RMA and NSB

*(**Acronym:** ILO: International Labour Organization; MoF: Ministry of Finance; MoLHR: Ministry of Labour and Human Resources; NSB: National Statistical Bureau; IMF: International Monetary Fund; RMA: Royal Monetary Authority of Bhutan; UNDP: United Nation Development Programme; WB: World Bank)*

3.4.2 Description of the data set

The descriptive statistics of the vital time series data are summarised in Table 12.

Table 12: Descriptive statistics of the key variables

Variables	Mean	Standard deviation	Min	Max
Real gross domestic product	24,239.12	10.82	5,391.08	55,050.89
Real gross domestic product growth rate	6.44	5.21	-0.408	25.09
Gross domestic investment	1,997.21	1,691.95	132.00	5,542.90
Gross hydropower investments	7,393.40	10,189.29	0	36,959.64
Total domestic labor	249,550.90	77,152.92	179.84.00	388,978.00
Total foreign labor	28,291.96	14,340.96	1900.00	52,000.00
Total electricity export to India	4,096.12	4,759.91	0	12,041.71
Total domestic sale of electricity	582.88	956.75	0	12,041.71
Domestic credit (% of GDP)	19.782	18.99	-1.305	59.591
Lending rate by the bank (in %)	15.141	.952	13.75	17
Population growth rate	1.718	.947	-.36	3.211
Unemployment rate	1.897	.978	.12	3.96
Construction share to real GDP	3363.747	2766.869	723.765	9979.736

From 1980 to 2017, the real GDP growth rate was approximately 6.44% average per annum. The maximum growth rate of 25.09% was observed in the year 1987 when the first hydropower plant *(Chhukha Hydropower)* was fully commissioned in that year. It was at this time that Bhutan exported its first electricity to India based on a bilateral agreement drawn between the two countries. The lowest economic growth rate of -0.41% was observed in the year 1991. During the year 1990 to 1994, no hydropower investments were made by the Bhutanese government. The country experienced its first internal strife with illegal migration from Nepal during this period, which halted the majority of developmental activities (Misra, 1996; Nidup, 2015).

The maximum amount of hydropower investment occurred in 2015 with the ongoing construction of five large and mega hydropower projects within that period. In terms of the export of electricity, Bhutan exported the highest load, worth Nu.12 billion, to India in 2016. That was mainly after the completion of the Dagachhu Hydropower Project (114 MW), which started its commercial operation in 2016.

The ratio of hydropower investment to real GDP has averaged around 16% for the measurement period. In addition, the share of hydropower investment to GDP ranges from a minimum of 1.2% to a maximum of 62.33% for the study period, as depicted in Figure 4. The significant slump in the development of hydropower was experienced during the period of internal strife during the years of 1990 to 1994 and in the year 2007.

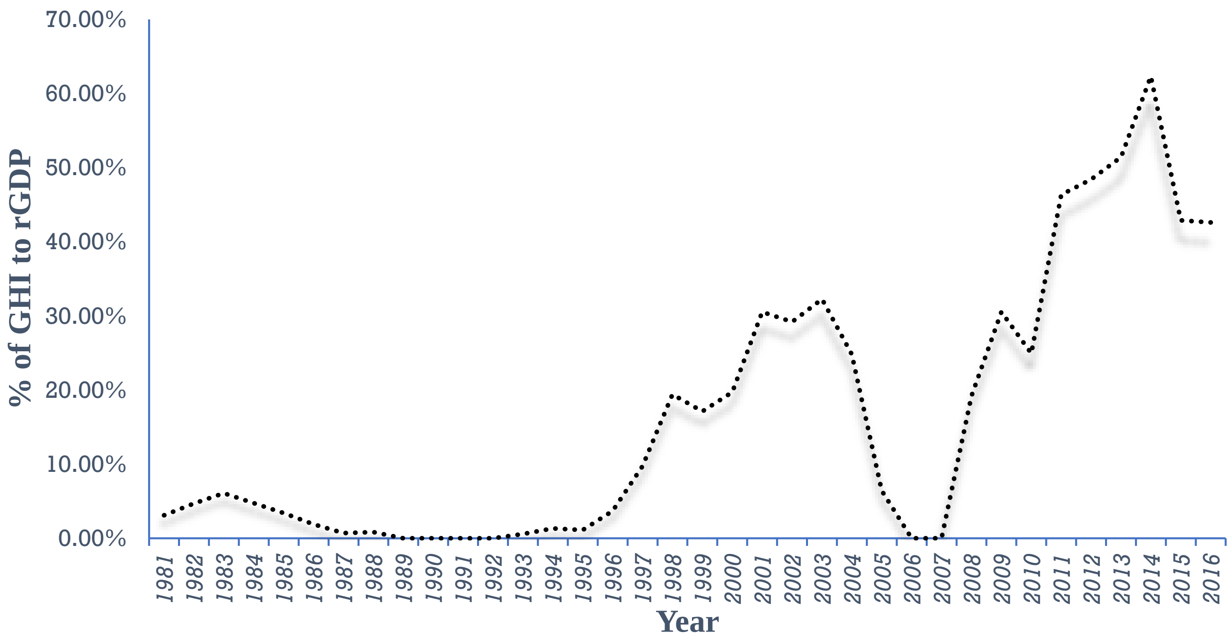

Figure 4: Percentage of hydropower investment share to the real GDP (1981 to 2016)

Source: (Royal Monetary Authority, 2018; National Statistical Bureau, 2017)

3.4.3 Correlation results

The correlation matrix of the variables is summarised in Table 13. This correlation matrix provides a preliminary estimation of the relationship between different variables used for the analysis.

From the matrix, it can be observed that there is a positive relationship between gross domestic investments, gross domestic labour, the export of electricity and sale of electricity for domestic consumption with the gross domestic product. The sale of electricity to the domestic market also has a positive impact on the gross domestic investments. On the other hand, the lending rate has a negative relationship with both the gross domestic product and the domestic investments. The growth of the construction sector and the export of electricity to India has a positive correlation with domestic labour.

This correlation matrix also detects any multicollinearity issues between the variables. Allen (1997) stated that if there are any multicollinearity issues, it will underestimate the statistical significance of the explanatory variables. As per Williams (2015), the high correlation usually above 0.80 in the pairwise correlation matrix may indicate a collinearity issues. Since none of the coefficient of the pairwise correlation regression in the matrix is above .80, there is no significant multicollinearity issues noticed at this moment.

Table 13: Correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1.Gross domestic product	1.00											
2.Gross domestic investment	0.45*	1.00										
3.GFI (hydropower investments)	0.18	0.06	1.00									
4.Gross domestic labour	0.34*	0.26	-0.15	1.00								
5.Gross foreign labour	-0.02	0.11	0.54*	-0.02	1.00							
6.Electricity export to India	0.53*	0.21	-0.03	0.30*	-0.08	1.00						
7.Electricity sale (Domestic)	0.31*	0.35*	0.28*	-0.00	0.20	0.24	1.00					
8.Domestic credit	-0.02	0.05	0.05	0.13	0.03	-0.09	0.15	1.00				
9.Lending rate	-0.29*	-0.43*	-0.12	0.11	0.05	0.05	-0.21	-0.03	1.00			
10.Population growth rate	0.40*	0.02	-0.17	0.15	-0.24	0.29*	0.14	-0.05	-0.24	1.00		
11.Unemployment rate	0.02	-0.04	0.04	-0.06	-0.00	-0.14	-0.23	0.02	-0.12	-0.23	1.00	
12.Construction growth	0.16	-0.14	0.31*	0.11	-0.04	-0.08	-0.28*	0.05	0.06	0.01	-0.01	1.00

*Significant at 10% confidence level

3.5 Estimation results and discussions

Before estimating the proposed model, a correlation test was performed using the Durbin–Watson statistics and extended tables for *d* statistics by Savin and White (1977). The test is to ascertain whether the error term in the linear regression follows the AR (1) process. The Durbin–Watson *d* statistic from the structural equation with time trend is 1.80 (Refer Appendix 1.1). Given 36 observations and six regressors in the model, the upper 1% bound is 1.666, a little lower than the computed *d* statistic. Therefore, the study accept the null hypothesis of no first-order serial correlation at the 1% significance level. Similarly, the Durbin–Watson *d* statistic for the structural equation without the time trend is 1.78, which is higher than the upper bound of 1.587 (Refer Appendix 1.2). This also indicates that there is no positive serial correlation observed at the 1% significance level. In the absence of serial correlation in the structural equation, the OLS estimator was efficient for the analysis.

3.5.1 OLS and TSLS estimation without the dummy variables

The primary goal of this thesis is to examine the impact of hydropower investments on economic growth, taking into account the effect of gross domestic investments, domestic labour and foreign labour. Before the estimation, the test was performed on whether a linear trend occurs in the estimation model. It is also to ascertain whether the Hicks neutrality[7] has any significant effect on the GDP growth in Bhutan. For this, the OLS was estimated with a time trend as the independent variable. The results indicated that the coefficient of time trend (Hicks neutrality) has no significant impact with its *p*-value of 0.272 (Refer Appendix 2). With this, the OLS and the TSLS was estimated without time trend as tabulated in Table 14.

Since each variable is expressed as a natural log, each coefficient can be interpreted in terms of elasticities. The OLS estimation indicates that the parameter of interest (foreign direct investment) in the form of hydropower investment has a marginal impact on GDP growth. A 1% increase in gross foreign investment in hydropower is associated with a 0.02% increase in real GDP per capita.

[7] The Hicks neutrality is based on the definition by Blackorby, Lovell, and Thursby (1976) , where “neutrality in the Hicksian sense concerns technical change which leaves marginal rates of substitution between each pair of inputs unchanged”

Similarly, 1% increase in the domestic investment and domestic labour is associated with a 0.17% and 0.12% increase in the real GDP per capita.

In order to increase the robustness of the study and to eliminate endogeneity issue, regression with two-stage least square was performed using the instruments for GDI and GDL. With the inclusion of the instruments, there is a significant change in the coefficient for domestic investment and domestic labour. As observed, a 1% increase in domestic investment increases GDP per capita by 0.264%. Similarly, for every 1% increase in domestic labour, the GDP increases by 0.43% holding other variables constant.

Table 14: The OLS and TSLS estimation without time trend

Variables	OLS estimation	TSLS estimation
Gross domestic investments	0.168**	0.264*
	(0.0667)	(0.148)
Gross domestic labour	0.116*	0.430**
	(0.0637)	(0.195)
Gross foreign investments	0.0214*	0.0311*
	(0.0115)	(0.0163)
Gross foreign labour	-0.0288	-0.0400
	(0.0218)	(0.0295)
Constant	0.0436***	0.0216
	(0.00938)	(0.0175)
Observations	36	36
R-squared	0.335	-
Note for TSLS:		
Instrumented: GDI1 GDL1		
Instruments: GFI1 GFL1 ElxDom1 Credit1 Rate1 rCons1 ElxExport1 PopRate1UnEmploymentrate1		

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

As the parameter of interest, hydropower investment has a minimal impact on the GDP growth for the study period. With a 1% increase in the hydropower investment, the GDP growth rate increased by 0.03%, which was much less than contributions by domestic investment and domestic labour.

To ascertain the real effect of hydropower investment on the Bhutanese economy, the GDP growth rate was compared with the year in which hydropower projects were commissioned. This is to compare the impact of hydropower on the GDP growth rate during construction and after commissioning of the projects. The real GDP growth rate of Bhutan for the period 1981 to 2016 is illustrated in Figure 5.

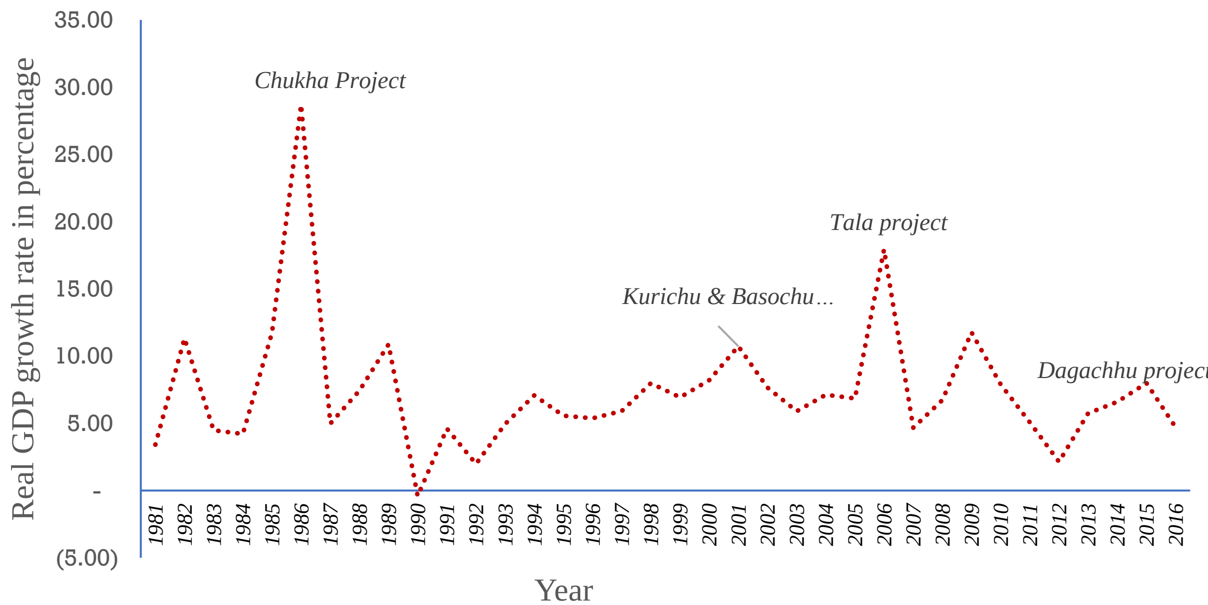

Figure 5: Real GDP growth rate of Bhutan for the period 1981 to 2016

Source: (Royal Monetary Authority, 2018; National Statistics Bureau, 2017)

On comparing Figure 5 with the history of hydropower development, it was observed that there had been an increase in the GDP growth rate when the hydropower plant was commissioned. The comparison of the GDP growth rate vis-à-vis the commissioning of the hydropower plant is summarised in Table 15.

Table 15: GDP growth rate and corresponding hydropower commissioning year

Sl. No	Name of the hydropower plant	Power generation (Mega Watt)	Construction period		GDP growth % (Project completion year)
			Start year	Completion (fiscal year)	
1	Chhukha hydropower plant	336	1978	1986-1987	25.09
2	Kurichhu hydropower plant	60	1995	2001-2002	16.19
3	Bashochhu hydropower plant	64	1997	2001-2002	16.19
4	Tala hydropower plant	1020	1997	2006-2007	13.68
5	Dagachhu hydropower plant	114	2009	2014-2015	5.04

(Druk Green Power Corporation Limited, 2018a; Gross National Happiness Commission, 2009b)

As observed, the maximum growth of GDP was observed in the fiscal years of 1986/87, 2001/02, 2006/07 and 2014/15, which are all linked to the commissioning of hydropower projects. Despite the global economic downturn in the year 2007, Bhutan achieved the third-highest GDP growth rate in its history, driven primarily by the export of electricity to India. The Royal Monetary Authority of Bhutan (2008) highlighted that hydropower investment is critical for Bhutan's economic growth constituting more than 32.1 % of the total export and contributing approximately 13% share to the Gross Domestic Product in the year 2017 alone. The above analysis shows that hydropower has a significant impact on GDP growth post commissioning of the project.

3.5.2 Robustness check with OLS and TSLS result using the dummy variables

In this section, the study attempts to evaluate the robustness of earlier results by using a dummy variable. The dummy variable for the year 1987 and the years 1990–1994 was created to control time-specific fixed effect for that period. This was essential as there are some outliers in the GDP and hydropower investment data for the period from 1980 to 2017. Maddala and Lahiri (1992) stated that very often, the estimates of the regression model are influenced by a few extreme observations as outliers, which need to be taken into account.

To ascertain the outliers in the GDP growth rate, first, the mean of GDP was calculated for the entire time series sample, which was then used to generate the deviations from the sample mean. It was observed that the GDP deviation in 1987 was almost 19%, which was extremely high compared to other variations. This was the period when the Chhukha Hydropower Plant, Bhutan’s first hydropower project, was commissioned during the fiscal year 1986/87. The GDP growth rate saw a drastic increase from 4.1% in 1985 to 11% in 1986 and then to 25.09% in 1987. Therefore, it is critical to include a dummy variable for this event, which could capture the jump in GDP growth. Although the ‘event effect’ lasted only one year, it is essential to ascertain whether it had any impact on the shift in the level of GDP for that year on the rest of the period.

The second outlier in the data was the period from 1990 to 1994 when no hydropower investment was made by Bhutan. Bhutan had experienced its first major internal crisis at this time (Misra, 1996; Nidup, 2015), when illegal immigrants from Nepal disrupted economic development in Bhutan, lasting for almost four years. Thus, it is essential to include a dummy variable for the period 1990–1994 to ascertain any spillover impact on the rest of the study period. The logic is to enforce the dummy variable ‘one’ for the period 1990–1994 and ‘zero’ for all remaining years. By adding these dummy variables in the model, the OLS errors will be forced to zero, thereby excluding the outlier from the sample period.

Table 16: OLS estimation with all dummy variables

Variables	Dummy 1987	Dummy 1990–1994	Combined dummies 1987 & 1990–1994
Gross domestic investments	0.0906	0.162**	0.0853
	(0.0646)	(0.0677)	(0.0654)
Gross domestic labour	0.0811	0.118*	0.0823
	(0.0578)	(0.0642)	(0.0582)
Gross foreign investments	0.0179*	0.0208*	0.0173
	(0.0103)	(0.0116)	(0.0104)
Gross foreign labour	-0.0226	-0.0279	-0.0219
	(0.0195)	(0.0220)	(0.0197)
D1987	0.141***	-	0.141***
	(0.0464)		(0.0468)
D1990to1994	-	-0.0161	-0.0152
		(0.0221)	(0.0197)
Constant	0.0480***	0.0464***	0.0505***
	(0.00846)	(0.0102)	(0.00915)
Observations	36	36	36
R-squared	0.492	0.347	0.502

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

To ascertain the overall impact of the extreme observations on the model, three OLS estimates were undertaken (dummy year 1987; dummy year 1990–1994; and combined dummy years 1987 and 1990–1994), as tabulated in Table 16.

From Table 16, it was observed that the dummy year 1987 has a significant impact on the GDP per capita growth for the year 1987, holding all other variable constant. However, the time dummy 1990-1994 has no significant impact on GDP per capita for the year 1990 to 1994. With the inclusion of the dummy year 1987, a 1% increase in hydropower investment is associated with 0.02 % increase in the GDP per capita. By including the dummy variable (year) 1990–1994, it was observed that a 1% increase in the domestic investment and labour had increased GDP per capita by 0.16% and 0.12%, respectively. As the parameter of interest, hydropower investment had a positive impact of 0.02% on the GDP growth rate, whereas foreign labour had no impact on both cases.

In order to increase the robustness of the study and to eliminate endogeneity issue, regression with two-stage least square was performed using the instruments for GDI and GDL as tabulated in Table 17

Table 17: 2SLS estimation with instruments and dummy variables

Variables	Dummy 1987	Dummy 1990–1994	Combined dummies 1987 & 1990–1994
Gross domestic investments	0.230	0.226	0.199
	(0.156)	(0.151)	(0.164)
Gross domestic labour	0.381*	0.464**	0.422*
	(0.228)	(0.195)	(0.232)
Gross foreign investments	0.0291*	0.0317*	0.0299*
	(0.0160)	(0.0166)	(0.0166)
D1987	0.0312		0.0304
	(0.0916)		(0.101)
Gross foreign labour	-0.0370	-0.0391	-0.0366
	(0.0281)	(0.0303)	(0.0293)
D1990to1994		-0.0124	-0.0127
		(0.0302)	(0.0278)
Constant	0.0258	0.0250	0.0284
	(0.0189)	(0.0191)	(0.0207)
Observations	36	36	36

Standard errors in parentheses ** *p<0.05, * p<0.1*

After inclusion of the dummy variable 1987 in the model, hydropower investment and domestic labour has a positive impact on the GDP per capita growth. With a 1% increase in hydropower investment, GDP per capita increased by 0.03%. On the other hand, with 1% increase in domestic labour, GDP per capita increased by 0.381%.

With the addition of the dummy variable 1990–1994, the hydropower and domestic labour had a positive impact on economic growth. The 1% increase in investment of hydropower is associated with a 0.03% increase in GDP per capita. Similarly, an increase in the percentage of domestic labour increased the GDP per capita by 0.46%. After including all the dummy variables, both the hydropower and domestic investment had an impact on the GDP per capita with an incremental increase by 0.03% and 0.42% respectively.

3.6 Conclusion and recommendations

This chapter has investigated the macroeconomic impact of hydropower investments on Bhutan's economic growth using the time series data from the 1980s to 2017. Consistent with the literature from other countries, energy consumption and trade has had a significant impact on economic growth for the study period in Bhutan. There is an increase in GDP growth rate in Bhutan concomitant with the years in which hydropower projects are commissioned. However, it was found that hydropower investment has a minimal impact on economic growth during the construction period compared to its post commissioning of the project. By taking into consideration the government's future plans for hydropower investment and its essential role in economic growth after the commissioning of the project, the study suggests the following two key recommendations:

First, policymakers should be aware that despite massive investments in the hydropower sector, this has not resulted in the much-anticipated positive impact on economic growth during the construction period. This is could be due to a modality in the financing and development option of the hydropower investment in Bhutan as emphasized by Boyreau and Rama (2015). As of now, all planning, preparation and construction of hydropower projects are undertaken using expertise from India with little or no involvement of Bhutanese labour and construction firms. With several decades of experience in investment in the hydropower sector, Bhutan should emphasise in the development of its own firm or company to execute some of the hydropower projects in partnership with Indian companies for future projects. This will not only create employment opportunities but will also contribute towards the GDP growth during the construction phase. It can also ensure that foreign labour will contribute towards economic growth of Bhutan.

Second, with many hydropower investments in the pipeline, the government should enhance the quality of the factors of productions and to strategies measures to invest in education and skills of its labour. Strong emphasis should be made to stimulate the diffusion of technological know-how from hydropower investment to Bhutanese capital and labour market. As of now, the Hicks technological progress has no impact on the economic growth in Bhutan. The empirical evidence has proven that there is a positive role of direct foreign investment on the transfer of technical know-how and improvement in human capital skills if proper coordination mechanisms between the FDI companies and host country are in place (Kheng, Sun, & Anwar, 2017; C. Li & Tanna, 2019).

CHAPTER FOUR : Rural electrification and its impact on entrepreneurship

4.1 Introduction

Access to clean energy is essential for human life, well-being and sustainable development (Ilskog, 2008). Electricity is the principal source of energy, which is vital for household needs and can positively affect capital and labour productivity. The immediate benefits for users is the improvement of lighting systems, which can have trickle-down effects on livelihood enhancement including social cohesion, educational achievements and efficiency gains in household activities (Cook, 2011; International Hydropower Association, 2018; Shahidur R. Khandker, Barnes, Samad, & Minh, 2009; Oda & Tsujita, 2011). Despite such vital roles played by electricity, 840 million people around the world in 2017 were deprived of access to electricity (International Energy Agency, 2019). The International Energy Agency, International Renewable Energy Agency, United Nations Statistics Division, World Bank, and World Health Organization (2019) highlighted that the global rural population access to electricity was 79%, thus lagging far behind the urban population access of 97% in the year 2017. This has motivated governments in Central and South Asia to focus on rural electrification projects, resulting in 48 million rural households being connected to the grid electricity between 2015 and 2017, more than double the urban figure.

Bhutan is an agrarian economy, with the majority of its population residing in rural areas. As per the National Housing and Population Census for the year 2017 (National Statistics Bureau, 2018d), around 62.2% of the population lives in rural areas. With this, improving the quality of life of the rural population has been a central priority for the Bhutanese government. The government has placed substantial resources in social policies and programs targeting health, education and infrastructure development since the start of the first Five-Year Plan (Gross National Happiness Commission, 2013). A critical component of this strategy that has been prioritised since the 1980s is the rural electrification project. When the project started in 1980, only 5% of the Bhutanese rural households had access to the grid electricity. This figure increased to 20% by 1995 (Kumar & Rauniyar, 2018) and to almost 99% by 2019. The trend of rural electrification for the years 2002, 2006 and 2018 is summarised in Table 18.

Table 18: Rural electrification coverage in 2002, 2006 and 2018

Name of the District	% of HH electrified at the end of the 8th FYP (2002)	% of HH electrified at the end of the 9th FYP (2006)	% of HH electrified at the end of the 11th FYP (2018)
Bumthang	53	79	99.6
Chhukha	31	61	88.6
Daga	10	36	100
Gasa	0	25	99.4
Ha	61	75	95.7
Lhuentse	16	39	99.4
Monggar	28	50	99.3
Paro	68	89	99.8
Pemagatshel	21	52	99.6
Punakha	45	70	99.6
Samdrup-Jongkhar	12	33	99.4
Samtse	14	38	97.6
Sarpang	16	44	98.3
Thimphu	87	100	98.3
Trashigang	45	70	98.7
Trashi Yangtse	29	54	99.1
Trongsa	19	39	99.8
Tsirang	2	34	99.6
Wangdue	28	49	99.8
Zhemgang	19	31	95.6
Overall (Average)	**30.80**	**53.70**	**99.00**

Source: (National Statistics Bureau, 2007, 2009, 2018; Department of Energy, 2005)

In terms of the electricity distribution as of 2018, 100% of households in urban areas have access to electricity while for rural areas the figure is approximately 98%, as summarised in Table 19.

Table 19: Distribution of household access to electricity by area in 2018 (in percentage)

Area	Total access to electricity (grid and off-grid)	Access to the grid electricity	Access to generator electricity	Access to solar electricity
Urban	100.0	99.7	0.1	0.2
Rural	98.4	97.1	0.2	1.2
Total	**99.0**	**98.0**	**0.2**	**0.8**

Source: (National Statistics Bureau, 2018b)

Because of the mountainous terrain of Bhutan, the villages located close to the roads and power substations were electrified first. Thus, the implementing agency for the rural electrification project (Bhutan Power Corporation) has adopted a radial approach. The government has emphasised that the rural electrification project is a strategy to raise the income and employment opportunities of the rural population (Gross National Happiness Commission, 2009a). In order to ease costs to the rural communities, the generation cost is borne by the government. At present, all household consumption of power less than 100 KWh/month in rural areas is completely subsidised by the government. With the provisioning of cheap electricity, the program intends to accelerate the economic development of rural communities through modernisation and the enhancement of agricultural activities. It is also intended to increase entrepreneurship and enable income diversification through the development of cottage[8] industries and various non-farming rural enterprises.

Despite such concerted efforts by the government to improve socio-economic conditions for its people, 8.2% of the Bhutanese population in 2017 was found to be poor (National Statistics Bureau, 2018c). Poverty in rural areas accounts for 11.9% of the population, which is significantly higher than the urban areas of 0.8%. In Bhutan, poor access to roads, electricity, health and education has been linked to a higher prevalence of subsistence-oriented farming and more deprived livelihoods (Nidup, Feeny, & de Silva, 2018; Tobgay & McCullough, 2008). Studies by Kumar and Rauniyar (2018) and Litzow, Pattanayak, and Thinley (2019) observe that access to electricity in rural Bhutan has enhanced household diversification of economic activities from agricultural production to other non-farming activities such as small-scale agriculture industries,

[8] The Ministry of Economic Affairs (2011) defines cottage industries in Bhutan as “industries with an investment of less than Nu.1 million and employing up to 4 people”.

weaving, carving, tailoring, etc. It was found that the non-farming income in Bhutan has increased by 61% since 2012 as a result of rural electrification.

Although these studies investigate the impact of rural electrification in Bhutan, the actual setting of the studies in terms of approach and data differ to the current study. The primary objective of research by Nidup, Fenny, and de Silva (2018) was to ascertain the correlation between income, multidimensional, and perceived poverty and the happiness indicators in Bhutan. Their conclusion on the impact of access to electricity on household welfare and poverty was an ancillary finding generated from the research. In the case of Kumar and Rauniyar (2018), their research investigated the impact of rural electrification on household income and children's schooling in Bhutan using the propensity score matching approach. They used primary data collected by the Asian Development Bank from a sampled district for the period 2006 to 2010. Research by Litzow et al. (2019) investigated the impact of rural electrification on social and environmental indicators such as health, fuelwood consumption, education and employment using a cost-benefit analysis approach. They used 2003, 2007 and 2012 data from the Bhutan Living Standard Survey (BLSS).

With this background, the objective of the current study is to understand how household access to the electricity grid in rural areas leads to income diversification among activities in relation to other complementary covariates by using panel data for the years 2007, 2012 and 2017. The study extends the literature on the relationship between access to the grid and rural income diversification in Bhutan in two ways. First, all studies on the impact of rural electrification in Bhutan were based on one of the cross-sectional survey data using difference-in-differences (DiD), propensity score, cost-benefit analysis approach, or OLS. None used a combination of fixed-effect and DiD approaches with balanced panel data for the three waves of the survey data. With a new approach using balanced panel data, the current study can validate the findings from the existing literature on the impact of rural electrification on household income diversification. Second, by using two approaches (a conditional fixed-effect regression and the difference-in-differences estimation), this study provides additional evidence on the impact of grid access on household income diversification relative to the timing of access to the grid. None of the studies cited in Bhutan has investigated the impact of access to the grid at different timing period. Even the global literature on the timing of access to the grid and its impact on household income diversification is scarce. The case on Bhutan can be an interesting extension of the literature as it is one of the few developing countries in the world on track to achieve the 100% rural electrification of households by the year 2020.

In the following section, the study will discuss the literature governing access to electrification and its impact, the research data, the econometric approaches along with the result and discussion, and the conclusions from the analysis.

4.2 Literature Review: electrification, entrepreneurship and economic welfare

Globally, while the number of empirical studies on the effects of household access to electricity has grown considerably, the evidence of its impact on income diversification is mixed (Rathi & Vermaak, 2018). Some researchers have found no impact, whereas other studies conclude that grid access delivers substantial benefits to the household. A considerable portion of research on access to electricity focuses on the positive benefits it provides through employment and income-generating activities. With access to electricity, the household will be able to diversify its economic activities, thereby generating more income, resulting in the improvement of livelihood. The real benefit accrues through technological shocks and greater time endowments as a result of electrification (Dasso & Fernandez, 2015). While there are many positive impacts of access to electricity on the household or individual income, key factors that are relevant to this study, such as female employment generation, improvements in agricultural development employment and income diversification, are also being discussed in the literature.

Some studies have found a positive correlation between access to electricity and female employment generation. Using an instrumental variable strategy and a fixed-effect approach, Dinkelman (2011) examined the impact of a mass rural electrification scheme instituted by the South African government for the period 1996 to 2001. It was observed that female employment increased by 9 to 9.5% due to electrification, generating more than 15,000 jobs for that period. In Nicaragua, a study observed that due to intense electrification projects between 1998 and 2005, women were able to work outside their home by 23%, resulting in higher earnings and improvements in livelihood (Grogan & Sadanand, 2013). In a similar study, Shahidur R Khandker, Samad, Ali, and Barnes (2014) found that with electrification, the employment hours for women increased by 17%, which was comparably higher than the 1.5% increase for men in India. As a result, the household per capita income increased by 38.6%, mainly due to the conversion of household activities to non-farm income-generating activities. In addition, the household per-capita expenditure also increased by more than 18% resulting in a 13.3% decrease in poverty. In Peru, a study by Dasso and Fernandez (2015) using the difference-in-differences and fixed-effect strategies have observed that after the electrification of the household, men tend to work more hours. Notably, there was a drastic improvement in the employment status and income-generating activities for women outside the agricultural sector.

Few researchers linked the improvements in agricultural productivity with rural electrification. A study by Barnes and Binswanger (1986) looking at 108 villages in India found that there has been a significant improvement in agriculture productivity with the onset of electrification. The direct effect was through the investment in water pumps for irrigation purposes, which could not have materialised in the absence of a reliable power source. In a similar study of 70 villages in Bangladesh (Barkat et al., 2002), it was observed that the average annual income of household post-rural electrification was almost 65% higher than a similar household that was non-electrified. A significant improvement of approximately 71% in literacy rate was observed for villages that were electrified, compared to non-electrified villages.

In recent years there has been a growing body of the empirical literature on access to electricity and its impact on household income diversification and employment creation. In South Africa, as a result of the rural electrification scheme, an increase in enterprise activity from 40% to 53% (Prasad & Dieden, 2007) saw a trickle-down effect on local communities in terms of employment generation and diversification of economic activities. The impact was more prominent in remote locations, where enterprise activity has increased by 40% amongst the previous non-connected households, compared to only 10% that were already connected to the grid. Using cross-sectional survey data, Khandker, Barnes, and Samad (2012b) investigated the impact of rural electrification on 20,000 households in Bangladesh for the year 2005. The results indicate that rural electrification has a significant positive effect on household income, expenditure and educational outcomes, thereby improving livelihoods. The study also found that the total income due to rural electrification can be as high as 30%, compared to the period when households had no access to electricity. Notably, there was a significant improvement in school enrolments, study time and school completion years, which had spillover benefits at a later stage. Another study looking at 36 states in Nigeria, found that village enterprises connected to the electricity grid are more profitable than enterprises not connected to the grid by 16.2% (Akpan, Essien, & Isihak, 2013). The latest study on the impact or rural electrification on entrepreneurship skills among 1067 households in

Kenya also found a positive correlation (Vernet, Khayesi, George, George, & Bahaj, 2019). By using the difference-in-differences approach, the study found that household access to electricity (treatment) resulted into establishment of 33 micro-enterprise compared to 20 micro-enterprise in the control site after project implementation. In all the electrified villages, there was a drastic improvement in household incomes, individual perceptions of social position, and opportunities for business establishment. On the other hand, a few case studies in Namibia and Kenya show that electrification does not have much impact on household welfare and economic activities. A study by Wamukonya and Davis (2001) on 371 Namibian households (140 non-electrified, 168 grid electrified, 63 solar electrified) found that the share of household income from income-generating activities was higher in those villages that are not electrified. Their study concluded that electrification is not a primary stimulating factor for household conversion to non-farming activities but other factors, such as access to finance and markets, have played a vital role in the diversification of the household income. Households had already started their micro-industries or home-based income-generating activities prior to the start of the electrification and, therefore, did not influence the overall findings. In a recent case, Lee, Miguel, and Wolfram (2019) studied 150 households in rural Kenya, providing them with a subsidy to connect to the electricity grid. The study was conducted between August 2013 and December 2017 using a randomised control trial, where some households were randomly selected and given access to the grid and their outcomes compared with households that remained off-grid. The study observed that rural electrification had not created meaningful medium-run impacts on outcome variables as anticipated. It was mentioned that key barriers, such as bureaucratic red tape, unreliable power grid, unaffordability of the services, the lack of household access to the finances and corruption issues in construction, have all suppressed the demand for electricity, thereby affecting the economic and non-economic outcomes.

The findings from the present study add further evidence to the literature that access to the electricity grid positively affects income diversification at the household level. Besides, this study also provides evidence whether a household that is connected to the grid earlier or later has any incremental effect on income diversification at the household level. On the one hand, households that have earlier access to the grid may have more opportunities to shape and participate in the development of their local entrepreneurial economy and, therefore, a higher probability of deriving income from non-farming activities than households that were connected later. On the other hand, households that received grid connections at later dates may benefit from more developed complementary services and may be better able to leverage their grid-connection for a variety of income-generating activities. Hence, the effect of electrification on income diversification may differ depending on when a household was connected relative to other households and depending on how far into the future the outcomes are measured.

This study contributes to the literature on the impact of access to electrification in three ways. Firstly, it provides empirical evidence for the positive impact of access to the grid in the case of a small, developing country like Bhutan, where the literature on such a field is minimal. Secondly, unlike most of the studies that rely on cross-sectional, aggregate and time-series data, the current study employs a combination of the balanced panel and cross-sectional data at the household level for three survey periods. Since the data has detailed information on both time-varying and invariant variables at the household level, the study improves the prediction of outcome variability more concisely, which can validate the findings from the literature. Importantly, the 2017 Bhutan Living Standard Survey data was recently released and has not been used by any studies to ascertain the impact of rural electrification. Thirdly, with a combination of different approaches, the study will be able to predict the effects of the timing of household access to the grid on income diversification, which is rarely studied in the global literature on rural electrification.

4.3 Research Data

The study uses longitudinal household data from the 2007, 2012 and 2017 Bhutan Living Standard Survey (BLSS) conducted by the National Statistics Bureau (NSB), Bhutan. The BLSS provides the latest and most comprehensive information on Bhutan's socio-economic indicators, such as demographics, education, health, housing, asset ownership, public facilities and access to services including electricity, roads, credits, schools and health facilities. The household data for the surveys are collected using a two-stage sampling method (National Statistics Bureau, 2018b). The sampling and data collection techniques are based on the World Bank's Living Standard Survey guidelines. The primary sampling units are collected from urban and rural localities of the enumeration areas, and the secondary sampling units are collected from the household within the selected enumeration area. The number of questionnaires distributed is proportionate to the number of households in different localities.

With a response rate of 97.98%, the BLSS (2007) covers a sample of 9,798 households, of which 6,856 are rural. The BLSS (2012) includes a sample size of 8,969 households representing 127,942 individuals. The BLSS (2017) covers a sample size of 11,553 households with 48,639 household members, representing 7.11% of the total households and 7.02% of the total population of Bhutan, respectively. The attrition rate across the three waves is high, with only 414 households interviewed in all three.

The cross-sectional and longitudinal data obtained from the BLSS (2007; 2012; 2017) is used in three different ways. First, the balanced panel data with 414 households is used for the estimation of the conditional fixed-effect regression. This method exploits the variation in the electrification of households in the panel dataset to determine the impact of access to the grid electricity on income diversification. Second, to determine the effect of the timing of access on income diversification, a difference-in-differences (DiD) method is used, which compares household outcomes across individual waves. With this, the estimation result will be able to ascertain the timing effect of access to the grid on household income diversification. Lastly, the cross-sectional survey data (BLSS 2007, 2012 and 2017) is used to estimate the OLS regression, summary statistics and test statistics to validate the significance of the variables used in the empirical model.

For this study, rural nonfarm income is defined as income derived from all nonfarm activities, being mainly involved in the sectors other than farming, raising animals or fishing. This definition has also been used by Adams (1993) and Canagarajah, Newman, and Bhattamishra (2001), where non-farming activities include all types of economic activities except agriculture, livestock rearing and fishing. The segregation of economic activities is based on the following key question from the Bhutan Living Standard Survey (2007; 2012; 2017) i.e.

"Which of the following best describes what (NAME) is mainly doing at present?

- ✓ *Working in farming, raising animals, forestry, or fishing;*
- ✓ *Working in a sector other than farming, raising animals or fishing."*

In addition, households with access to the grid electricity are distinguished from households with no access to the grid electricity.

Table 20 presents the summary statistics of the variables used in the study. It compares the mean observables between household in the full surveyed sample for the year 2007, 2012 and 2017 survey data.

Table 20: Summary statistics showing mean for the full surveyed households for the year 2007, 2012 and 2017

Variables	BLSS 2007	BLSS 2012	BLSS 2017
Nonfarm income	0.39	0.47	0.63
Household access to grid	0.66	0.90	0.98
Household attended schools	0.32	0.48	0.72
Household own house	0.73	0.49	1.00
Household own vehicle	0.14	0.26	0.28
Household own land	0.63	0.99	0.67
Household access to subdistrict	0.64	0.62	0.94
Household head male	0.69	0.73	0.60
Household head age	45.30	43.71	40.23
Household access to nearest road	0.10	0.15	0.98
Household head or any members obtained loan in last one year	0.52	0.82	0.96
Household head married	0.95	0.93	0.84
Number of observations	**9798**	**8969**	**11553**

The summary statistic shows that the variable of interest, i.e. non-farming income and access to the grid saw a drastic improvement over the three-survey period. Household access to the grid has increased from 66% in 2007 to 90% in 2012 and then to 99% in 2017. The household who derived income from the nonfarm income increased to 63% in 2017 from 39% in 2007 and 47% in 2012. Other variables, which has a drastic improvement in the year 2017 are school attendance (72%), access to subdistrict (94%), access to road (98%) and loan access (96%).

The summary statistics comparing the mean observables between households in the full surveyed sample and the balanced panel for the year 2007survey data are summarised in Table 21.

Table 21: Descriptive statistics for all surveyed households in 2007 and the households that comprise the balanced panel in 2007

Variables	Whole data	Balance data	Balanced-Whole survey data	
	Mean	Mean	Difference	*p*-value
Nonfarm income	0.39	0.41	0.02	0.370
Household access to grid	0.66	0.23	-0.43	0.000
Household attended schools	0.32	0.53	0.21	0.000
Household own house	0.73	0.87	0.14	0.000
Household own vehicle	0.14	0.21	0.07	0.000
Household own land	0.63	0.31	-0.32	0.000
Household access to subdistrict	0.64	0.80	0.16	0.000
Household head male	0.69	0.54	-0.15	0.000
Household head age	45.30	46.16	0.86	0.198
Household access to nearest road	0.10	0.74	0.64	0.000
Household head or any members obtained loan in last one year	0.52	0.47	-0.05	0.057
Household head married	0.95	0.73	-0.22	0.000
Number of observations	**9798**	**414**		

Source: (National Statistics Bureau, 2018b)

Table 21 displays the sample average of variables used for the analysis for the full sampled survey and the balanced panel data for the year 2007. It depicts the differences in means and the *p*-value from the two sampled *t*-tests, where the null hypothesis is that sample means are equal in both the surveyed and the panel sample data. The balanced panel is not significantly different from the full sample in key observables such as non-farming income, the age of the respondent and whether or not the household had obtained a loan in the last 12 months. However, there are significant differences between the panel households and the full sample in other observables, including educational level, house and vehicle ownership, access to sub-district, age of the respondent and access to the roads. These results also motivate the later DiD analysis that leverages larger sample sizes of households that were interviewed in consecutive waves, as opposed to having been followed across all three waves.

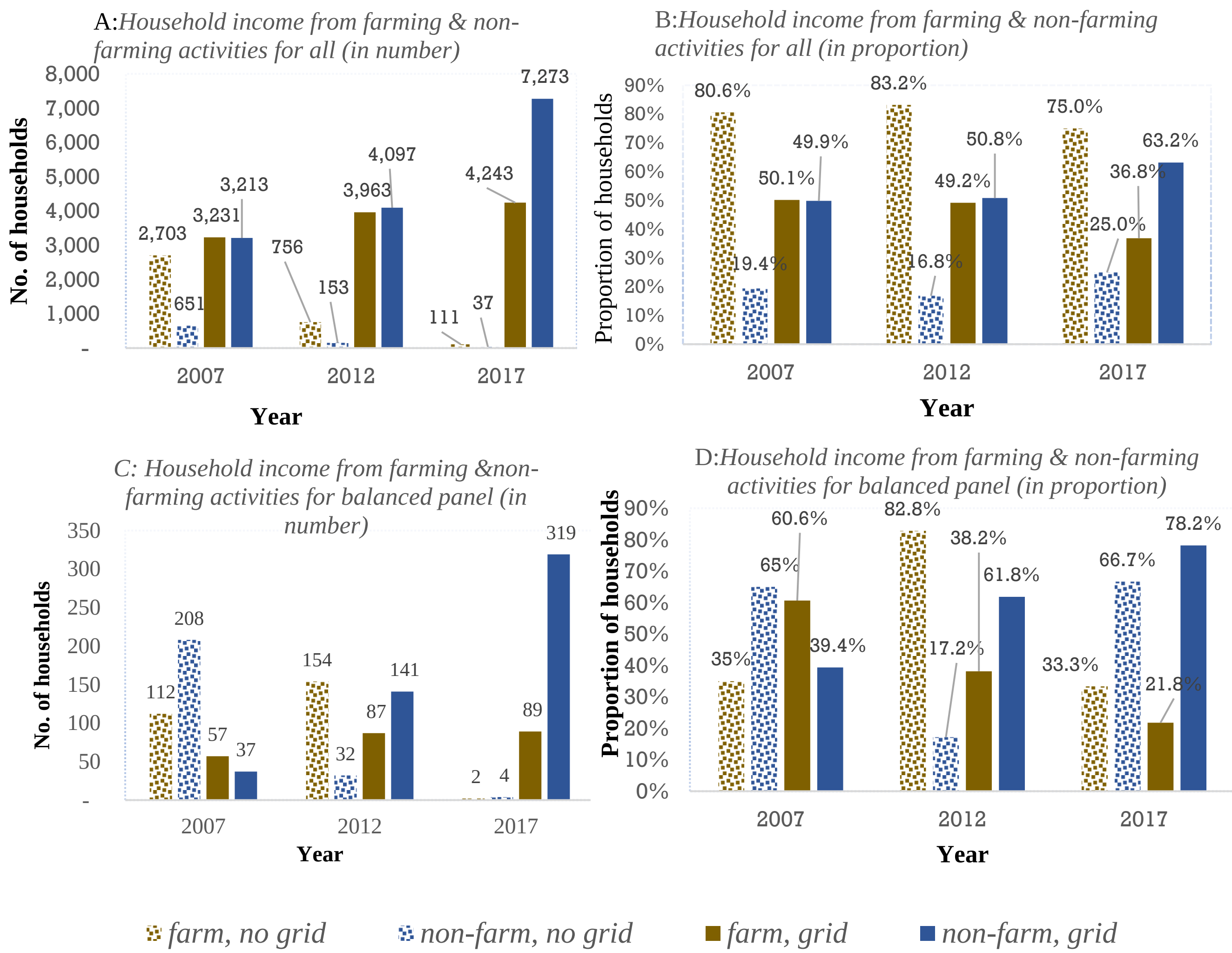

Figure 6:Number and per cent of households by income source and access to the grid electricity in each survey wave (panel A and B) and for the balanced panel (C and D)

Source: National Statistics Bureau (2007, 2012 and 2017)

Given the results in Table 21, Figure 6 depicts whether the process of electrification and income diversification is comparable for households in the full sample and those in the balanced panel across all three survey waves. Figure 6 A and B reflect the full sample, i.e., number and proportion of households with and without access to the electricity grid that derive income from farming and non-farming activities. The overall proportion of non-electrified households with farming activities was 80.6% in 2007, 83.2% in 2012 and 75% in 2017. The proportion of non-electrified households with non-farming activities has increased from 19.4% in 2007 to 25% in 2017. With intensive rural electrification projects occurring for the last two decades, the proportion of electrified households with farming has reduced from 50.1% in 2007 to 36.8% in 2017. Concerning the portion of electrified households with non-farming activities, the numbers have increased from 49.9% (2007) to 50.8% (2012) and then to 63.2% (2017)

The summary of 414 households that are surveyed in all three waves of the cross-sectional study is illustrated in Figure 6 C and D. The proportion of non-electrified households with farming was 35% in 2007, 82.8% in 2012 and 33.3% in 2017. The proportion of non-electrified households with non-farming was 65% in 2007 and 66.7% in 2017. Concerning the electrified households, the proportion of farming activities was 60.6% in the year 2007, which fell to 38.2% in 2012 and further fell to 21.8% in 2017. By contrast, the proportion of electrified households with non-farming activities increased from 39.4% (2007) to 61.8% (2012) and then to 78.2% (2017). From this analysis, it may be observed that the electrification pathway is comparable between the whole sampled survey and panel data for the years 2007 and 2012. However, for the year 2017, households that were not yet connected to the grid in the panel data formed a much lower percentage than those not connected to the grid in the whole sampled survey data.

4.4 Research approach, estimation result, and discussion

To ascertain the actual impact of access to the grid, it is crucial to ascertain the cause-and-effect relationship between access to the grid and the outcome variable. This suggests that experimental research designs, such as randomised experimental design, would be appropriate to construct research that requires validation of cause and effect (Jennings & Maldonado-Molina, 2016). However, in the absence of such experimental research design, this study has relied on the secondary data from the Bhutan Living Standard Survey (2007; 2012; 2017). Therefore, two different econometric models i.e., conditional fixed-effect and difference-in-differences estimation strategies are used to ascertain the impact of access to the grid, including its covariates on the non-farming income diversification.

The study chose the conditional fixed-effect logit model for two main reasons: a) the fixed effect with clogit estimation controls unobserved heterogeneity in the panel data and reduces the omitted variable bias (Stammann, Heiss, & McFadden, 2016); b) clogit has the advantage of fitting the maximum likelihood model with dichotomous dependent variables, which is relevant for this study as the dependent variable (non-farming income) is a dummy variable. Similarly, the DiD was chosen for two main reasons: a) it also allows time-invariant unobserved heterogeneity that is constant over time and that may affect household outcome variables; b) the DiD has the advantage of estimating the impact of access to the grid by comparing the pre- and post-intervention changes in the outcome variables, which has been widely used in the impact evaluation literature. By using three-panel data, the study will estimate the pre- and post-impact of access to the grid on income diversification at different time periods.

4.4.1 Fixed-effect conditional logit model

For this method, the study has used the balanced panel data from three waves of the survey, as discussed in section 4.3. A total of 414 households were surveyed in all three waves and form the balanced panel for ascertaining the impact of access to the grid on household non-farming activities.

4.4.1.1 Econometric model and identification strategy

The fixed-effect logit model is used for the panel data, which uses the outcome variable (non-farming income) as a binary variable. The reason for using the binary variable as the dependent variable is to maintain consistency in the analysis. For the 2012 and 2017 BLSS, the survey data capture annual household income from non-farming activities, which was not available for the 2007 BLSS.

Since the farming and non-farming economic activities are dependent on various time-variant and invariant variables, it is essential to include those controls for the analysis. As discussed earlier, the villages located closer to the sub-district and road network receive priority for the grid rollout. It is also possible that the villages partaking in non-farming activities may also be likely to be connected earlier due to other factors. Therefore, it is vital to take into account the effect of control variables such as the distance of the household from the nearest road and subdistrict. The household who have access to the road and who are nearer to the subdistrict are more likely to be electrified and will have an impact on their economic activities. The empirical evidence indicated that the decision for the rural households to diversify their economic activities beyond traditional farming depends on various factors such as ownership of assets, educational level, entrepreneurial skills, access to electricity and roads (Abdulai & Delgado, 1999; Canagarajah et al., 2001; Deininger, Jin, & Sur, 2007; Demissie & Legesse, 2013; Isgut, 2004; Jin & Deininger, 2008). It was also found that participation in non-farming activities at rural communities is strongly influenced by the human capital-related variables (such as gender, age of household head and education level of the household head) and other household characteristics (such as income of the household, proximity to essential infrastructures, and ownership of critical assets including land, cattle, machinery, etc.).

Therefore, the selection of the control variable was based on the results of the literature review, which is summarised in Table 22.

Table 22: List of variables

Variable	Definitions
non-farm_income	Binary dummy variable taking the value of 1 if the household derives income from a sector other than farming, raising animals or fishing and 0 otherwise
access_grid	Binary dummy variable taking the value of 1 if the household has access to the electricity grid, and 0 otherwise
educational_level	Categorical variable taking the value of 0 if the household head has not attended school, 1 if the household head attended primary school, and 2 if the household head attended at least secondary school
owns_house	Binary dummy variable taking the value of 1 if a home is owned, otherwise 0
owns_vehicle	Binary dummy variable taking the value of 1 if the household owns a vehicle, otherwise 0
owns_land	Binary dummy variable taking the value of 1 if the household owns the land, otherwise 0
access_sub-district	Binary dummy variable taking the value of 1 if the household has access to the sub-district administration within six hours' drive, otherwise 0
male	Binary dummy variable taking the value of 1 if the household head is male, otherwise 0
age_respondent	Age of the respondent
road	Binary dummy variable taking the value of 1 if the village of the residence is directly accessible by road, otherwise 0

Source: National Statistical Bureau (2007, 2012 and 2017)

An advantage of using the fixed-effect approach in the panel data is that the model can control all stable characteristics of the individuals, even if such characteristics are not measurable (Halaby, 2004). For instance, the household decision to choose non-farming income activities also depends on other stable characteristics such as race, ethnicity, cultural influences, religion, the teamwork of the household members, household members' intellectual capacity, etc., which are all difficult to measure.

The conditional (fixed-effect) logit model (CLM), as developed by McFadden (1973), was used to predict how access to the electricity grid affects the probability of a household earning income from non-farming activities. The CLM, also known as McFadden's qualitative choice behaviour model is estimated by the maximum likelihood methods, where the predicted probability of observing outcome K_{1i} is given by (Hosmer Jr, Lemeshow, & Sturdivant, 2013):

$$\Pr\left(y_i \,\middle|\, \sum_{t=1}^{T_i} y_{it} = K_{1i} \right) = \frac{\exp\left(\sum_{t=1}^{T_i} y_{it} X_{it} \beta \right)}{\sum_{d_i \in s_i} \exp\left(\sum_{t=1}^{T_i} d_{it} X_{it} \beta \right)} \quad ;$$

where $i = 1, 2......n$ represents the households in the panel data; $t = 2007$, 2012 and 2017 and denotes the time period in the sampled study. The $y_{it} =$ is the dependent variable taking the value of 0 or 1 at any time period, e.g., 2007, 2012 and 2017. The $y_i = (y_{i2007}, y_{i2012}, y_{i2017})$ is the outcome for the i^{th} household at any time period and X_{it} is a vector of both the time-variant and invariant covariates (refer Table 22). $K_{1i} = \sum_{t=1}^{T_i} y_{it}$ is the observed number of ones for the dependent variable for each household *i*; $d_{it} =$ zero or one with $\sum_{t=1}^{T_i} d_{it} = K_{1i}$; and $s_i =$ set of all possible combination of K_{1i} ones and K_{2i} zeros.

The equation for the panel estimation, which is estimated by the CLM is:

$$y_{it} = \varphi_t + \gamma access\_grid_{it} + \beta X_{it} + \mu Z_i + a_i + \varepsilon_{it} ;$$

where y_{it} is the probability that the response variable is equal to 0 or 1; φ_t is the intercept that is different for each time period; X_{it} comprises the time-variant covariates; Z_i consists of time-invariant covariates; a_i is the household fixed effect; and ε_{it} is the error term.

4.4.1.2 Result estimations and discussions

The appropriateness of the estimation technique was checked using the Hausman test for individual fixed-effect presence (Wooldridge, 2016). The Hausman test (refer appendix 3) with a *p*-value of

0.0201 with chi-square (13) of 25.46, rejected the null hypothesis that "*unobserved individual-level effects are uncorrelated with the other covariates*". By rejecting the null hypothesis, the fixed-effect model was preferable over the random effect model in this panel data analysis.

By using "*non-farm_income*" as the dependent variable, the conditional (fixed-effect) logit model was estimated using the variable of interest "*access_grid*" and other covariates. First, the clogit was performed without covariates on the outcome variables, as summarised in Table 23.

Table 23: FE using clogit model (odds ratio and factor change in odds) without covariates

Variables	clogit with odds ratio		clogit with factor change in odds		
	Log odds	**Std. Err.**	**z**	**p>z**	**e^b**
access_grid	0.889***	0.272	3.274	0.001	2.433
Year 2012	-0.261	0.185	-1.413	0.158	0.770
Year 2017	1.332***	0.292	4.565	0.000	3.790

*** $p<0.01$, ** $p<0.05$, * $p<0.1$; b = raw coefficient and z = z-score for test of b=0

Note: multiple positive outcomes within groups encountered.
Note: 134 groups (402 obs) dropped because of all positive or all negative outcomes

As observed in Table 23, 32.37% of the data has been dropped either due to positive or negative outcomes. This is because when non-farming income equals either zero or one for all observations for that particular household, this household's contribution to the log-likelihood is zero (Long & Freese, 2006; StataCorp, 2004). The result indicates that if there are two otherwise similar households, one connected to the grid and the other not yet connected, the household connected to the grid will increase the odds of choosing non-farming activities by a factor of 2.443, holding other variables constant.

The coefficient estimates, together with their standard error, odds ratio, and the factor change in odds from the CLM after the inclusion of covariates, are presented in Table 24.

Table 24 shows that grid access has a positive and significant impact on household income diversification activities. With similar household access to the grid, the log odds of household diverting towards non-farming income activities increases by 1.263 on average, holding all other variables constant. In terms of the factor change in odds, the household having access to the grid increases the odds of choosing non-farming activities by a factor of 3.535. This result indicates that households connected to the grid have a higher probability of choosing non-farming income activities, with this result being both quantitatively and statistically significant. The result is consistent with the findings by Prasad and Dieden (2007), Shahidur R. Khandker, Barnes, and Samad (2012a), Rao (2013), Akpan et al. (2013) and Vernet et al. (2019), who all found a significant impact of electrification on household income from non-farming income activities.

Table 24: FE using clogit model (odds ratio and factor change in odds) with covariates

Variables	clogit with odds ratio		clogit with factor change in odds		
	Log odds	**Std. Err.**	**z**	**p>z**	**e^b**
access_grid	1.263***	0.350	3.611	0.000	3.535
HH head education primary schools	-0.166	0.400	-0.415	0.678	0.847
HH head education at least secondary school	0.694***	1.222	0.568	0.570	2.002
owns_house	-0.145	0.408	-0.356	0.721	0.865
owns_vehicle	0.066	0.322	0.206	0.837	1.069
owns_land	-0.559	0.424	-1.318	0.188	0.572
access_subdistrict	-0.382	0.358	-1.067	0.286	0.683
road	-0.913***	0.331	-2.762	0.006	0.401
loan	2.261***	0.320	7.072	0.000	9.593
male	0.905***	0.275	3.286	0.001	2.471
age_respondent	-0.038***	0.012	-3.134	0.002	0.963
married	-0.358	0.301	-1.186	0.236	0.699
Year 2012	-0.345	0.342	-1.011	0.312	0.708
Year 2017	0.865*	0.469	1.841	0.066	2.374

**** p<0.01, ** p<0.05, * p<0.1;* b = raw coefficient and z = z-score for test of b=0

Note: multiple positive outcomes within groups encountered.
Note: 134 groups (402 obs) dropped because of all positive or all negative outcomes

The estimated impact in Table 24 is much higher than the previous estimates (Table 24) by a factor of approximately 110[9] percentage points. This indicates that after controlling other variables which affects the outcome variable and access to grid, the impact of access to grid on the outcome variables increased drastically. The control variable that have a significant effect on the outcome variables, in addition to access to the grid, are the household head being male, the household head having obtained loans and the household head who had at least a secondary level of education. For the household head being a male, the log odds of household that participated in non-farming income activities increased by a factor of 2.471. This result is consistent with the findings from Démurger, Fournier, and Yang (2010), where the household head being male strongly influenced household non-farming diversification in a northern China township. The household head who has at least a secondary level of education increased the odds of the household working in non-farming income activities by a factor of 2.002. This finding is similar to the existing literature, where the household head or member's educational qualification has a positive impact on income diversification (Neudert, Goetter, Andriamparany, & Rakotoarisoa, 2015; Rahut, Mottaleb, & Ali, 2018).

Out of all other control variables, households (household head including any members of the household) that obtained loans in the past year has a significant impact on the outcome variable. It increases the odds of working in non-farming activities by almost 9.593 factors, holding the values of other alternatives constant. These outcome estimations (except access to road) are all consistent with the empirical evidence from other researchers, where it was shown that access to public assets such as roads, electricity and credit plays a vital role in diversification of income (Berdegué, Ramírez, Reardon, & Escobar, 2001; Escobal, 2001; Shahidur R Khandker, 1996).

The control variable that negatively impacted the outcome variables are household access to the nearest road and age of the household head. This result is contrary to the latest findings by Satoru, Ikumo, and Tsubota (2018), Wagale, Singh, and Sarkar (2019) and Odoh, Nwibo, Eze, and Igberi (2019) which indicate that road access positively impacts household welfare and income diversification. The findings partially agree with a study by Nidup (2016), which found that road

[9] The percentage change in odds for access to the grid without covariates was 143.3% (refer appendix 4.1). With the inclusion of covariates, the percentage change in odds for access to the grid was 253.5% (refer appendix 4.2).

access in rural areas of Bhutan had a differential impact on households depending on their income level, whereby only the lowest income households were found to have benefited from road access. With access to roads, there was a demonstrable increase in wealth (mainly through economic diversification) of a very poor household by 39.61% mainly through income diversification at the household level. However, no impact was found for the poor, medium, rich and very rich category of the households. Moreover, with Bhutan, being located in the high Himalayas and characterised by harsh geographical terrain and erratic climatic conditions, many roads are subject to landslides and floods throughout the year. Road condition is not observed in the dataset and therefore cannot be included as a covariate to test its effect on income diversification. Regarding the impact of age, older household heads are less likely to have diversified their income from non-farming activities. For each annual increase in the age of the household head, the probability of the household choosing non-farming income activities reduces by 0.963 factors, holding all other variables constant. The probable reason for this negative relationship is that younger household heads are well educated with innovative skills, more energetic, have better access to technology and a well-planned outlook for the future market environment.

As observed, a household in 2017 is more likely to be diversified compared to a 2007 and 2012 household. The log odds of households diverting towards non-farming income activities increases by 2.374 on average in 2017 compared to 2012 and 2007, holding all other variables constant.

To ascertain the significance of the variables in the model a Wald test was performed on all the independent variables (refer appendix 5). With chi2 (12) equal to 74.55 and $p < 0.00$, the null hypothesis that all those independent variables are simultaneously equal to zero was rejected at the 0.01 level. This test shows that all these covariates play a significant role in the estimation model, particularly those variables that have significantly affected the outcome variables.

4.4.2 Difference in differences model

In the second approach, the study used difference-in-differences estimation to ascertain the effect of the timing of grid access on household participation in the entrepreneurial economy. The previous analysis showed an overall positive impact of grid access on income diversification among households, but with differences across three waves. The DiD is aimed at understanding whether the benefits of grid access are independent of whether access occurs early versus later in the sample period. The empirical evidence has indicated numerous benefits of access to electricity but the timing of access and its impact at the household level has rarely been investigated in the literature. Importantly, similar to any large-scale infrastructure projects, focusing on the short-run impact of access to the grid may fail to cover the crucial issues of long-run impact created by the access to the grid. This has motivated the current study to investigate and compare the impact of household access to the grid at three different periods.

a) First, the study compared the outcomes for households with access to the grid, depending on the timing of access. Here, the control is always the households that have access to the grid in both the periods, while the treatment group is the household that acquired access between the two periods. With this, the study estimated the effect of early versus midway access (2007 and 2012), early versus late access (2007 and 2017) and midway versus late access (2012 and 2017) (refer Table 25).

b) Second, the study compared the outcomes for a household with access to the grid to the outcomes for households without access at a different period. Here, the control group is always the household with no access in both periods while the treatment group is household with no access in the earlier period and access in the later period. The study compared i) household outcomes in 2012 for households gaining grid access midway through the sample period to households with no grid access and ii) 2017 household outcomes for those with late access to the grid with no grid access (refer Table 27)

From these two analyses, the study provides an answer to two questions: first, does late grid access penalise households compared with those that have benefited from early access? Second, if there is a penalty, is it still beneficial to have grid access at all? This analysis leveraged all households that were common to both waves under consideration: a) 414 households, which are common to 2007 and either of the later waves in 2012 and 2017; and b) 1387 panel households, which were interviewed in both 2012 and 2017.

Based on similar studies by Wacholder (1986), Horrace and Oaxaca (2003), Afendulis, He, Zaslavsky, and Chernew (2011) and Monheit, Cantor, DeLia, and Belloff (2011), the current study used the OLS linear probability model (LPM) for the DiD estimation. Despite its drawbacks, such as its predicted probability which is $\rho_i > 1$ and $\rho_i < 0$ with heteroskedasticity issues, many researchers prefer to use LPM for its easily interpretable results in the linear DiD estimations.

Wooldridge (2016) stated that these two issues are not often serious if we want to estimate the partial effects of the independent variable for the middle ranges of the data.

4.4.2.1 DiD design, result estimations, and discussions

Previous research has suggested that a positive relationship exists between household access to necessary infrastructure and services, such as electricity, market and credit, on household income diversification (Ahmed, 2012; Fujii, Shonchoy, & Xu, 2018; Shahidur R. Khandker et al., 2012a; Prasad & Dieden, 2007; Schwarze & Zeller, 2005; Senadza, 2012). The latest study by Lewis and Severnini (2020) found that early access to the grid has a long-term impact in terms of population growth, employment creation, income diversification and increase in property values. The ninth, tenth and eleventh Five-Year Plan documents emphasise that Bhutan has attached the highest priority to the rural electrification project to improve livelihoods (Gross National Happiness Commission, 2009b, 2013). The intention is that with electrification, the rural households would be able to diversify their income-generating activities along with improvements in their socio-economic and living conditions. From this, it is evident that household access to the grid for a longer period of time is expected to diversify economic activities.

In this research, the study aims to find additional evidence for the positive effect of access to the grid on household income diversification from non-farming activities at different periods. For this, two DiD approaches are estimated using a balanced panel dataset with waves and pairwise comparisons (2007 and 2012; 2007 and 2017; and 2012 and 2017).

A. **Approach one:** DiD design for comparing households with grid access depending on the period of access

In the first scenario, the predicted result with the number of households in the control and treatment group based on the period of access is summarised in Table 25.

First, DiD was constructed to ascertain the impact of midway access to the grid versus early access in the year 2012 using BLSS 2012 and 2007 data. This compares households that received treatment after the year 2007 against households that had access to the grid before 2007 in the year 2012 outcome. Here, 99 households make up the control group, and 315 households are in the treatment group. From the empirical evidence (Shahidur R. Khandker et al., 2012a; Lewis & Severnini, 2020), the household that is connected earlier to the grid will be better off in terms of diversifying their economic activities. This shows that if household which are connected to the grid at later stage are compared with the household which are connected earlier, the impact in terms of income diversification would be negative for later households. With this, the expected result will be negative as the household receives treatment at a later stage in 2007, whereas the control already has access to the grid before 2007.

Table 25: DiD design for comparing households with grid access depending on the period of access

Timing of access	Outcome (Year)	Treatment		Control		Expected effect
		Access	Obs	Access	Obs	
Model 1 Midway versus Early	2012	After 2007 *(Midway)*	315	Before 2007 *(Early)*	99	Negative
Model 2 Late versus Midway	2017	After 2012 *(Late)*	956	After 2007 *(Midway)*	431	Negative
Model 3 Late versus Early	2017	After 2012 *(Late)*	182	Before 2007 *(Early)*	232	Negative

The second model analysed DiD for the late versus midway access, i.e., access to the grid after the year 2012 and before the year 2017 using BLSS 2012 and 2017. Similar to model 1, the expected result will be negative as the treatment was received in the year 2012, which was compared to the group who had access to the gird before 2012 and after the year 2007. In this model, 956 households are treated against 431 households chosen under the control group. The last model analysed the DiD for the late versus early access to the grid using BLSS 2007 and 2017 data. Here 182 households are treated in the year 2012 against the 232 households chosen under the control group. Similar to the previous model, the expected result will be negative as the household receives treatment at a later stage in 2012, whereas the control already has access to the grid before 2007.

From the three analyses, I expect to ascertain whether households that received late access to the grid were better or worse off than those that already had access to the grid. The findings predict the penalty if households that are connected at a later stage are worse off in terms of diversifying their economic activities. The DiD estimation using LPM for the three models (midway versus early, late versus midway and late versus early access to the grid) is tabulated in Table 26.

In the first model, the parameter of interest, which is time*treated is negative and statistically significant at the 1 percentage points confidence level, as expected. This indicates that with all other factors being equal, households that gained access to the grid at the midway point (2012) have 24.6 percentage points lower chances of deriving income from non-farming income activities than households that have early access to the grid (before 2007). In other words, households that have earlier access to the grid will be 24.6 percentage points more likely to derive income from non-farming activities than those that gain access at a later stage.

Table 26: DiD estimation by OLS for household access to the grid midway versus early, late versus midway and late versus early

Variables	Model 1 Midway versus Early	Model 2 Late versus Midway	Model 3 Late versus Early
time	0.0772	0.103***	0.140***
	(0.0629)	(0.0327)	(0.0433)
treated	-0.0309	-0.0416	0.0936**
	(0.0432)	(0.0253)	(0.0455)
Did (time * treated)	**-0.246***	**-0.0710**	**0.0418**
	(0.0661)	(0.0338)	(0.0673)
HH head education (primary school)	0.0412	0.204***	0.0626
	(0.0343)	(0.0253)	(0.0435)
HH head education (at least secondary school)	0.278***	0.374***	0.288***
	(0.0383)	(0.0290)	(0.0398)
owns vehicle	-0.101**	0.104***	0.0473*
	(0.0444)	(0.0312)	(0.0262)
owns land	0.0683**	-0.296***	-0.130***
	(0.0302)	(0.0183)	(0.0281)
access to road	-0.0611*	-0.127***	-0.0331
	(0.0357)	(0.0212)	(0.0231)
obtained loan (HH head or any member)	0.298***	0.250***	0.611***
	(0.0283)	(0.0402)	(0.0321)
HH head being a male	0.161***	-0.0280	0.0852***
	(0.0315)	(0.0186)	(0.0220)
HH head age	-0.00710***	-0.00110	-0.00412***
	(0.00126)	(0.000753)	(0.000826)
HH head married	0.00184	-0.0468*	0.0206
	(0.0342)	(0.0282)	(0.0249)
constant	0.443***	0.472***	0.111**
	(0.0758)	(0.0589)	(0.0547)
Observations	828	2,774	828
R-squared	0.333	0.166	0.606
Household chosen under control	99	431	232
Households chosen under treatment	315	956	182

Standard errors in parentheses *** *p<0.01*, ** *p<0.05*, * *p<0.1*

Similarly, in the second model, if the household has late access (after 2012), the probability of deriving household income from non-farming income activities is 7.10% lower than that households that have gained access around the midway point (after 2007). Interestingly, by 2017 there is no detectable treatment effect of late access to the electricity grid.

From these three analyses, the coefficient demonstrates that households that have gained access to the grid earlier have a higher probability of deriving income from non-farming activities than those connected to the grid at a later midway stage. Households that missed out on an early connection suffer the highest penalty in the medium term: this medium-term penalty decreases over time. By 2017, there no longer appears to be penalty for late access to the electricity grid.

From the complementary covariates, the household head (including members) who have obtained loans in the past year has a strong and positive impact on household income diversification in all three models. Similarly, household heads with at least a secondary level of education also positively affect the outcome variables. These results are consistent with the findings from the previous analysis. The household head being a male and a household that owns land positively affect the outcome variables for model 1. For model 2, household ownership of a vehicle positively affects the outcome variable, whereas households that own the land, household heads who are married and household access to roads negatively affects the income diversification activities.

B. Approach two: DiD design for comparing outcomes for households *with* and *without* access to the grid at different times

The previous DiD estimation indicated that households without early connection to the grid suffer the highest penalty in the medium term, which decreases over time. So, it is important to ascertain whether it is still beneficial for the household to connect to the grid if there is a penalty. To address this issue, the outcomes for households with and without access to the grid were compared at different times, as tabulated in Table 27.

First, the DiD for 2007 and 2012 was constructed to ascertain the impact of access to the grid after the year 2007 using BLSS 2007 and 2012 data. From this result, we can study the impact of access to the grid between 2007 and 2012 versus no access for this period. The expected effect will be positive as 227 households received treatment after the year 2007 and thus have access to the grid in 2012. In the second estimation, the DiD for the years 2012 and 2017 was constructed to establish the impact of access to the grid in 2017 versus none in 2012 and 2017. With this, we can study the impact of access to the grid between 2012 and 2017 versus no access to the grid for this period.

Table 27: DiD design for comparing outcomes for a household with and without access to the grid at different times

Timing of access	Outcome (Year)	Treatment		Control		Expected effect
		Access	Obs	Access	Obs	
Model 1 Midway versus None	2012	After 2007 *(Midway)*	227	None	187	Positive
Model 2 Late versus None	2017	After 2012 *(Late)*	110	None	1277	Positive

Similar to the previous model, the predicted effect will also positive as almost all household in the year 2017 had access to the grid compared to having no access in 2012. From these two estimations, the study expects to estimate whether a household is better off with access to the grid compared to having no connection in terms of non-farming income diversification.

Table 28: DiD estimation by OLS for households with midway versus no access to the grid and with late versus no access to the grid

Variables	Model 1 Midway versus No Access	Model 2 Late versus No Access
time	-0.181***	0.0358
	(0.0379)	(0.0276)
treated	0.121**	-0.223***
	(0.0523)	(0.0616)
Did (time * treated)	**0.166****	**0.160****
	(0.0795)	(0.0784)
HH head education (primary school)	-0.00817	0.201***
	(0.0443)	(0.0288)
HH head education (at least secondary school)	0.201***	0.409***
	(0.0434)	(0.0297)
Owns vehicle	-0.121***	0.111***
	(0.0422)	(0.0295)
Owns land	0.0571	-0.279***
	(0.0397)	(0.0237)
Access to road	-0.0532	-0.133***
	(0.0364)	(0.0203)
Obtained loan (HH head or any member)	0.304***	0.256***
	(0.0290)	(0.0400)
HH head being a male	0.158***	-0.0348
	(0.0285)	(0.0222)
HH head age	-0.00688***	-0.00109
	(0.00109)	(0.000796)

Variables	Model 1 Midway versus No Access	Model 2 Late versus No Access
HH head married	0.00828	-0.0623**
	(0.0373)	(0.0294)
Constant	0.378***	0.463***
	(0.0758)	(0.0547)
Observations	828	2,774
R-squared	0.340	0.169
Household chosen under control	187	1277
Households chosen under treatment	227	110

Standard errors in parentheses *** *p<0.01, ** p<0.05, * p<0.1*

The DiD estimation for the household with midway access to the grid versus no access is tabulated in Table 28. In both models, the variable of interest (time*treated) has a significant impact on the outcome variable. In model 1, households connected to the grid after 2007 were 17 percentage point higher in choosing a non-farming activity than those not connected to the grid, holding other variables constant. In the second model, households connected to the grid at a later stage were 1 percentage point lower in choosing a non-farming activity. This supports the previous findings that earlier access to the grid is better than late access in terms of household income diversification. Despite the penalty for late connection, households still benefit in terms of diversifying their economic activities when connecting to the grid even at the later stage. By comparison, households that are connected to the grid at a later stage still benefit by 16 percentage in terms of diversifying their economic activities than those with no connection at all.

Likewise, and in keeping with the previous findings, the complementary variables (such as household heads with at least a secondary level of education, being male and having obtained loans) positively affects the household decision to choose non-farming income activities in model 1. On the other hand, the household head's age and whether the household owns a vehicle has a negative impact on the income diversification for model 1. For model 2, the household's ownership of land, access to road and whether the household head is married negatively affects the outcome variables. Whereas households who own a vehicle and obtained loans in the past year positively affect the outcome variables.

C. OLS results on the number of years that households have access to the grid *(OLS result on the impact of the number of years' access to the grid on household incomes derived from non-farming activities in 2017)*

From the previous analysis, it was confirmed that the households that missed out on an early connection suffer the highest penalty in the medium term, which decreases over time. This motivated the study to conduct further analysis in the year 2017, whether there is any significant impact of household access to the grid on non-farming income diversification. In this model, the dependent variable is the log of annual income derived from all nonfarm activities, being mainly involved in the sectors other than farming, raising animals or fishing. To ascertain the actual impact created to the household, based on the number of years household are connected to the grid, an OLS was estimated as tabulated in Table 29 . The variable (*years_access*) was created using the year in which the household was connected to the grid.

Since the cross-sectional data suffers from heteroscedasticity issues (Greene, 2003), first the Breusch–Pagan (1979) and Cook–Weisberg (1983) tests for the OLS was estimated. The *p*-value for the OLS is less than the 0.05 significant level, thereby rejecting the null hypothesis that the "*variance of the residuals is not heteroscedastic*". To correct for heteroscedasticity issues, the OLS model was estimated using a Huber–White-type estimator.

Table 29: OLS estimation for the impact of access to the grid on household income in 2017 using a number of years that the household is connected to the grid

Variables	**Impact on 2017 income**
Number of year access to the grid	0.00123**
	(0.0006)
Household head being a male	0.0305**
	(0.0130)
Household head age	-0.0111***
	(0.000470)
Household head married	0.251***
	(0.0189)
Household access to subdistrict	-0.124***
	(0.0293)
Household access to grid	0.0402
	(0.0525)
Household obtained loans	0.464***
	(0.0323)
Household owns a car	-0.00720

Variables	**Impact on 2017 income**
	(0.0131)
Households own land	0.0102
	(0.0138)
Household head has at least primary school education	0.0504***
	(0.0159)
Household head has at least secondary school education	0.0212
	(0.0161)
Constant	10.71***
	(0.0636)
Observations	11,553
R-squared	0.069

Standard errors in parentheses and *** $p<0.01$, ** $p<0.05$, * $p<0.1$

The result shows that household access to the grid has a small positive impact on household annual income from nonfarm income activities. With each additional year of access to the grid, the expected income from the non-farming activities increases by 0.12%, holding all other variables constant. This finding shows that household access to the grid is beneficial in terms of diversifying their economic activities but with marginal impact.

Likewise, the household head being a male and the household head being married increases the income from non-farming activities by 3.05% and 25.1%, respectively. Significantly, with each additional household head (including any member) who has obtained loans in the past year, the predicted income increases by 46.4% for non-farming income activities. Similar to the previous estimation, household access to sub-district and the household head's age has a negative impact on the outcome variables. From this analysis, it indicates that the household access to the grid is no longer a detrimental factor for nonfarm income diversification in the year 2017. The reason could be improvement in other socio-economic conditions of the household as observed in the summary statistics. As observed, there is a drastic improvement in school attendance of the household (72%), access to subdistrict (94%), household who obtained loans (96%), and the household head who are married (84%) in the year 2017.

4.5 Conclusion and recommendations

This chapter has estimated how access to rural electrification has an impact on household non-farming activities. By using the Living Standard Survey for 2007, 2012 and 2017, the chapter illustrated different approach to ascertain the impact of household access to the grid on non-farming income diversification. From all the analysis, there is evidence that household access to the electricity grid has a positive impact on household income diversification. In relation to the timing of access, household are better off in the early stage of electrification compared to the medium stages but the benefit has eroded over time, with no late access penalty being detected by 2017. Nevertheless, on comparison of the treatment group which are connected to the grid with the control group which are not connected, the former has a higher probability of choosing nonfarm income activities.

From the analysis and discussions, the following key policy recommendations are proposed:

Firstly, households (household head, including any members) that have obtained loans have a higher probability of choosing non-farming economic activities. Though there is a drastic improvement in terms of household who have obtained loans compared to the year 2007 and 2012, there are still some issues in terms of its affordable access. As per the recent national economic survey, 40.8% of the respondents indicated access to finance as their main obstacle in diversifying income and setting-up of SMEs in Bhutan (National Statistics Bureau, 2019). The World Bank report also indicated that limited access to finance caused by factors of both supply and demand had constrained the growth of small firms in Bhutan (Santini, Tran, & Beath, 2017). Therefore, the government should emphasise the need to improve and facilitate access to financial services, mainly savings and credit products. Such affordable financial services, if provided to the household will complement the household access to grid, that can expand the opportunities for income diversification.

Secondly, household heads with at least a primary or secondary level of education have a significant impact on household income diversification. As per the National Statistics Bureau (2018), Bhutan’s literacy rate for the population above six years of age is 66%. From this, the literacy rate of the urban population is 82% and the rural is 58%, indicating a vast discrepancy. Although education has declared free of cost and affordable to all Bhutanese as of 2019, there is a policy lapse to fill the gap in the literacy rate. The reason could be that Bhutan opened its economy to the outside world just three decades ago, and as a result, most of the adult population may not have availed themselves to the formal education system. If this is the case, the government should emphasise the need to provide non-formal education to those who have missed out on formal education opportunities.

Lastly, the timing for the household access to the grid has a significant impact on household income diversification for the early and mid-stages connection. By 2017, any penalty from gaining access to the electricity grid later than other households is no longer detectable and also only marginally evident in terms of the income generated from non-farm activities. However, household which are connected to the grid was much better off than the household which are not connected at all on income diversification. Therefore, Bhutan should expediate up the electrification of the remaining household, which are yet to be connected. Besides, to provide reliable and higher impact of electrification on the household income diversification, government should continue to provide the electricity subsidy to the rural households.

5.1 Introduction

Foreign direct investment in the form of hydropower projects has played a significant role in Bhutan's socio-economic development over the last four decades. As outlined in the Bhutan Power System Master Plan (2003), Bhutan has about 30,000 MW of hydropower potential from which 23,765 MW was found to be techno-economically feasible. In 2018, only 6.79% (1,614 MW) of the total hydropower capacity of Bhutan was tapped, but electricity accounted for almost 36.96% of the country's total exports (Royal Monetary Authority, 2018). Since the 1980s, the revenue from the sale of electricity to India has financed much-needed social and development activities in Bhutan (Gross National Happiness Commission, 2009b, 2013; Royal Monetary Authority, 2018).

With an ambitious plan to achieve 10,000 MW by 2020, primarily with the assistance from the Government of India, the Bhutanese economy has begun to see an unprecedented inflow of capital and labour. Empirical evidence from the literature indicates that FDI with massive inflow of foreign capital, labour and technology can stimulate domestic investment and innovation for the host economy, thereby contributing to its economic growth (Bosworth, Collins, & Reinhart, 1999; Brooks, Fan, & Sumulong, 2003; Selma, 2013; Virtanen, 2006). As a major FDI initiative in Bhutan, hydropower investment is, therefore, expected to affect economic growth positively. However, the empirical evidence on the impact of Bhutan's hydropower investment during its construction phase is scarce. Most studies have focused on the impact of hydropower projects after the commissioning of the project. Since the government has earmarked several mega hydropower projects for the next five years, the motivation for this study was to ascertain how hydropower investment during the construction phase impacted the GDP growth with the onset of the first hydropower plant in 1980.

Due to the commissioning of several hydropower projects over the last four decades, Bhutan has embarked on an ambitious journey to provide electricity to all its people by 2020. The plan is currently on track with 98% of households connected to the electricity grid. But such a plan will not fully materialise if there is no significant upsurge in the development of hydropower in Bhutan.

Given this background, the thesis has also sought to investigate how household access to the grid in rural Bhutan has an impact on household non-farming income diversification.

5.2 Key conclusion

Chapter three of the thesis investigated the overall impact of hydropower development on the Bhutanese economy at a macro level, with a focus on economic growth during the investment phase. The study also ascertained how domestic investment, domestic labour and foreign labour has contributed to the GDP growth in Bhutan. Based on the theoretical framework on the new endogenous growth theory by Romer (1994), the study has assumed that the economic growth of a country is dependent on the accumulation of physical capital, human capital, labour and technological change. By using a Cobb–Douglas production function, the study captured the relationship between potential output and its structural determinants such as domestic investment, domestic labour, foreign investments, foreign labour, and Hicks neutral technical change. Due to a simultaneous causality and the omitted variable bias in the structural equation, the study used the two-stage least squares estimation as proposed by Wright (1928) and Theil (1961). Findings from the analysis suggest that hydropower investment has contributed a marginal impact on economic growth for the study period during its construction phase. The impact was much lower than the contribution made by domestic investment and domestic labour on the GDP per capita. On the other hand, foreign labour does not contribute to the economic growth for the entire study period. However, there is an increase in the GDP growth rate when the hydropower projects are commissioned in Bhutan. The time dummy 1987 has a significant impact on GDP growth in the year 1987. By contrast, the crisis that has occurred from 1990 until 1994 had no impact on the GDP per capita growth for the period 1990 t0 1994.

Chapter 4 investigated the impact of household access to the grid on non-farming income diversification using the Bhutan Living Standard Survey (2007; 2012; 2017). The study used two different econometric models: i.e., conditional fixed-effect logit regression and the difference-in-differences estimation strategies. By using the first approach, it was observed that the households connected to the grid have a higher probability of diversifying their income sources away from farming activities than the households that are not connected. This result is consistent with the findings of Prasad and Dieden (2007), Shahidur R. Khandker et al. (2012a), Rao (2013), Akpan et al. (2013) and Vernet et al. (2019), which all register a significant impact of electrification on household income from non-farming income activities. The findings from the second approach present a similar result: household access to the grid has a positive impact on household income diversification. Concerning the timing of access, the household is better off in the early stages of electrification compared to the midway point, but the benefit has eroded over time. Compared to the household's treatment group, which are connected to the grid while the control group remain unconnected, access to the grid is statistically significant and has a positive impact throughout the entire period under observation.

5.3 Key contribution to the literature

Only a few studies have been conducted by international donor agencies including the World Bank (2005; 2009), Asian Development Bank (2008) and the United Nations Development Programme (2006), on the impact of hydropower on Bhutan's economy. Most of the analyses are focused on the export of electricity after the commissioning of the project. This study contributes to the literature in demonstrating that hydropower investment during the construction phase has a marginally positive impact on the economy compared to domestic investment and domestic labour.

Similar to chapter three, research on the impact of having access to the grid on household income diversification using balanced panel data from three survey waves is scant. With a combination of approaches, this study has predicted the effects of the timing of gaining access to the grid on household income diversification. Chapter four contributes to the literature that having access to the grid has a positive impact on household non-farming income diversification for all survey periods. This chapter also contributes to the literature, indicating that the early and midway timing of gaining access to the grid is essential. It also provides evidence that such benefits erode over time, based on improvements in complementary variables that also affect income diversification.

5.4 Limitations and direction for future studies

Although the key objective of the research has been addressed, this thesis possesses several limitations that require further analysis.

The study in chapter three is constrained by a lack of sufficient time-series data. The number of observations for the 37-year period is too few to conduct a causality analysis to ascertain the impact of hydropower investment on economic growth during its construction phase. As the database grows, future research should aim to address this limitation to provide a better understanding of the impact of hydropower construction on economic growth. Moreover, it is critical to visit the few hydropower project sites (to collect primary data) to ascertain the impact on the local economy that has a detrimental effect on the country's economic growth. More research is still required on the hydropower sector in Bhutan. One possible avenue for future research is to incorporate the export of electricity and the tourism sector in the augmented production function and ascertain how it has an impact on economic growth in Bhutan. The reason is that the export of electricity to India along with tourism is the single largest source of revenue in Bhutan. The other area of research could be on the impact of climate change on the hydropower sector and its knock-on effects on economic growth in Bhutan. The research might ascertain the effects of changes in rainfall patterns in different climatic scenarios and the subsequent impact this has on power generation.

In chapter four, one of the severe limitations of the study is the number of sampled households in the panel data for the three waves. The attrition rate across the three waves is high, with only 414 households interviewed in all three cases. Also, with a lack of appropriate segregation of income in the year 2007 and 2012, the study has needed to rely on dummy outcome variables for which the linear probability model regression was used. As demonstrated, the linear probability model suffers from a 'binary choice problem', where its response probability does not lie in the unit interval of zero and one. In future, with an increase in the number of balanced panel data, the study could use the continuous outcome variable that can predict the exact impact of access to the grid on household non-farming income diversification. A possible research avenue in this area is to investigate, in-depth, why households with access to the grid in 2017 are better off than those which had earlier access to the grid (before 2007) in terms of income diversification. Other areas for further research include exploring the links between access to grid and poverty reduction, inequality, happiness and female education in Bhutan.

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Appendix 1.1: Durbin–Watson test statistics with time trend

```
. reg GDP1 t GDI1 GDL1 GFI1 GFL1

      Source |       SS           df       MS      Number of obs   =        36
-------------+----------------------------------   F(5, 30)        =      3.24
       Model |  .033302269         5  .006660454   Prob > F        =    0.0186
    Residual |  .061650301        30   .00205501   R-squared       =    0.3507
-------------+----------------------------------   Adj R-squared   =    0.2425
       Total |   .09495257        35  .002712931   Root MSE        =    .04533

------------------------------------------------------------------------------
        GDP1 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
           t |  -.0006381   .0007509    -0.85   0.402    -.0021717    .0008955
        GDI1 |   .1690956   .0670415     2.52   0.017     .0321785    .3060127
        GDL1 |   .1037434   .0657567     1.58   0.125    -.0305498    .2380366
        GFI1 |   .0217211    .011582     1.88   0.070    -.0019324    .0453747
        GFL1 |  -.0283139   .0219182    -1.29   0.206    -.0730768     .016449
       _cons |   .0564872   .0178148     3.17   0.003     .0201044    .0928699
------------------------------------------------------------------------------

. estat dwatson

Durbin-Watson d-statistic(  6,    36) =  1.805688
```

Appendix 1.2: Durbin–Watson test statistics without time trend

```
.
. reg GDP1 GDI1 GDL1 GFI1 GFL1

      Source |       SS           df       MS      Number of obs   =        36
-------------+----------------------------------   F(4, 31)        =      3.91
       Model |  .031818418         4  .007954605   Prob > F        =    0.0111
    Residual |  .063134152        31  .002036586   R-squared       =    0.3351
-------------+----------------------------------   Adj R-squared   =    0.2493
       Total |   .09495257        35  .002712931   Root MSE        =    .04513

------------------------------------------------------------------------------
        GDP1 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        GDI1 |     .16817   .0667315     2.52   0.017     .0320702    .3042699
        GDL1 |   .1164829   .0637372     1.83   0.077      -.01351    .2464758
        GFI1 |    .021407   .0115241     1.86   0.073    -.0020965    .0449104
        GFL1 |  -.0288027   .0218122    -1.32   0.196     -.073289    .0156835
       _cons |   .0436422   .0093846     4.65   0.000     .0245022    .0627822
------------------------------------------------------------------------------

. estat dwatson

Durbin-Watson d-statistic(  5,    36) =  1.785543
```

Appendix 2: OLS result on time trend

Source	SS	df	MS			
				Number of obs	=	36
				F(1, 34)	=	1.25
Model	.003356231	1	.003356231	Prob > F	=	0.2722
Residual	.091596339	34	.00269401	R-squared	=	0.0353
				Adj R-squared	=	0.0070
Total	.09495257	35	.002712931	Root MSE	=	.0519

GDP1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
t	-.0009295	.0008327	-1.12	0.272	-.0026218	.0007629
_cons	.0825859	.0183987	4.49	0.000	.0451951	.1199766

Appendix 3: Hausman test result

```
. hausman XTlogitFE XTlogitRE
```

	(b) XTlogitFE	(B) XTlogitRE	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
	Coefficients			
access_grid	1.824781	1.43578	.3890006	.2432678
male	.4415072	.5218269	-.0803196	.2025676
age_respon~t	-.0288201	-.034412	.0055919	.0100882
married	-.4682063	-.1630469	-.3051593	.2348767
Education_~1				
2	-1.649927	-.9694372	-.6804902	1.361528
3	-1.853634	-.9380464	-.9155875	1.315759
owns_house	-.073306	.2716159	-.3449218	.2927964
owns_vehicle	.401424	-.3531266	.7545506	.2699245
owns_land	-1.645144	-.4594275	-1.185717	.3686358
access_sub~t	-.2800098	-.076132	-.2038778	.2691013
road	-.6033153	-.4714008	-.1319145	.2426244
loan	2.243388	1.874057	.3693307	.241268
access_cre~t	1.959269	1.028703	.930566	.3646727

```
                  b = consistent under Ho and Ha; obtained from xtlogit
   B = inconsistent under Ha, efficient under Ho; obtained from xtlogit

    Test:  Ho:  difference in coefficients not systematic

                 chi2(13) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =       25.46
                Prob>chi2 =      0.0201
```

Appendix 4.1: Percentage change in odds for access to the grid without covariates

clogit (N=837): Percentage Change in Odds

Odds of: 1 vs 0

nonfarm_in~e	b	z	P>|z|	%
access_grid	0.88918	3.274	0.001	143.3
2012.year	-0.26143	-1.413	0.158	-23.0
2017.year	1.33217	4.565	0.000	278.9

(note: file Myfile.doc not found)

Appendix 4.2: Percentage change in odds for access to the grid with covariates

clogit (N=837): Percentage Change in Odds

Odds of: 1 vs 0

nonfarm_in~e	b	z	P>|z|	%
access_grid	1.26267	3.611	0.000	253.5
Dprimary	-0.16596	-0.415	0.678	-15.3
Datleast_S~y	0.69424	0.568	0.570	100.2
owns_house	-0.14542	-0.356	0.721	-13.5
owns_vehicle	0.06633	0.206	0.837	6.9
owns_land	-0.55922	-1.318	0.188	-42.8
access_sub~t	-0.38158	-1.067	0.286	-31.7
road	-0.91316	-2.762	0.006	-59.9
loan	2.26106	7.072	0.000	859.3
male	0.90456	3.286	0.001	147.1
age_respon~t	-0.03783	-3.134	0.002	-3.7
married	-0.35753	-1.186	0.236	-30.1
2012.year	-0.34527	-1.011	0.312	-29.2
2017.year	0.86453	1.841	0.066	137.4

Appendix 5: Wald test for all the independent variables

```
 ( 1)  [nonfarm_income]access_grid = 0
 ( 2)  [nonfarm_income]Dprimary = 0
 ( 3)  [nonfarm_income]Datleast_Scondary = 0
 ( 4)  [nonfarm_income]owns_house = 0
 ( 5)  [nonfarm_income]owns_vehicle = 0
 ( 6)  [nonfarm_income]owns_land = 0
 ( 7)  [nonfarm_income]access_subdistrict = 0
 ( 8)  [nonfarm_income]road = 0
 ( 9)  [nonfarm_income]loan = 0
 (10)  [nonfarm_income]male = 0
 (11)  [nonfarm_income]age_respondent = 0
 (12)  [nonfarm_income]married = 0

           chi2( 12) =   74.55
         Prob > chi2 =    0.0000
```