Time Series Analysis of Electricity Sector and Economic Growth of Bhutan

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Abstract

This study aims to investigate the time series analysis of the electricity sector and the economic growth of Bhutan. The present study indicates that electricity production from hydropower is subject to fluctuations due to changes in seasonal inflows and weather patterns applying regression analysis. These fluctuations may lead to challenges in balancing electricity supply and demand. Moreover, it highlights the importance of the electricity sector for the country's economic development and analyzes the relationship between gross domestic product (GDP), electricity consumption, and tourism growth using time series analysis techniques such as regression model and correlations analysis. The results reveal a positive relationship between GDP, electricity consumption, and tourism growth in Bhutan. The conclusions indicate that the electricity sector shall remain the mainstay of Bhutan's economy as the leading contributor to government revenues and the country's GDP. Fundamentally, the electricity sector's development and exports have driven Bhutan's economic growth and generated revenues for social and financial investments.

Keywords: Electricity sector, Gross domestic product, Economic growth

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Chapter 1. Introduction

This study examines the hydropower sector's dominance in Bhutan's electricity sector, including seasonal variations. In addition, it analyzes the correlation between Gross Domestic Product (GDP), electricity usage, and the tourism industry to demonstrate the importance of the electricity sector for Bhutan's economic development. This chapter highlights a time series analysis to study Bhutan's electricity sector and economic growth.

1.1. Background

This study conducts a time series analysis of Bhutan's electricity sector and economic growth. Time series analysis has long been an effective tool for examining the connections between various economic phenomena. Primarily, time series analysis provides a reliable analytical tool to find trends and causal correlations in the context of the energy sector and its effect on economic growth. One of the main benefits of time series analysis is to consider the time-based dependencies and patterns frequently present in economic data. Particularly in the electricity sector, seasonality, cyclical oscillations, and long-term tendencies have been seen (Hyndman & Athanasopoulos, 2018). A time series analysis can offer more precise and trustworthy insights into the relationship between energy consumption and economic growth by including these time-dependent structures.

Moreover, time series analysis enables a greater comprehension of the causal links between variables, which is extremely important when examining the power sector's contribution to economic growth. Furthermore, the handling of non-stationary data, which is frequently encountered in the context of studies on electricity and economic development, is another benefit of time series analysis. Researchers can recognize and account for non-stationarity, making more accurate and valid conclusions (Engle & Granger, 1987).

This study examines Bhutan's electricity sector by analyzing monthly statistics over the 22 years between 2001 and 2022 on electricity production, consumption, import, and export. Using these statistics, policymakers and investors may better comprehend the trends and patterns in electricity production, consumption, and exchange. The study indicates that Bhutan's electricity sector is dominated by Hydropower, with hydropower facilities producing almost all of the nation's electricity. Consequently, the analysis presents how much electricity is produced by hydroelectric plants and seasonal variations in production levels brought on by weather patterns and water availability changes.

Additionally, the paper explores the correlation between GDP, electricity consumption, and tourism growth to demonstrate the importance of the energy sector, mainly electricity, for Bhutan's economic development by using the annual statistics over 21 years between 2001 and 2021. A review of Bhutan's tourist industry is included in the study to investigate how GDP, electricity use, and tourism are related. The study uses a time series analysis to comprehend the patterns and trends in the data. The findings indicate a favorable correlation between energy use and economic growth in Bhutan, particularly in the travel and tourism industry. According to the study's findings, the electricity sector has a critical role in the sustainable economic growth of Bhutan.

1.2. Problem statement

The time series analysis of the electricity sector and economic growth is proposed considering the Government's sustainable hydropower development and its importance in economic growth. Notably, Bhutan's abundant hydropower potential, which accounts for more than 99% of its electricity generation, has been a major driver of its economic growth, as it has enabled the country to export electricity to neighboring countries and earn significant foreign exchange. In addition, Bhutan's strategic location between India and China has made it an important transit hub for trade and investment in the region.

An Umbrella Agreement was signed between the Royal Government of Bhutan (RGoB) and the Government of the Republic of India (GoI) in March 2009 for the development of 10,000MW hydropower projects by 2020, thus calling for the need to outline a power evacuation plan for the 10,000MW initiative projects as well as other future potential projects and also to integrate the same with the power evacuation system being developed adjacently in India. The Sustainable Hydropower Development Policy of 2008 supplied the general policy parameters. The 10,000MW by 2020 target was not met, even though basic principles have not changed much. It was suggested in the most recent Hydropower Development Strategy Report, which conducted a thorough analysis of the industry, that Bhutan should rationalize and adopt a more reasonable pace for hydropower development.

The hydropower sector has contributed to the Government's revenues through royalties, dividends, and taxes. In 2020, Druk Green Power Corporation (DGPC) earned a total income of Nu. 13.342 billion with a profit before tax of Nu. 7.310 billion (DGPC, 2021). Regarding O&M expenditures, less than 5% of its electricity revenues are expensed towards generation and maintenance costs. Thus, it is imperative for Bhutan and DGPC, in particular, to devise pragmatic policies and strategies to promote Bhutan's hydropower development to fuel the national economy.

A renewable energy source that depends on water availability is hydropower generation. The amount of water that may be used to generate electricity by hydropower relies on several variables, including precipitation, snowpack, and water storage. The primary sources of water for hydropower production are rainfall and snowfall. Rainfall and snowfall patterns are significant in determining where there is access to water for hydropower generation. The volume and flow rate of water available for hydropower generation depends on the frequency and amount of precipitation in the catchment areas of rivers and lakes.

Of growing concern with global warming and climate change is the unpredictability of hydrological flows, as was the experience during 2018 with Bhutan seeing very lean river flows in quite some time, resulting in the lowest recorded generation from most hydropower plants. The impending policy on environmental flows could also adversely affect the viability and profitability of the power plants. This will require careful consideration of the Government as any e-Flow decision could make current and planned future investments in hydropower unviable.

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 the 'resource curse' 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).

Moreover, the International Monetary Fund (IMF) stated that Bhutan's exports are characterized 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 at risk of debt unless suitable risk-management measures are considered (Ansar, Flyvbjerg, Budzier, & Lunn, 2014; Awojobi & Jenkins, 2015; Cernea, 2004).

Further, the growth of various sectors of the economy, including agriculture, industry, and services, has led to a steady increase in electricity consumption in Bhutan. According to the Bhutan Power Corporation, the country's electricity consumption increased from 1,048 gigawatt-hours (GWh) in 2009 to 2,622 GWh in 2019, representing a compound annual growth rate of 10.5%. This increasing electricity consumption has significant implications for the country's economic growth and sustainable development.

This study seeks to address the lack of understanding of the relationship between electricity consumption and economic growth in Bhutan and the factors that influence this relationship. While Bhutan's electricity consumption has been increasing steadily over the years, the impact of this growing consumption on the country's economic growth is poorly understood. Some studies suggest a positive relationship between electricity consumption and economic development. In contrast, others suggest that the relationship may not be straightforward and depends on various factors, including the economy's sectoral composition, the availability and cost of electricity, and the level of technological development.

In addition, Bhutan is committed to promoting sustainable economic development underpinned by Gross National Happiness (GNH). Therefore, it is essential to understand the long-term implications of the high electricity sector on the country's economy. Verily, the need to understand the interdependencies between electricity production and consumption, social factors, and economic growth is essential for policymakers to devise strategies that meet the country's energy demand while promoting sustainable development. A comprehensive analysis of these factors is lacking for Bhutan, which this research aims to address.

1.3. Research Questions and Objectives

This study's primary objective is to examine the patterns and trends of Bhutan's electricity production, consumption, import, and export over time. This may include seasonal variations, growth rates, and fluctuations in demand and supply using monthly data from 2001 to 2003.

The present study also seeks to ascertain and evaluate the performance of Bhutan's economy from the year 2001 to 2020 concerning the electricity sector over the past two decades. Bhutan has developed and commissioned twelve 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.

The Government of Bhutan has set an economic development objective to become an upper-middle-income country with a per capita GNI of USD 11,000 by 2030. The main driver of this Bhutanese economic transformation will be the electricity sector. Based on this per capita GNI target, projections have been made on the Government's revenue sources and expenditure levels and, more importantly, on the expected contributions from the hydropower sector (SHDP, 2021).

Thus, this research aims to examine the connections between the electricity sector and economic development in Bhutan, pinpoint the variables that affect these connections, and suggest policies and tactics for fostering sustainable electricity and economic growth in the nation. The study's particular goals are as follows:

The following research questions will be addressed:

- What is the variation in electricity production and consumption in Bhutan over time?
- What is the relationship between GDP, electricity consumption, and tourism growth?

Accordingly, the objectives of this research are:

- To analyze the historical variations in electricity production and consumption (demand and supply scenarios).
- To examine the relationship and causality between GDP, electricity consumption, and tourism growth.

Chapter 2. Overview of Bhutan's Electricity Sector

This chapter encompasses a comprehensive overview of Bhutan and its Electricity sector. It highlights the sustainable electricity sector development, which is critical for Bhutan to reap the benefits of this huge hydropower reserve. The economic gains from this development to the people of Bhutan in financial, economic, and social terms will be immense.

Further, several policies and acts directly impacting the electricity sector are incorporated. These policies and acts are the roadmaps to promote hydropower development and other renewable energy sources, ensure energy security, and support the country's sustainable development goals.

Bhutan is a small landlocked country in South Asia, nestled between China and India. Its unique development philosophy, Gross National Happiness (GNH), is a distinctive concept emphasizing sustainable development, environmental preservation, cultural preservation, and good governance. The nation's 38,394 km2 of land is divided into an east-west dimension of around 300 km and a north-south boundary that is more than 170 km long (Kingdom of Bhutan, 2020 SDG). The nation is heavily mountainous, with elevations ranging from 100 meters in the lowlands to more than 7,500 meters toward the north. Bhutan has a variety of climates because of its rugged terrain and geographic position. Bhutan is influenced by the North Indian monsoons, from which 90 per cent of the country's precipitation occurs during the monsoon and pre-monsoon seasons (20 per cent). The capital city of Bhutan is Thimphu, which is also Bhutan's political and economic center and is situated in the western central part of the country.

One of the least populated nations in Asia is Bhutan. 728,700 people were deemed to be Bhutan's entire population as of 2017. In general, population growth is relatively moderate. According to ESCAP (2021), the total population was 591,000 in 2000, a 1.2 per cent annual growth rate from 2000 to 2017. In 2017, the average population density was 19 people per km2, although Thimphu had a large population with a density of 67 people per km2. (Kingdom of Bhutan, 2020).

Bhutan's GDP in 2017 was estimated at US$ 2.53 billion, which translates into a GDP per capita of US$ 3,472. Bhutan was once categorized as a Least Developed Country (LDC). Due to its remarkable socio-economic growth, Bhutan is scheduled to graduate from the category of LDC in 2023. It is now classified as a lower-middle-income economy (World Bank, 2021). The World Bank projected Bhutan's GDP to reach $2.6 billion in 2020, with an annual growth rate of 1.5%. The nation's per capita income in 2020 was $3,456, which is low compared to other countries in the region.

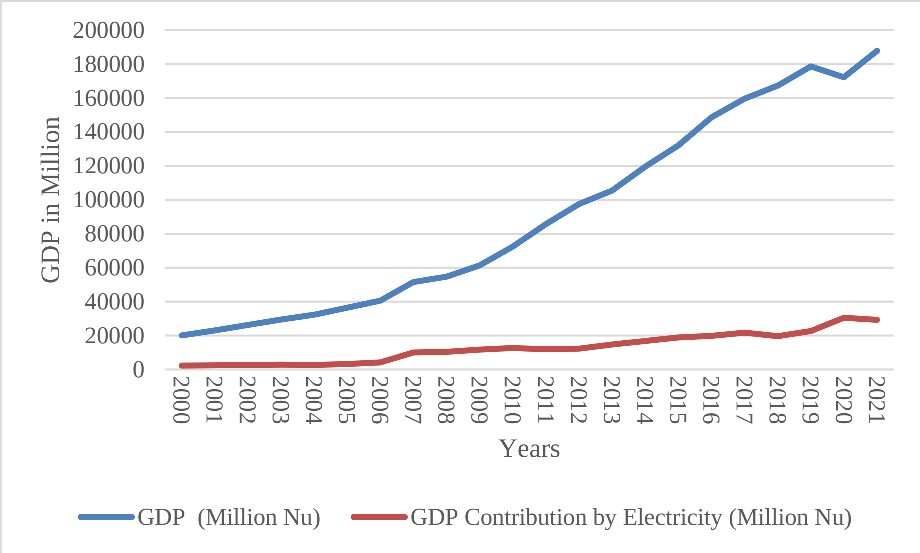
Over the past few decades, Bhutan has achieved considerable strides in eliminating poverty, with the country's poverty rate falling from over

23% in 2007 to 8.2% in 2017. With over 98% of the population having access to basic healthcare services and a literacy rate of over 71%, the nation has also made considerable investments in education and healthcare.

The key economic sectors of Bhutan are agriculture, Hydropower, and tourism (Kingdom of Bhutan, 2020). Electricity production and consumption are crucial to the country's economic growth and social well-being. Hydropower is the primary source of electricity in Bhutan, and the Government has significant potential for further development in this sector.

Bhutan's electricity sector is dominated by Hydropower, which accounts for over 99% of its electricity generation. With its vast hydropower potential estimated to be around 30,000 MW, the country has embarked on an ambitious plan to harness this resource and become a green energy powerhouse. As of 2021, Bhutan's installed hydropower capacity was around 2,500 MW, with several more projects in the pipeline. The hydropower sector has been crucial in driving the country's economic growth. The development of hydropower projects has led to investments in infrastructure, job creation, and increased revenue from electricity exports. As a clean and renewable energy source, Hydropower has also helped the country achieve its environmental commitments and promote sustainable development.

Figure 1: Real GDP and Contribution of Electricity Sector



Source: NSB 2023

Bhutan has experienced remarkable economic growth over the last few decades, with an average GDP growth rate of around 7% between 2000 and 2020. This growth has been driven by several factors, including the expansion of the hydropower sector, growth in the services sector, and increased investment in infrastructure. The country has witnessed a steady increase in electricity consumption in recent years, with per capita consumption rising from 1,763 kWh in 2010 to 2,968 kWh in 2020. This growth can be attributed to several factors, including increasing access to electricity, urbanization, and economic development. As more households connect to the grid and industries expand, the electricity demand is expected to grow in the coming years.

Bhutan has some of the lowest electricity prices in the region, thanks to its abundant hydropower resources. The domestic electricity tariffs are highly subsidized, with residential consumers paying lower rates than industrial and commercial users. This pricing structure aims to provide affordable electricity access to all citizens and promote economic growth. The export of electricity to neighboring countries, primarily India, provides an essential source of revenue for Bhutan. The Government has preferential trade agreements with India, allowing it to export electricity at competitive rates. This revenue from electricity exports helps fund infrastructure projects and social programs, contributing to the country's overall development.

Bhutan is also known for its Gross National Happiness (GNH) philosophy worldwide. The concept of Gross National Happiness (GNH), a comprehensive strategy for advancement and development, was initially put forth in 1972 by Jigme Singye Wangchuck, the fourth king of Bhutan. With this alternative development strategy, the emphasis is shifted from solely economic metrics like the GDP to a more comprehensive and well-rounded assessment of pleasure and well-being. International acknowledgement of the GNH ideology has led to other nations studying and using it in diverse ways.

In addition, Bhutan's ancient legal code of 1629 stated, "If the government cannot create happiness for its people, then there is no purpose for the government to exist". The code stressed that Bhutanese laws must promote happiness for all sentient beings – as a Buddhist nation, it is clear that the cultivation of compassion stemmed from this ancient wisdom. The focus was not just on the economic progress of Bhutan but on a flourishing human society living in harmony with nature. Today there is much research showing that wealth alone does not contribute to life satisfaction or happiness. GNH measures the quality of its development more holistically and believes that the beneficial development of human society occurs when material and spiritual development occurs side by side. Bhutan has been considered a living example by many for sparking the debate on what is real human development (GNHC 2021).

Four decades later, Bhutan adopted democracy in 2008. Article 9 of the Bhutanese Constitution further guaranteed the inclusion and persistence of GNH ideals by outlining tasks like: "The State shall strive to promote those conditions that will enable the pursuit of Gross National Happiness." Therefore, Bhutan ensures that the conditions are in place for happiness to be its only development goal. GNH has changed over time from a lofty goal to a more quantitative tool, partly due to the incredible global attention it has attracted.

The GNH idea has value beyond Bhutan and can also teach other nations a lot. The GNH philosophy presents an alternative approach to development that prioritizes people's health and happiness while acknowledging the significance of environmental conservation and cultural preservation. The world faces many challenges, including income inequality, environmental degradation, and cultural homogenization.

Bhutan's Gross National Happiness (GNH) concept is an original and cutting-edge method of growth that may be able to solve many of the problems that face contemporary civilizations. The GNH ideology presents a more balanced and inclusive model for development by highlighting the significance of well-being, sustainability, cultural preservation, and good governance development (GNHC 2021).

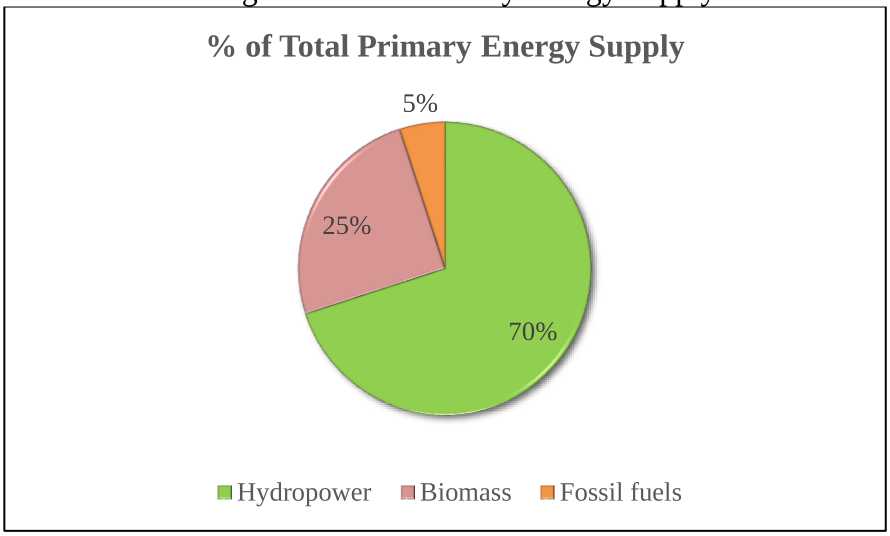
The Royal Government of Bhutan is pursuing the original idea of Gross National Happiness (GNH) as its development philosophy, demonstrating its concern for preserving its rich cultural heritage and pristine environment while ensuring economic growth and the general well-being of its people. Conceptually, GNH is built on the pillars of good governance, preservation of cultural values, environmental conservation, and promoting sustainable development. The Royal Government of Bhutan has committed to absorbing more carbon than it emits - and to maintain its status as a net sink for Green House Gases (GHG) through the Declaration of the Kingdom of Bhutan dated December 11 2009.

Bhutan has a wealth of natural resources, including the potential for Hydropower, solar, wind, a sizable forest cover, and mineral riches. These resources aren't just a part of Bhutan's diverse ecology; a balanced approach to resource development and conservation has also aided the nation's advancement. Hydropower sales comprised the greatest portion of the GDP in 2011 and supplied almost all of the nation's electricity requirements.

As stated in the 10th Five-Year Plan, a key component of Bhutan's strategy is exploiting untapped hydropower potential. Hydropower offers the nation several advantages, including economic gains from export income, environmental gains from the clean nature of energy production, and an edge in terms of electricity security due to the availability of key domestic resources.

Bhutan's primary energy supply mainly comes from Hydropower, biomass, and imported fossil fuels (primarily diesel and petrol).

Figure 2. Total Primary Energy Supply



Source: World Bank (2021)

In Bhutan, Hydropower is the main energy source. The installed hydroelectric capacity was at 2,400 MW as of 2021, and several more projects are now being built or are in the planning stages.

Electricity supply in Bhutan in the 1990s (including the operation of mini HPPs and diesel power plants) was the responsibility of the DOP, which was part of the Ministry of Trade and Investment. A major turning point in the overall development of the power sector was the commissioning of the 336 megawatts (MW) Chhukha Hydro Power Plant, together with transmission links to connect the power station to both Bhutan's domestic network and the Indian grid in 1988. The project was implemented as a joint venture between the Government of India and the Government of Bhutan and then incorporated in July 1991 under the Companies Act 1989 as Chhukha Hydro Power Company (CHPC), a government-owned company.

Table 1. Total Electricity Generation per Sources

Energy Source	**% of Total Electricity Generation**
Hydropower	99.5%
Solar, Wind, and Others	0.5%

Source: Department of Energy, Bhutan (2021)

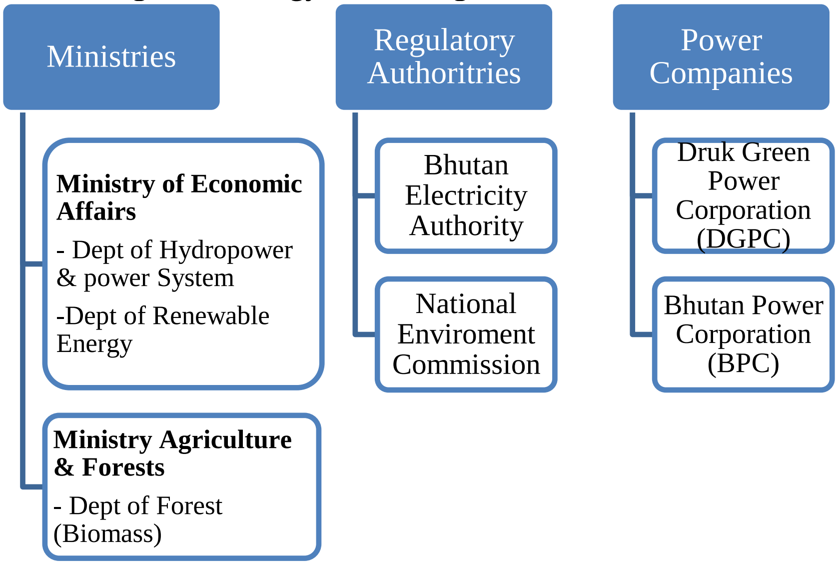
As a government organization, the DOP was funded directly by the Ministry of Finance from the national budget. The Ministry of Finance received (i) funds from domestic consumers from power sales and (ii) dividends from the profits generated by CHPC's sales. In 2001, the Government undertook far-reaching institutional reforms with the enactment of the Electricity Act to increase the commercial orientation of the power sector entities; delineate the responsibilities for sector policy formulation, utility operation, and regulatory oversight; and improve the investment climate for new investments in the export-oriented power sector. The DOP was bifurcated into (i) BPC, a public utility; (ii) the DOE, a government department; and (iii) BEA, a regulatory body under the DOE.

BPC was established on July 1 2002 under the Companies Act 2000. Its mandate includes (i) the distribution of electricity for the entire country, (ii) the provision of transmission access for generating stations for both domestic and export supply, and (iii) the operation of embedded and off-grid mini and micro HPPs and diesel plants. The DOE was responsible for policy formulation, planning, and coordination of activities for the energy sector and the overall responsibility for implementing the Government's ambitious rural electrification program and developing the new export-oriented hydropower projects.

The economic and technical regulation of power sector entities, including tariff setting and licensing, was entrusted to BEA, a functional autonomous agency established under the DOE in 2006 following the Electricity Act (Section 7). BEA became financially independent in 2007 while functioning as a division of the DOE. It became administratively independent in January 2010 when staff was de-linked from the civil service.

All export-oriented HPPs were consolidated under Druk Green Power Corporation (DGPC) in 2008; Tala HPP was brought under DGPC in 2009. DGPC is mandated to operate the country's existing hydropower resources and act as the counterparty in developing new hydropower projects. The Government's ownership of BPC and DGPC is consolidated under Druk Holding and Investments; a holding company set up in November 2007 to manage the Government's existing and future investments. The company is responsible for corporate oversight and setting commercial targets for BPC, DGPC, and several other state-owned entities. Companies with primarily social mandates remained with the finance ministry. The National Environment Commission (NEC) retained responsibility for approving the environmental impact assessments and enforcing the ecological safeguard requirements (ADB report, 2021).

Figure 3. Energy Sector Organizational Structure



Source: Department of Energy, Bhutan (2023)

Bhutan has been focusing on developing its energy sector under its Five-Year Plans. The country has undertaken several hydroelectric projects in cooperation with India, whose output is traded between the two countries. The energy sector of Bhutan is administered under two ministries, namely the Ministry of Agriculture and the Ministry of Economic Affairs. In 2002, Bhutan's energy sector underwent a major restructuring to separate commercial management and ownership from the Government.

The main development challenges Bhutan's power sector faced in the mid-1990s were identified as the institutional weakness of the sector and its lack of capacity to manage the sector effectively. However, Bhutan's many hydroelectric plants provide energy far over its domestic demand for energy in household, commercial, and industrial sectors.

In the early 21st century, about 70 per cent of all energy consumption in Bhutan was in the household sector, with heating and cooking with firewood accounting for between 70 and 90 per cent of total energy consumption and virtually 100 per cent of household energy consumption.

To date, the Bhutanese electric energy supply has been virtually entirely hydroelectric. However, due to the vulnerability of the water supply amid climate change, the Bhutanese Government began exploring alternative energies such as solar, wind, and biogas in the early 21st century. Climate change also poses a threat to Bhutan's hydropower sector, which is the country's main source of revenue.

In 2019, Bhutan's primary energy trade grew 21.4 per cent, with non-renewable energy increasing by 44.4 per cent and renewable energy increasing by 17.8 per cent. The country's renewable energy sector has been growing steadily, with a 7.0 per cent increase in 2018-195.

Bhutan's energy sector has been primarily focused on hydroelectric power, with the country's many hydroelectric plants providing energy far over its domestic demand. However, the Government has been exploring alternative fuels such as solar, wind, and biogas due to the vulnerability of the water supply amid climate change. The renewable energy sector has been growing steadily, with a 7.0 per cent increase in 2018-19.

The world's theoretical hydropower potential is approximately 40,470 TWh/year and the total technically feasible hydro potential is about 14,322 TWh/year. One-fifth of the global electricity supply comes from Hydropower, and hydropower development has promoted and helped shape economic growth in many countries, such as Bhutan, Canada, Norway, and the United States (World Bank 2009).

Table 2. World Hydropower Potential

SN	**Location**	**Theoretical Potential (TWh/a)**	**Technical Potential (TWh/a)**	**Economic Potential (TWh/a)**
1	Africa	4000	1750	1000
2	Asia	19300	6700	3600
3	Australia	600	270	105
4	Europe	3220	1225	775
5	North & Central America	6330	1657	1000
6	South America	7020	2720	1600
	World	**40,470**	**14,322**	**8,080**

Source: A. Gurbuz, 2006

Hydropower has four advantages: it is renewable and produces negligible amounts of greenhouse gases. It is the least costly way of storing large amounts of electricity, and it can easily adjust the amount produced to the amount demanded by consumers. Thus Hydropower can play an important role in addressing the growing demand worldwide for clean, reliable, and affordable energy. Moreover, properly designed and implemented multipurpose water infrastructure projects offer other development opportunities such as irrigation, fisheries, and domestic and industrial water supply for developing nations *(World Bank 2009; Billington and Jackson 2006; ICOLD 2010).*

However, hydropower projects are complex and are often associated with serious economic, social, and environmental risks. These risks are often cited by those opposed to large-scale hydropower projects by stakeholders such as civil society organizations, communities, donor agencies, and governments in developed countries.

In Bhutan, electricity was introduced sometime in 1966 when the first 256 kW diesel generating plant was installed to supply power to Phuentsholing, a border town in the Southwest and gateway to Bhutan. Bhutan's first hydroelectric plant of 360 kW installed capacity was commissioned in 1967 to supply power to the capital, Thimphu. After that mini hydropower plants of 300 kW to 1250 kW capacity were built in 5 districts' headquarters to supply electricity primarily for the lighting energy need by 1974. The development of the first major hydroelectric project started in 1974 when a bilateral agreement was signed between

India and Bhutan for the construction of 336 (4x84) MW Chukha hydel project (468 meters, Pelton turbine) across river Wangchu in Western Bhutan for meeting the internal power demand and export of the surplus electricity to India. The Project was commissioned in 1986-88 *(Tshering & Bharat, 2004).*

Druk Green Power Corporation (DGPC), a wholly-owned government company, is mandated to promote, develop and maintain the hydropower assets of Bhutan sustainably. Druk Green Power Corporation Limited (DGPC) was incorporated on January 1, 2008, under the Companies Act of the Kingdom of Bhutan 2000, with the mandate to promote, develop, and sustainably maintain hydropower assets of Bhutan. Since then, DGPC has successfully amalgamated the erstwhile hydropower corporations in the country for better synergy and optimization of its limited resources. DGPC has also ventured into constructing new hydropower projects on its own and through partnerships and establishing subsidiary companies to provide ancillary services to support its mandates. For hydropower projects being constructed under the auspices of the Royal Government of Bhutan, DGPC has ensured that it is ready to assume responsibility for the operation and maintenance of such projects once they are commissioned.

Bhutan's GDP growth rate over the decade to 2020 has averaged around 7.3% per annum; it is driven primarily by investment in Hydropower and the subsequent export of electricity to India *(Balasubramanian & Cashin, 2019; World Bank, 2018b)*. Given the importance of hydropower development for the Bhutanese economy and the achievement of national objectives, the expansion of this sector has become one of the highest priorities for the Bhutanese Government to maximize wealth and revenues to the nation.

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

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

Table 3. Status of the Hydropower Development in Bhutan as of 2020

SN	Category of hydropower plants	Total no. of Plants	Tariff Nu/kWh	Capacity in MW
1	Mini hydropower plants	12	1.59	7.70
2	Micro hydropower plants	9	1.59	0.42
3	Medium hydropower plants *a) Kurichhu (60 MW)* *b) Basochhu (64 MW)* *c) Dagachhu (126 MW)*	3	2.12 2.12 2.90	250
4	Large hydropower plants *a. Chhukha Hydropower plant (336 MW)* *b. Mangdechhu Hydropower plant (720 MW)*	2	2.25 4.12	1056
5	Mega hydropower plant (Tala)	1	2.12	1020
	Total	27		2334.12

Source: DGPC, 2018

Aligning with the recommendations of the Hydropower Strategy report, the Government is pursuing the development of mega reservoir projects. The Government will focus on enhancing its involvement in the current projects that are being implemented under the Inter-Governmental (IG) model. Exploring other regional energy markets and the sale of energy through another market mechanism, including ancillary services, will be explored. It will continue to develop competencies to carry out hydropower feasibility studies and conduct field studies on behalf of the Government for future planned hydropower projects. It will also focus on the studies for other augmentation projects to enhance the generation capacity of the existing power plants during the lean season *(DGPC, 2021).*

Table 4. Power Plants Under Construction as of 2020

SN	Category of hydropower plants	Total no. of Plants	Capacity in MW	Construction start date	Project completion date
1	Medium hydropower plants (Nikachu)	1	118	February 2016	January 2023
2	Large hydropower plants (Kholongchu)	1	600	September 2015	February 2024
3	Mega hydropower plants	2	2,220		
	a. *Punatshangchhu I (1200 MW)*			November 2008	July 2025
	b. *Punatshangchhu II (1020 MW)*			December 2010	December 2023
	Total	4	2,938		

Source: DGPC, 2021

The principal laws which govern or have an influence on the development of the energy sector in Bhutan are:

- Electricity Act of Bhutan, 2001
- Bhutan Sustainable Hydropower Development Policy, 2021
- Foreign Direct Investment Policy, 2010
- The Economic Development Policy of the Kingdom of Bhutan, 2010
- Bhutan Renewable Energy Policy, 2013

The Electricity Act of 2001 provides the framework for the institutional sector and governance of the electricity sector in Bhutan. The creation of new institutions has superseded some of the provisions of the Act.

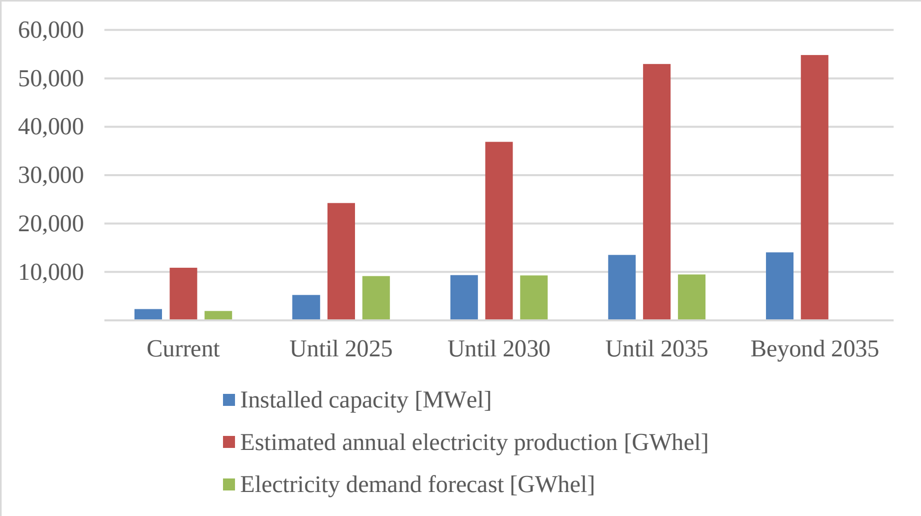
The Hydropower Policy 2021 provides the framework and guidelines for accelerated hydropower development in the country. The Policy allows the RGoB to develop hydropower projects with public, private or public-private participation and in collaboration with the Government of development partner countries. The Foreign Direct Investment Policy also supports private sector participation in developing medium and large hydropower projects and other RE projects. It provides incentives for foreign entities to invest in Bhutan's energy sector.

The Sustainable Hydro Power Development Policy 2008 and the Economic Development Policy (EDP) 2010 recognize the need for a Renewable Energy Policy to promote RE sources to ensure national energy security through a diversified energy mix.

The RE Policy of 2013 is an important document which elucidates the RGoB's objectives for developing the RE sector in the country and provides the policy framework to address key issues relating to the promotion of RE and public and private sector participation in the development of RE projects. The Policy also addresses the issue of incentivizing RE given the low cost of large hydropower projects and the subsidized tariffs in Bhutan, which make small-scale RE generation unviable.

The BEA does not require the BPC to design and develop supply or demand-side EE programs, which, coupled with the subsidized electricity tariffs, hinders the implementation of EE. Thus, an urgent need is to create and adopt a comprehensive EE policy to incentivize the public and private sectors to implement EE projects. The UNDP is supporting the preparation of a study to examine the potential for 15 Bhutan: Rapid Assessment and Gap Analysis energy efficiency in the transport, buildings, industry and agriculture sectors, and it is expected that this study will provide the basis for formulating an EE policy. RE and EE policies are lacking and critical for promoting RE/EE development in the country. And, also there is a need for an "Energy Plus" approach to energy access and poverty reduction (DHPS, 2020).

Figure 4: Installed capacities and estimated electricity generation



Source: DGPC 2023

Chapter 3. Literature Review

This chapter provides a comprehensive overview of the existing literature on the proposed research topic. It includes identifying research gaps, establishing the context, evaluating the quality of existing research, developing theoretical frameworks, and informing the research design. Several studies have addressed different aspects of the research topic. Some key studies are summarized below:

Hydropower potential and challenges in Bhutan (Dorji et al., 2015): This study assesses the hydropower potential and challenges in Bhutan, highlighting the sector's importance for the country's economic growth and the need for sustainable development. The study presents the current status of hydropower development in Bhutan, highlighting the country's significant potential for hydropower generation, its existing hydropower projects, and the challenges faced in harnessing this potential through existing literature review and field surveys. It also discusses financial constraints, environmental concerns, and technical challenges, such as the need for infrastructure development and skilled human resources using a discounted cash flow analysis and Environmental impact assessments.

The paper's recognition of the significance of sustainable development is one component that sticks out. It stresses the necessity for Bhutan to balance hydropower growth and social and environmental factors, such as the effects on residents and the need to maintain the nation's distinctive biodiversity. The study offers insightful information about Bhutan's hydropower business, potential, and difficulties. It provides a helpful resource for decision-makers, academics, and professionals interested in hydropower development in Bhutan and other developing nations.

Electricity consumption, economic growth, and population growth nexus in Bhutan (Tshering & Wangdi, 2017): This paper investigates the relationship between electricity consumption, economic growth, and population growth in Bhutan using time series data, finding a bidirectional causality between electricity consumption and economic growth. The study used VECM to analyze electricity consumption, GDP, and population growth in Bhutan from 1980 to 2015. The causal relationship between these variables was also investigated using various statistical techniques, and long-run equilibrium relationships were evaluated.

The study's main finding is that Bhutan's electricity usage and economic growth are positively correlated. This research implies that developing the nation's energy infrastructure could have beneficial knock-on benefits for economic growth. The study also demonstrates that population expansion has a detrimental effect on economic growth, underscoring Bhutan's need for population control measures.

Despite the study's excellent planning and execution, certain restrictions exist. The study, for instance, uses aggregate data, which can hide the variability of the links between energy consumption, economic growth, and population increase in different Bhutanese regions. The study does not consider how trade and foreign direct investment might affect economic growth. The research offers helpful insights into the intricate connection between Bhutan's population increase, economic growth, and energy usage. The study's conclusions could guide planning and Policy in Bhutan and other emerging nations that want to balance economic growth and environmental development.

Sustainable development and energy transition in Bhutan: Progress and challenges (Choden & Tshomo, 2020): This paper discusses the progress and challenges of sustainable development and energy transition in Bhutan, emphasizing the importance of energy efficiency and renewable energy sources in meeting the country's energy demand using literature review and SWOT analysis.

The paper's emphasis on Bhutan's distinctive approach to sustainable development, which significantly emphasizes holistic well-being and environmental conservation, is one of its strong points. The authors thoroughly analyze Bhutan's Gross National Happiness (GNH) index, which gauges happiness by considering elements including health, education, and environmental protection. This method of development recognizes the interconnectedness between ecological health and human well-being, making it particularly pertinent in climate change.

The In-depth information about Bhutan's progress in converting to renewable energy sources, particularly Hydropower, is also included in the report. The authors point out that Bhutan has made great advancements in this area, with Hydropower providing nearly 99% of the nation's electricity. The study also discusses some difficulties Bhutan faces in developing its renewable energy sector, including a lack of technical know-how, limited financial resources, and worries about the environmental effects of large-scale hydropower projects.

Overall, the study is an instructive and well-researched examination of Bhutan's efforts to transition to a sustainable energy system. Although Bhutan has made significant progress in these areas, the authors also point out some of the country's difficulties in maintaining its momentum. Bhutan's distinctive approach to sustainable development and renewable energy may provide important lessons for other nations to consider as the globe struggles with climate change's effects.

The Electricity Consumption, Output, and Trade in Bhutan, (Hooi Lean and Russell Smyth et al., 2014). The paper provides a detailed analysis of Bhutan's electricity consumption, production, and trade patterns. The paper used a range of statistical techniques, including unit root tests, Granger causality tests, co-integration analysis, and a VECM, to analyze the data and estimate the short-run and long-run effects of changes in electricity consumption, output, and trade.

The particular reliance of Bhutan on Hydropower as a source of electricity is the paper's main point. The hydropower industry in the nation is thoroughly examined, which covers its background, present capacity, and future expansion goals. It also presents the possible advantages of selling surplus electricity to other nations, which might help Bhutan's economy by bringing in much-needed funds.

The paper also examined the variables that affect electricity generation, consumption, and commerce in Bhutan is another area of strength. The authors utilize a variety of statistical models to pinpoint the main factors influencing these trends, which include population increase, trade ties with nearby nations, and economic growth. This method offers insight into the intricate processes supporting Bhutan's electricity system.

Overall, the paper thoroughly explores the patterns of electricity production, consumption, and trade in Bhutan. The writers explain the nation's reliance on Hydropower and the possible advantages and difficulties of exporting extra electricity to nearby countries. The analysis is made more in-depth using econometric tools, showing the intricate aspects affecting Bhutan's electricity sector.

The impact of energy consumption on GDP growth: Evidence from South Asia (Awan et al., 2019): This study examines the relationship between energy consumption and economic growth in the South Asian region, including Bhutan using panel data from 1980-2015 applying Autoregressive Distributed Lag (ARDL) and also sensitivity analysis.

One of the paper's strengths is its focus on the South Asian region, which has experienced rapid economic growth in recent years but also faces significant energy challenges. The authors provide a detailed overview of the energy sector in the region, including its sources of energy, consumption patterns, and policy frameworks.

Another strength of the paper is its use of econometric techniques to examine the relationship between energy consumption and GDP growth. The authors use a range of statistical models to analyze the impact of energy consumption on economic growth, while also controlling for other factors such as investment, labor, and trade openness.

The study is a well-researched and instructive examination of the connection between energy use and regional economic development in South Asia. The authors offer insightful explanations of the complex variables that affect this relationship, such as the significance of energy regulations, technological development, and regional integration. The research is strengthened and deepened by using econometric methods, further emphasizing how crucial sustainable energy policies are for fostering regional economic growth.

Following are a few other papers following similar methodologies in different countries:

Table 5. Papers with Similar Topic and Methodology

Author(s)	Country	Period	Method	Main Variables	Causality
Zhang and Cheng (2009)	China	1960-2007	Granger causality	GDP, electricity consumption	Y → EC
Lee, Chang (2005)	Taiwan	1955-2003	Granger causality, cointegration, VECM	GDP, electricity consumption	EC → Y
Glasure, Lee (1998)	Singapore	1961-1990	Cointegration, error Correction	GDP, electricity consumption	EC → Y
Shiu and Lam (2004)	China	1971-2000	Error correction model	GDP, electricity consumption	EC → Y
Yoo (2006)	Singapore	1971-2002	Johansen-Juselius Cointegration	GDP, electricity consumption	EC → Y
Cheng (1999)	India	1952-1995	Cointegration, ECM, Granger causality	GDP, electricity consumption	Y → EC
Ghosh (2009)	India	1970-71 to 2005-06	ARDL, Granger causality	GDP, electricity supply	Y → EC
Ang (2008)	Malaysia	1971-1999	Johansen cointegration, VEC model	GDP, electricity supply	Y → EC
Nicholas (2009)	South Africa		The error-correction model	GDP and electricity consumption	Y → EC
Masih, Masih (1996)	Pakistan	1955-1990	Granger causality	GDP, electricity consumption	EC←→Y
Dritsakis	Greece	1996-2000	Granger causality	GDP, Tourism	T←→Y

These studies provide valuable insights into the research topic. However, all the studies mentioned above used the annual data as a main data source for examining the performance of the power sector. However, this study employs monthly data analysis to offer a more in-depth and precise insight into the sector's dynamics, particularly regarding supply and demand changes. Seasonal, monthly, and intra-monthly changes in power demand and supply can be seen in monthly data but are not apparent in annual data.

The study may thoroughly understand how the electricity sector has changed over time by using monthly data spanning 22 years. Long-term trends and patterns that might not be obvious in annual data can be found with its assistance.

Additionally, there is little literature that investigates the causal relationships between all three variables; GDP, electricity consumption and tourism growth, despite studies looking at the relationships between GDP and electricity consumption and between tourism growth and GDP. And also no similar study is conducted in Bhutan till date.

Therefore, there is a need to investigate the causal relationship between GDP, electricity consumption, and tourism growth. This study may provide a comprehensive analysis of the interplay between these variables interact and may assist in policies and strategies aimed at promoting sustainable economic development in Bhutan.

Chapter 4. Data and Methodology

In this study, the first part of the electricity sector analysis shall use monthly data on electricity production, consumption, imports, and exports for the 22 years between 2001 and 2022 will be evaluated using straightforward correlation and regression models. To assess whether or not a time series is stationary or non-stationary, the Unit root test is first performed in time series analysis. As a presumption for many statistical models, including regression analysis, stationarity is a key idea in time series analysis. On the other hand, non-stationary time series might produce erroneous regression findings.

For the second part of the analysis, the data from the years 2001 through 2021 were used in this analysis. The period is chosen based on secondary data from the DGPC (2022) and NSB (2022). The total value added to household power consumption, expressed in GWh, is obtained from DGPC as the source of energy consumption data. Where the GDP and tourism growth data are obtained from NSB (2022). For this study, the actual GDP statistics in millions of Ngultrums will be utilized, and tourism growth shall be measured by the number of tourists the nation receives each year.

Time series analysis is a statistical technique used to analyze and model time-dependent data. It is widely used in various fields, such as finance, economics, engineering, and environmental science. This literature review aims to provide an overview of the different methodologies used in time series analysis.

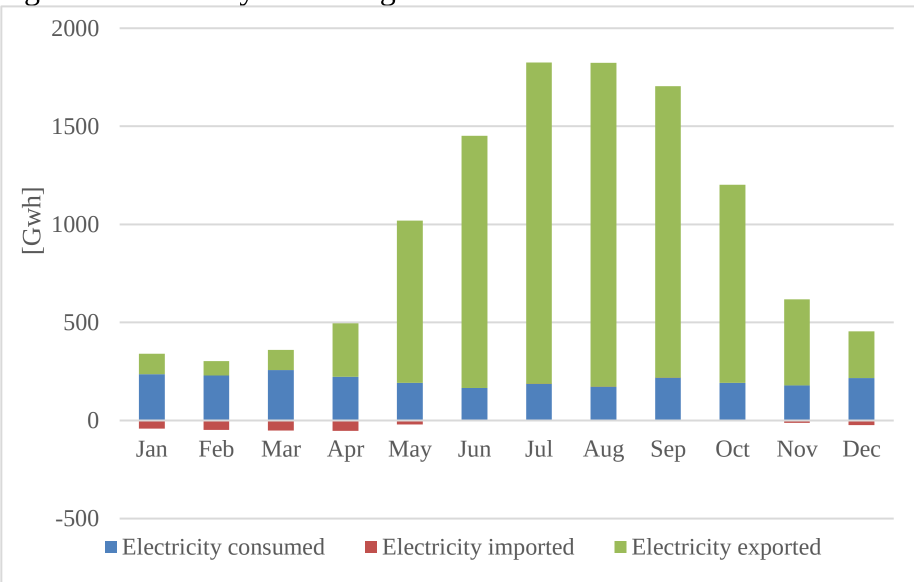
Time series analysis is a powerful statistical technique for analyzing and modelling time-dependent data. The different methodologies used in time series analysis have been applied in various fields such as finance, economics, and healthcare. The choice of methods depends on the nature of the data and the research question. Researchers should carefully consider the strengths and limitations of each methodology before selecting the appropriate method for their research (Greene, W. H. (2018).

In this study, the empirical analysis shall be in two parts as follows:

4.1. The Systemic Analysis of the Electricity Sector

This research will analyze monthly data on electricity production, consumption, imports, and exports over 22 years from 2001 to 2022 by applying simple correlation and regression models.

Figure 5: Electricity Sector Figures 2021



Source: DGPC 2022

Firstly, the Unit root test is used in time series analysis to determine whether a time series is stationary or non-stationary. Stationarity is an important concept in time series analysis because it is a necessary assumption for many statistical models, including regression analysis. Non-stationary time series, on the other hand, can lead to spurious regression results.

One of the earliest and most widely used unit root tests is the Dickey-Fuller (DF) test, introduced by Dickey and Fuller (1979). This test and its extensions, such as the augmented Dickey-Fuller (ADF) test, are used to test the null hypothesis that a time series contains a unit root against the alternative hypothesis that the time series is stationary. Further, several other unit root tests have been developed over the years, such as the Phillips-Perron (PP) test and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test. The choice of test depends on the specific data and research question.

For many statistical models, the assumption that a time series is stationary or non-stationary must be true. Hence unit root tests are crucial in time series analysis. Unit root tests are vital for guaranteeing the validity of statistical studies in time series data because non-stationary time series might produce erroneous regression findings.

After the above test, Ordinary Least Square (OLS) Regression shall be applied. OLS is a common statistical technique in econometrics for estimating the connection between a dependent variable and one or more independent variables regression. The fundamental goal of OLS regression is to identify the line or curve that minimizes the sum of squared differences between the observed and predicted values and best fits the data points.

Additional explanatory factors can be added to OLS regression, such as lagged dependent variables, interaction terms, or polynomial terms.

This makes it possible to construct intricate interactions between variables with greater flexibility.

Overall, OLS regression is a powerful econometrics method utilized in various applications to estimate correlations between variables. It is a straightforward and uncomplicated approach that can be expanded to incorporate more intricate modelling of interactions between variables (Greene, W. H. (2018).

4.2. The Casual Relationship between Electricity Consumption, GDP and Tourism Growth

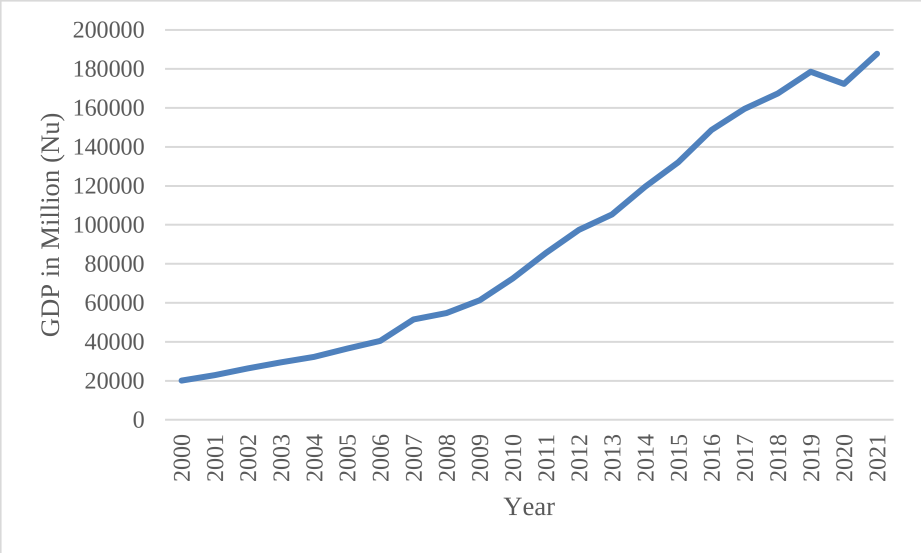
The dataset used for this analysis is from the period 2001–2021. The time range is taken according to secondary data from the DGPC (2022) and (IEA, 2022). Electricity consumption data is taken from DGPC, the cumulative value added of domestic electricity consumption in GWh. Meanwhile, GDP and Tourism Growth data are taken from NSB (2022). The real GDP data in millions of Ngultrum shall be used, and for Tourism Growth, the foreign exchange rate earnings shall be used to study the tourism growth of Bhutan.

Stata software will be used to analyze the causal link discussed in this study. The variables that will be investigated in this study are outlined in table 1 below.

Table 6. List of Variables

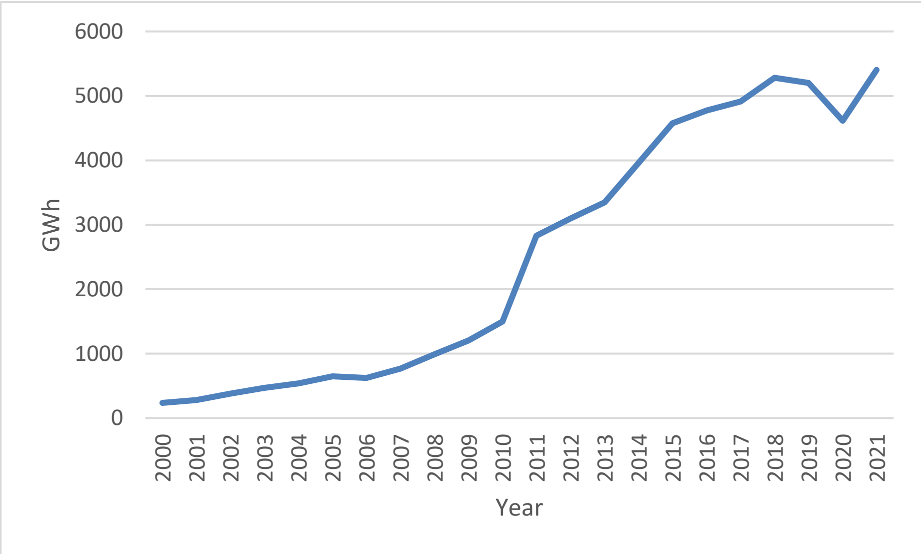
Variables	Description	Unit	Source
G	GDP	Nu (Million)	(IEA, 2022)
E	Electricity Consumption	Million Units	DGPC (2022)
T	Tourism Growth	Nu (Million)	(IEA, 2022)

Figure 6: GDP in Million



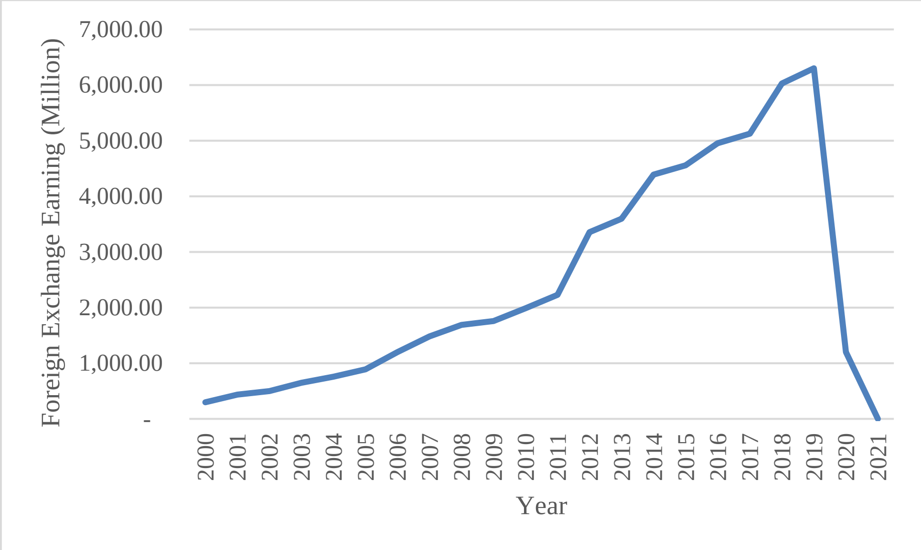
Source: NSB 2022

Figure 7: Domestic Electricity Consumption



Source: DGPC 2022

Figure 8: Tourism Growth



Source: BTCL 2022

The following methodology shall be applied:

4.2.1.Unit Root Test

A unit root test assesses whether the examined variables are stationary. The unit root test employs the most prevalent statistical methods, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) (Iao & Hillips, 1998). If the variable series are stationary and have a comparable order of integration, such as I(1), a linear combination of these series should exist, assuming they are cointegrated (Engle et al., 1987). The unit root test can be carried out using the Ordinary Least Square (OLS) method, as detailed below.

$$\Delta X_t = \alpha_1 + \alpha_2 T + \delta X_{t-1} + \sum_{i=1}^{n} \lambda_i \Delta X_{t-1} + \varepsilon_t$$

where X_t refers to the model's variables G_t, E_t and T_t across time. T denotes time trend. The difference operator is represented by Δ. The interest coefficient is called δ. In contrast to the alternative $\delta < 0$, the null hypothesis implies that there is a unit root or that X is non-stationary ($\delta = 0$). The variables are not cointegrated if one or more are discovered not to be I(1). In other words, there are no long-term correlations between these variables. There may be short-run causality in this situation.

4.2.2.Cointegration Test

When both series are integrated with the same sequence, it is possible to test for cointegration. For this objective, the Johansen maximum likelihood approach is utilized. The (Johansen & Juselius, 1990) technique is a vector autoregressive (VAR)-based test for cointegration constraints in the unconstrained VAR. The null hypothesis is H0, which states that the number of cointegration relations varies, as opposed to H1, which states that all VAR series are stationary. Based on the Granger representation theorem, the vector X_t is represented by the auto-regressive error correction illustrated below.

$$\Delta X_t = \alpha_1 + \alpha_2 T + \pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-1} + \phi D_t + \omega_t$$

where $\Pi = \sum_{i=1}^{p} A_i - 1$ and $\Gamma_i = \sum_{j=i-1}^{p} A_j$

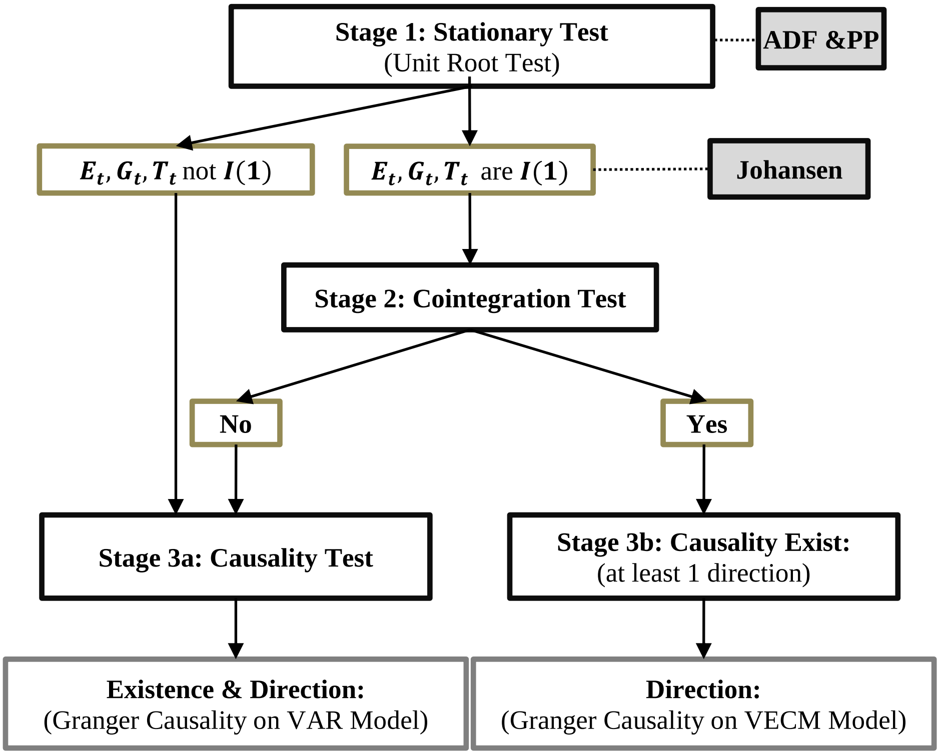
X_t refers to the model's variables G_t, E_t and T_t across time in which all are I(1). T denotes time trend. The difference operator is represented by Δ. π, Γ_i, and ϕ are matrices of estimated parameters, D_t is a vector of deterministic components, and ω_t is a random error matrix.

4.2.3.Vector Error Correction Model (VECM) analysis

This research will conclude by analyzing the causality test by using the Vector auto-regressive model (VAR). If a causal link exists between one time-series data and the forecast of another time-series data, the forecast may be produced with more accuracy. If the cointegration result indicates that two variables satisfy a cointegration equation, the paper will use the Vector Error Correction Model (VECM) analysis. Using VECM, the causality analysis may identify three types of causality: short-run, long-run, and strong causality. Short-run causality examines the statistical significance of the two types of hypotheses in the VAR scenario, whereas long-run causality demonstrates both short-run and long-run causation.

The following figure provides a concise overview of all the steps mentioned above:

Figure 9. Empirical Analysis Procedure (Modified from Chontanawat (2020))



Where:

E_t : Electricity Consumption in Bhutan

G_t : Gross Domestic Product in Bhutan

T_t : Tourism Growth in Bhutan

Chapter 5. Empirical Analysis

As per the study findings, the correlation results show complex connections between the production, import, domestic use, and export of electricity. Given the strong positive association between total generation and total export, it is likely that the quantity of power generated has a major impact on exports. The fact that total imports, total generation, and total exports have negative correlations shows that total imports and total electricity exports typically have a negative relationship. The weakly positive correlation between domestic usage and total export suggests that there may be a slight positive relationship between domestic power consumption and exports.

The regression analysis shows a positive correlation between total power generation and domestic consumption, electricity imports, and electricity exports. The high coefficients for domestic consumption and power exports show that these variables significantly affect electricity production.

The total generation data for each month appears to be non-stationary at a 10% significance level, according to the findings of the PP and ADF tests, since the test statistics are constantly higher than the critical value. This indicates potential underlying trends or seasonality of electricity generation from hydropower plants in Bhutan.

The regression analysis's findings indicate the importance of total export and domestic consumption to overall generation. While only during the lean seasons (January, March, and April), there is a substantial correlation between total generation and import. This shows that the weather can change from month to month, which could affect the energy demand and supply. For instance, since less energy is produced during the winter, it is required to import additional electricity to meet domestic demand.

There is a statistically significant negative association between monthly rainfall and total generation, even though it may not be significant, as shown by the relationship between total generation and rainfall, which shows that the coefficient for monthly rainfall is -0.001 and the p-value is 0.00. This suggests that monthly rainfall may not be the only source for hydropower plants, as Bhutan's river source also depends on the snowline on the mountains and glacier lakes.

To highlight the significance of the energy sector, particularly electricity, for Bhutan's economic development, the paper also analyzes the relationship between Gross Domestic Product (GDP), Electricity Consumption, and Tourism Growth using annual figures collected over 21 years between 2001 and 2021. The study also examines Bhutan's tourism sector to examine the connections between GDP, power use, and tourism. The study employs a time series analysis to understand the patterns and trends in the data. The research shows a positive relationship between GDP, Electricity Consumption and Tourism Growth in Bhutan. The study's conclusions indicate that the electricity sector is vital to Bhutan's continued economic growth.

5.1. Time Series Analysis of the Energy Sector

5.1.1. Correlation Analysis

The following table shows the pairwise correlations between total electricity generation, electricity imports, domestic use of electricity, and electricity exports:

Table 7: Result of Correlation Analysis

Variables	Total Generation (GWh)	Total Import (GWh)	Domestic Consumption (GWh)	Total Export (GWh)
Total Generation (GWh)	1			
Total Import (GWh)	-0.8459	1		
Domestic Consumption (GWh)	0.1697	-0.1527	1	
Total Export (GWh)	0.9997	-0.8446	0.1463	1

The correlation coefficient between Total Generation and Total Import is -0.8459, indicating a strong negative correlation between the two variables. This suggests that the need for importing electricity decreases as electricity generation increases, and vice versa. The correlation coefficient between Total Generation and Domestic Use is 0.1697, indicating a weak positive correlation between the two variables. This suggests that as electricity generation increases, domestic electricity use also tends to increase, but the relationship is not very strong.

The correlation coefficient between Total Generation and Total Export is 0.9997, indicating a strong positive correlation between the two variables. This suggests that as electricity generation increases, the amount of electricity that is exported also tends to increase, and vice versa. The correlation coefficient between Total Import and Domestic Consumption is -0.1527, indicating a weak negative correlation between the two variables. This suggests that as domestic use of electricity increases, the need for importing electricity tends to decrease, but the relationship is not significant.

The correlation coefficient between Total Import and Total Export is -0.8446, indicating a strong negative correlation between the two variables. This suggests that as the amount of imported electricity increases, the amount of exported tends to decrease, and vice versa. The correlation coefficient between Domestic Consumption and Total Export is 0.1463, indicating a weak positive correlation between the two variables. This suggests that as domestic use of electricity increases, the amount of electricity that is exported also tends to increase, but the relationship is not that significant.

These correlation findings indicate that the linkages between electricity production, import, domestic usage, and export are intricate. Given the very significant positive correlation between total generation and total export, it is likely that electricity exports are largely influenced by the amount of electricity generated. The fact that there are negative correlations between total imports, total generation, and total export suggests that imports and exports of electricity tend to be negatively associated. According to the weakly positive association between domestic use and total export, domestic power consumption and exports may have a marginally favorable link.

5.1.2.Unit Root Test

The Unit Root Test is performed to determine whether a time series variable is stationary or not.

$$Y_t = a + bY_{t-1} + e_t$$

Table 8. Unit Root Test Results

Variables	ADF (Zero lag)	PP (Default lag)
Total Generation	-3.459*** (-4.38)	-3.989*** (-6.511)
Domestic Consumption	-3.459 (-1.364)	-3.130* (-3.295)
Total Import	-3.459*** (-5.185)	-3.990*** (-8.526)
Total Export	-3.459*** (-4.497)	-3.989*** (-6.529)

- t-statistics are in parenthesis
- ***** denoted rejecting null hypothesis that there exists unit root at the 1 % significance level, ** denotes at the 5% and * denotes at the 10% level.**

5.1.3. Regression

Since the time series variables are found to be stationary, it is then appropriate to move on to regression analysis. One common method is Ordinary Least Squares (OLS) regression, a linear regression technique that estimates the relationship between a dependent variable and one or more independent variables. OLS regression can be used to forecast the dependent variable based on the values of the independent variables or to understand the relationship between the variables *Erdem Ozgur and M. Kemal Ozgur (2018).*

$$\boldsymbol{Y_t = a + Y_{t-1} + e_t}$$

The following table shows the results of an OLS regression analysis:

Table 9. Results of a Regression Analysis

Total Generation	**Coef.**	**P Value**
Domestic Consumption	0.979	0.000
Total Import	0.362	0.010
Total Export	0.991	0.000
Constant	-8.207	0.043

- Dependent variable: Total Electricity Generation
- Independent variables: Domestic Electricity Consumption, Electricity Import and Export

The coefficient for domestic consumption is 0.979, which indicates a strong positive relationship between electricity generation and domestic consumption. This suggests that as domestic consumption of electricity increases, total electricity generation also tends to increase, holding other variables constant. The p-value of 0.000 indicates that this coefficient is statistically significant.

Similarly, Electricity generation and imports are positively correlated, as shown by the coefficient of 0.362 for total electricity imports. This implies that assuming other factors are constant, overall power generation tends to increase as electricity imports rise. The statistical significance of this coefficient is shown by the p-value of 0.010 for the test.

Electricity generation and exports are strongly positively correlated, as shown by the total electricity exports coefficient of 0.991. Assuming other factors are fixed, overall power generation tends to increase as electricity exports rise. The statistical significance of this coefficient is indicated by the p-value, which is 0.000.

Overall, the regression analysis results indicate that domestic consumption, electricity imports, and electricity exports all have positive associations with total electricity generation. It is clear from the large coefficients for domestic consumption and power exports that these factors significantly impact electricity generation.

5.1.4.Unit Root Test (Monthly)

The Unit Root Test for the monthly variable is performed to determine whether a time series variable is stationary or not to the seasonal fluctuation of the electricity generation in the hydropower sector.

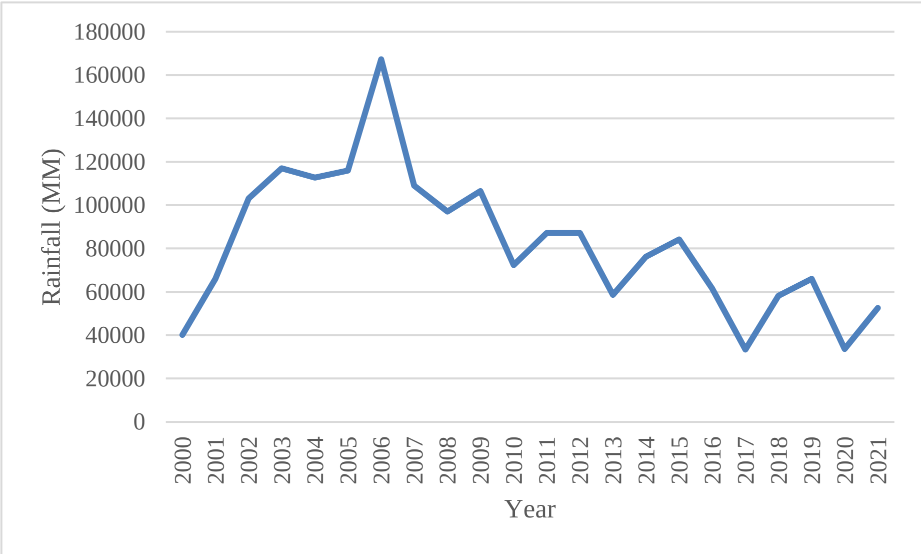
The following are the results of a stationarity test for each month's total generation using the Phillips-Perron (PP) test and the Augmented Dickey-Fuller (ADF) test:

Table 10. Results of a Stationarity Test

Months	**Total Generation**				
	Test Statistic		**Critical Value**		**Conclusion**
	PP	**ADF**			
January	-4.102	-2.119	-2.630	10%	Non-Stationary
February	-4.279	-2.109	-2.630	10%	Non-Stationary
March	-1.509	-0.949	-2.630	10%	Non-Stationary
April	-2.501	-1.556	-2.630	10%	Non-Stationary
May	-2.590	-1.610	-2.630	10%	Non-Stationary
June	-2.341	-1.331	-2.630	10%	Non-Stationary
July	-2.60	-1.397	-2.630	10%	Non-Stationary
August	-1.941	-1.041	-2.630	10%	Non-Stationary
September	-1.598	-0.942	-2.630	10%	Non-Stationary
October	-2.201	-1.201	-2.630	10%	Non-Stationary
November	-2.636	-1.636	-2.630	10%	Non-Stationary
December	-2.280	-1.456	-2.630	10%	Non-Stationary

According to the PP and ADF test results, the total generation data for each month appears to be non-stationary at a 10% significance level since the test statistics are consistently higher than the critical value. This means that the data may have some underlying trends or seasonality, which should be considered when analyzing or forecasting the data.

Figure 10: Rainfall Data (MM)



Source: NSB 2022

5.1.5. Regression on Month-wise Data

Ordinary Least Squares (OLS) regression is used to estimate the relationship between a dependent variable and one or more independent variables every month. OLS regression can be used to forecast the dependent variable based on the values of the independent variables or to understand the relationship between the variables.

$$Y_t = Y_{t-1} + E_1 Jan + E_2 Feb \dots\dots\dots + E_{11} Nov + e_t$$

Table 11. Results of Regression (Monthly)

Total Generation	Total Import		Domestic Consumption		Total Export	
	Coef.	**P Value**	**Coef.**	**P Value**	**Coef.**	**P Value**
January	.452	0.042	.858	0.00	1.03	0.00
February	.316	0.107	0.870	0.00	1.08	0.00
March	.51	0.030	.853	0.00	1.05	0.00
April	.750	0.005	.782	0.00	.979	0.00
May	.213	0.458	.871	0.00	1.03	0.00
June	.439	0.353	.824	0.00	1.03	0.00
July	.652	0.295	1.04	0.00	1.00	0.00
August	.040	0.954	1.04	0.00	1.00	0.00
September	.723	0.319	.930	0.001	1.01	0.00
October	1.47	0.143	.949	0.001	1.01	0.00
November	0.463	0.531	1.018	0.001	.092	0.00
December	-.745	0.106	1.22	0.00	.965	0.00

According to the regression results, the domestic consumption and total export are significant to the total generation. At the same time, the relationship between total generation and import is only substantial during lean seasons (January, March & April). This indicates that weather conditions can vary monthly, impacting energy demand and supply. For instance, the energy generation in winter months will be less, so the import of electricity is necessary to meet domestic consumption.

5.1.6.Regression on Monthly Rainfall

Rainfall is essential for hydropower production in Bhutan since it directly impacts the water level and flow rate of the rivers that are utilized to produce energy. Bhutan is a hilly nation, and most of its electricity is produced by hydroelectric stations along rivers and streams.

$$Y_t = a + b_1 Y_{t-1} + c\ Rainfall + e_t$$

The following table shows the results of an OLS regression analysis:

Table 12. Results of an OLS Regression Analysis

Total Generation	**Coef.**	**P Value**
Domestic Consumption	0.921	0.000
Total Import	0.350	0.010
Total Export	1.006	0.000
Monthly Rainfall	-0.001	0.00
Constant	1.966	0.660

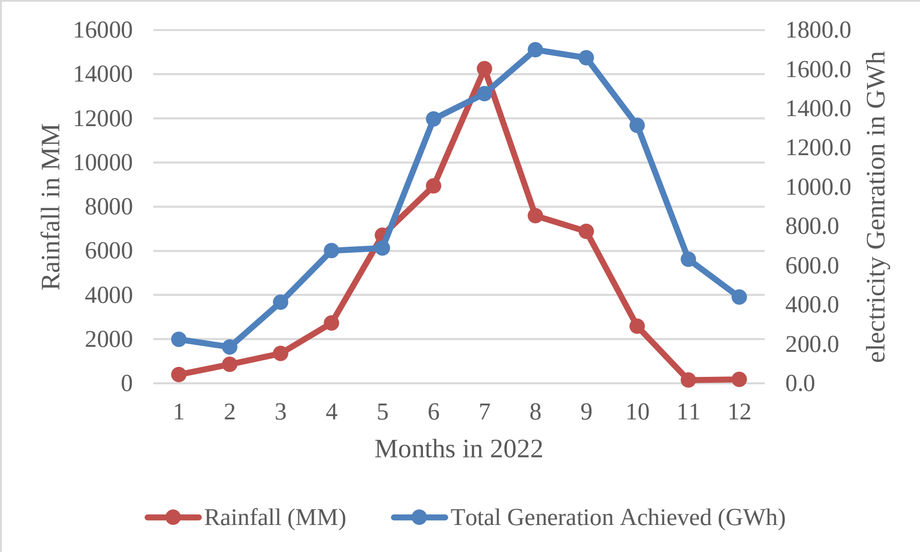
- Dependent variable: Total Electricity Generation
- Independent variables: Domestic Electricity Consumption, Electricity Import, Export and Rainfall

The relation between total generation and rainfall indicates that the coefficient for Monthly Rainfall is -0.001, and the p-value is 0.00, which shows a statistically significant negative relationship between Monthly Rainfall and Total Generation though it may not be significant. This means that a one-unit increase in Monthly Rainfall is associated with a -0.001-unit decrease in Total Generation, while other variables are constant.

The primary water supply for these hydropower facilities is rainfall, and the quantity and timing of rainfall are important variables that affect the amount of water available for power production. The majority of the rain falls in Bhutan between June and September, which is the rainy season. Water levels in rivers and streams rise during this season, increasing the flow rate and enabling hydropower plants to produce more electricity. However, Hydropower plants in Bhutan require a certain amount of water to operate efficiently. If there is excess rainfall or water, it may be spillover as all hydropower plants in Bhutan don't have reservoir dams or water storage capacity.

On the other side, the water levels in rivers and streams decline during the dry season, which normally lasts from November to April, which lowers the flow rate and makes it challenging for hydropower plants to produce electricity. Consequently, the quantity of rain throughout the rainy season is essential for maintaining a constant electricity supply.

Figure 11: Rainfall and Electricity Generation 2022

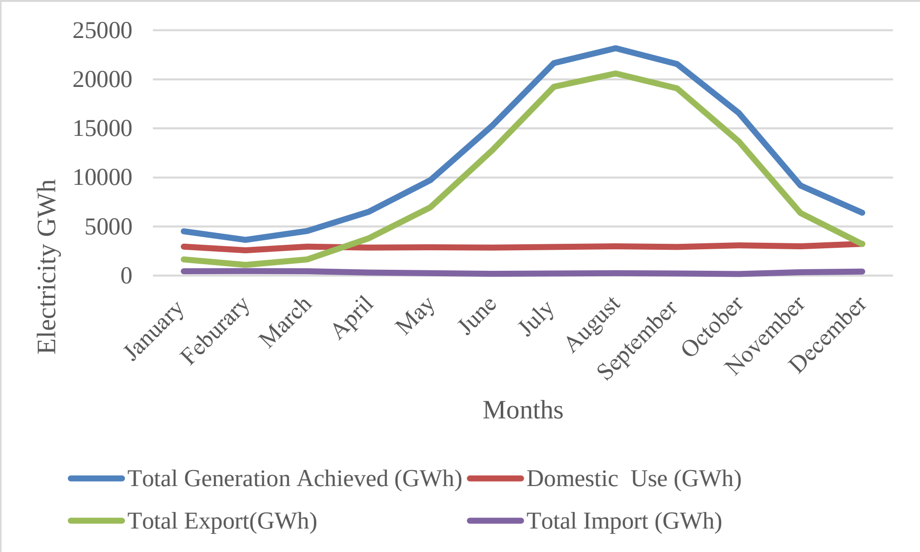


Source: NSB 2023

The quantity and timing of rainfall are important variables that impact water availability for power generation in Bhutan, where rainfall is essential for hydropower production. Due to the nation's reliance on Hydropower, it is especially vulnerable to changes in rainfall patterns brought on by climate change, which can considerably influence the amount of water available for power generation, the economy, and society.

Bhutan faces several challenges that could impede its future development. One of the key challenges is its heavy dependence on Hydropower, which makes the country vulnerable to fluctuations in demand and supply and changes in weather patterns that can affect the reliability of hydropower generation. The following graph shows the monthly electricity fluctuations in electricity generation, consumption, import, and export over 22 years from 2000 to 2022.

Figure 12: Monthly Electricity Fluctuations for 22 years



Source: DGPC, 2022

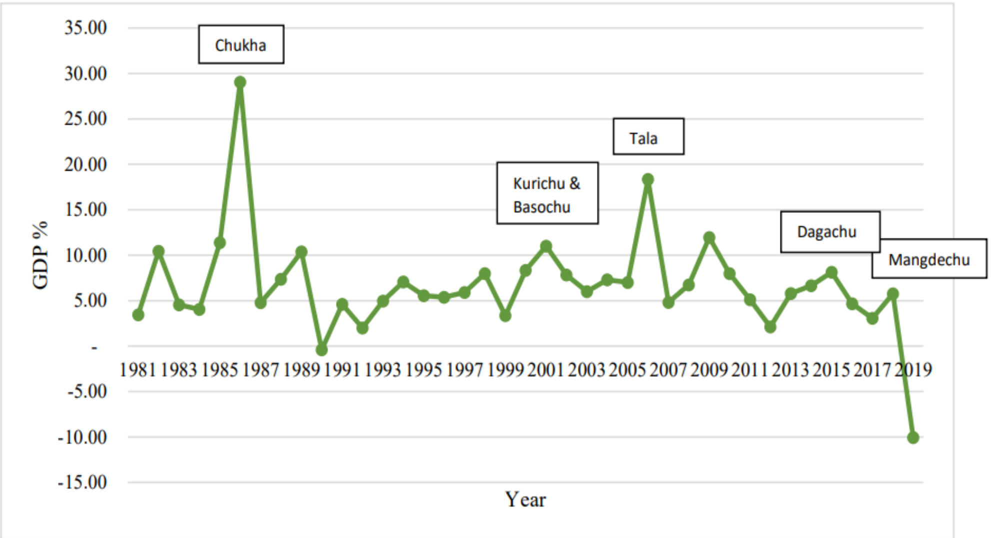
The graph indicates that Bhutan's hydropower generation is characterized by substantial variations between the dry and rainy seasons. Bhutan often sees considerable rainfall from June through September during the rainy season, which causes a spike in hydropower generation. However, during the dry season, a large decline in power production due to a lack of water might cause a deficit of energy and end up importing electricity from neighboring country India.

This seasonal variability in hydropower generation poses challenges for energy security, as it can lead to electricity supply disruptions and affect the reliability of the power grid in the country.

However, Bhutan's abundant hydropower potential, which accounts for more than 99% of its electricity generation, has been a major driver of its economic growth, as it has enabled the country to export electricity to neighboring countries and earn significant foreign exchange.

To ascertain the real effect of hydropower development 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 the commissioning of the projects. The real GDP growth rate of Bhutan for the period 1981 to 2020.

Figure 13: Real GDP growth rate of Bhutan



Source: NSB 2022

5.2. The Casual Relationship between GDP, Electricity Consumption and Tourism Growth

To highlight the significance of the energy sector, particularly electricity, for Bhutan's economic growth during 21 years between 2001 and 2021, the research looks at the relationship between Gross Domestic Product (GDP), Electricity Consumption, and Tourism Growth. The study also examines Bhutan's tourism sector to determine how GDP, Electricity use, and Tourism are related. A time series analysis is used in the study to understand the patterns and trends in the data. As per the research findings, economic growth, electricity consumption and tourism sector have a long-term relationship

Tourism is a major contributor to the Bhutanese economy and plays a significant role in the country's development and the well-being of its people. The tourism sector is the main source of foreign currency for Bhutan. The amount of tourism-related earnings in 2019 was USD 92 million, or roughly 6.5% of the nation's GDP. Around 30,000 Bhutanese are engaged directly in the tourism industry, and many more work in allied fields, including hospitality, transportation, and handicrafts. Tourism is a major source of employment for the country (World Bank 2021).

One of the main reasons why governments support and promote tourism throughout the world is that it has a positive impact on economic growth and development *(Ivanov & Webster 2007).*

Bhutan's tourist industry is founded on a distinctive model of ethical and ecological travel ingrained in Bhutanese culture and values. Preserving Bhutan's natural and cultural legacy is a top priority for the Government, and tourism is considered a way to promote and safeguard these ideals. Tourists are expected to pay a minimum daily charge that covers amenities, including lodging, food, transportation, and an authorized guide. This tax supports national conservation initiatives and social welfare programs.

The development of Bhutan's infrastructure, including its roads, airports, and telecommunications systems, is a result of the expansion of the tourism industry. This has aided in the growth of other economic sectors and raised the living standard for those living in the nation's rural areas. International relations between Bhutan and other countries have benefited from tourism. Visitors visiting Bhutan have the chance to learn about the distinctive culture and values of the nation, which has aided in fostering greater appreciation and understanding between Bhutan and other countries.

The hydropower and agriculture sectors are the two main economic drivers in Bhutan. The expansion of the tourism industry has made it possible to diversify the nation's economy and lessen its reliance on these sectors. The Bhutanese economy and population place a high value on the tourist industry. It boosts the economy, advances Bhutanese culture and values, aids in infrastructural development, fosters international ties, and diversifies the economy. To guarantee that the industry continues to benefit the nation and its citizens for many years, the Bhutanese Government has acknowledged the value of tourism and strongly emphasized sustainable and responsible tourism (World Travel and Tourism Council, 2019).

However, determining the economic impact of tourism necessitates taking a more comprehensive approach to the study of the relationship between tourism and GDP. For instance, the stagnation of other businesses and/or the substitution of such industries by tourism may cause an increase in the share of tourism in GDP. Therefore, this paper using the foreign exchange earnings to investigate the tourism growth (Dritsakis, 2004).

5.2.1. Unit Root Test

The empirical analysis begins with carrying out the unit root test (Stage 1). The unit root test is carried out to check whether the variable used is stationary. The test is carried out using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP).

5.2.1.1. Augmented Dickey-Fuller

Before the ADF is carried out, a test is carried out to determine the lagged values of the dependent and independent variables. For example, last year's electricity consumption may be correlated with this year's consumption. This demonstrates lag values. Thus, if past values affect today's values, more lags will be necessary. The first step is to apply lag selection criteria to determine the precise level of lag.

There are three lags of criterion in STATA software, as follows:

- AIC: Akaike's Information Criterion
- SBIC: Schwarz's Bayesian Information Criterion
- HQIC: Hannan and Quinn Information Criterion

Table 13. Lag Selection for ADF

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	-499.298		3.5e+20	55.8109	55.8314	55.9593
1	-426.498	145.6	3.0e+17	48.7219	48.8038	49.3155
2	-418.677	15.641	3.8e+17	48.853	48.9962	49.8918
3	-409.582	18.189	5.0e+17	48.8425	49.0471	50.3264
4	-366.257	86.652*	2.3e+16*	45.0285*	45.2945*	46.9577*

The above tables show that all three criteria show the optimal level for the lags, except the FPE (Final Prediction Error) is at fourth lag. Accordingly, Lag 4 shall be used as the lags property for the ADF method.

5.2.1.2. Phillips-Perron (PP)

The Phillips-Perron test is used to confirm the result of the ADF test. Unlike the ADF test, in which the optimal lags must be manually obtained using STATA software, the optimal lags for PP are automatically accepted. The optimal lag for the PP test is Lag 1.

Here is the result of the unit root test using the ADF and the PP methods:

Table 14. Result of the Unit Root Test

Variables	ADF	PP	ADF (1st Diff.)	PP (1st Diff.)
GDP	-3.750 (-0.238)	-3.750 (1.326)	-3.00** (-3.732)	-3.750*** (-3.764)
Electricity Consumption	-3.750 (-1.360)	-3.750 (-0.094)	-3.750*** (-4.233)	-3.750*** (-4.147)
Tourism Growth	-3.750 (-1.376)	-3.750 (-1.549)	-3.000** (-3.308)	-3.000** (-3.289)

- t-statistics are in parenthesis
- *indicate 1% critical values
- **indicate 5% critical values
- ***indicate 10% critical values

Based on the unit root test, the result shows that all variables are non-stationary on the level but stationary on the first difference I(1). Variable GDP is stationary for its first differences at 5% of the critical value on the ADF and 10% of the critical value PP tests. The Electricity Consumption is stationary for its first differences at 10% of the critical value on both ADF and PP. lastly, Tourism Growth is stationary for its first difference at 5% of the critical value on both ADF and PP.

5.2.2.Cointegration Test

Stage 2 is a cointegration test between electricity, industrial energy consumption, and CO2 emission. It will be conducted using the Johansen cointegration test with the previous lag property, Lag 1.

The trace statistic test checks the null hypothesis. $H_0: r = 0$ against the alternative hypothesis $H_1: r > 0$ or $r \leq 0$ to see how many cointegration vectors are between the variables (r equals the number of cointegrating vectors).

The maximum statistics test looks at the null hypothesis, $H_0: r = 0$, and the alternative hypothesis, $H_0: r > 0$. If the likelihood ratio value is larger than the critical values at a certain level of significance, the null hypothesis $H_0: r = 0$ is rejected in favor of the alternatives.

Table 15. Cointegration Test Result

Max Rank	**Trace Statistic**	**Critical Value**		**Max Statistic**	**Critical Value**	
		5%	**1%**		**5%**	**1%**
0	30.214	29.68	35.65	24.229	20.97	25.52
1	5.984	15.41	20.04	5.914	14.07	18.63
2	0.070	3.76	6.65	0.070	3.76	6.65

The table above shows the cointegration test result using the Johansen test. Both trace and maximum statistics show that all the variables (GDP, Electricity Consumption, and Tourism Growth) are cointegrated at two equations, as shown in the Max Rank 1 and 2. In detail, the explanations are as follows:

Max Rank 0: $H_0 = No\ cointegration, H_1 = There\ is\ cointegration$

The trace statistics show 30.214, which exceeds 5% of the critical value. It means that we must reject the H_0. We can conclude that there is a cointegration between GDP, Electricity Consumption, and Tourism Growth in the time series. The maximum statistic test also resulted in the same, with its values showing 24.229, exceeding 5% of the critical value. It confirms the cointegration between all three variables.

Max Rank 1: $H_0 = Cointegration\ of\ equation\ 1, H_1 = No\ cointegration\ in\ equation\ 1$

The trace statistics show 5.984, which does not exceed 5% of the critical value. It means that we accept the H_0. We can conclude that there is cointegration in equation 1 between GDP, Electricity Consumption, and Tourism Growth in the time series. The maximum statistic test also resulted in the same, with its values showing 5.914, not exceeding 5% of the critical value. It confirms there is cointegration in equation 1 between all variables.

Max Rank 2: $H_0 = Cointegration\ of\ equation\ 1, H_1 = No\ cointegration\ in\ equation\ 1$

Similarly, the trace and maximum statistics show 0.070, which does not exceed 5% of the critical value. It means that we accept the H_0. We can conclude that there is cointegration in equation 2 between GDP, Electricity Consumption, and Tourism Growth in the time series.

5.2.3. Vector Error Correction Model (VECM)

The cointegration test concludes a cointegration between GDP, Electricity Consumption, and Tourism Growth. Therefore, this study does not apply the Vector Auto Regression (VAR). This study will then use the vector Error Correction Model (VECM).

The result of the VECM model is as follows:

5.2.3.1. VECM on GDP

Table 16. Result of the VECM Model on GDP

Type	Variable	Coefficient	p Value
Long-Run	$\boldsymbol{GDP_t}$	0.269	0.069
Short-Run	$\boldsymbol{EC_t}$	5.033	0.683
Short-Run	$\boldsymbol{TG_t}$	-2.067	0.003

The VECM model of causality on GDP has one long-run causality, and short-run causality with Tourism Growth. In more detail, the interpretation is as follows:

- The GDP equation has a long-run causality at the 5% level.
- The Electricity Consumption does not cause GDP growth in the short run.
- The Tourism Growth cause GDP growth in the short run.

5.2.3.2. VECM on Electricity Consumption

Table 17. Result of VECM Model on Electricity Consumption

Type	Variable	Coefficient	p Value
Long-Run	EC_t	0.005	0.131
Short-Run	GDP_t	0.008	0.309
Short-Run	TG_t	-0.055	0.262

The VECM model of causality on Electricity Consumption has neither short-run nor long-run causality. In more detail, the interpretation is as follows:

- There is no long-run causality in the Electricity Consumption equation.
- GDP does not cause Electricity Consumption in the short run.
- Tourism Growth does not cause Electricity Consumption in the short run.

5.2.3.3. VECM on Tourism Growth

Table 18. Result of VECM Model on Tourism Growth

Type	Variable	Coefficient	p Value
Long-Run	TG_t	0.029	0.451
Short-Run	GDP_t	0.029	0.756
Short-Run	EC_t	4.942	0.125

The VECM model of causality on Tourism Growth has neither long-run causality nor short-run causality. In more detail, the interpretation is as follows:

- There is no long-run causality in the Tourism Growth equation.
- GDP does not cause Tourism Growth in the short run.
- Electricity Consumption does not cause Tourism Growth in the short run.

Chapter 6. Conclusion

This study presents the dynamics of Bhutan's electricity sector, including production, consumption, import, and export. The study explains the recurring patterns and trends in Bhutan's electricity production, consumption, import, and export, including seasonal variations, growth rates, and changes in electricity supply and demand.

The second part of the study evaluates the impact of the electricity sector on the economic growth of Bhutan by assessing the relationship between the GDP and other variables, such as domestic electricity consumption and tourism growth. The importance of this study derives from the analysis of interdependence relations since Hydropower is considered the growth engine for the Bhutanese economy and is prioritized as the national strategic area.

6.1. Key Findings:

The electricity sector is fueling economic growth, and the export of electricity for revenues will remain strategically imperative for Bhutan. The following are the key finding of this study:

- Electricity generation has a major influence on export and import, whereas electricity consumption has remained constant for Bhutan for over two decades.
- The regression analysis results demonstrate a positive association between total power generation and domestic consumption, electricity imports, and electricity exports. The high coefficients indicate the strong effects of these factors on the production of electricity for domestic consumption and power exports.
- The PP and ADF tests' results indicate that the monthly data on energy generation appear to be non-stationary at a 10% significance level. This suggests possible underlying patterns or the seasonality of Bhutan's hydroelectric electricity production.
- The regression analysis results indicate the importance of total export and domestic consumption to overall generation. Interestingly, only during the lean seasons (January, March, and April) is there a substantial correlation between total generation and import.

- The relationship between electricity generation and rainfall in Bhutan is highly significant. Around 99% of Bhutan's electricity is produced from hydropower, and the availability of rainwater is crucial for the operation of hydropower plants. Ergo, rainfall variability significantly impacts hydropower generation in Bhutan, and the relationship between rainfall and hydropower is nonlinear *(Tenzin Wangchuk 2018).*
- The cointegration analysis results suggest a cointegration relationship among GDP, electricity consumption, and tourism growth variables, indicating the presence of a common trend or long-run relationships among the variables.
- The VECM results exhibit a long-term causality between GDP, energy consumption, and tourism growth, suggesting that these variables are cointegrated. Thus, the policymakers in Bhutan may focus on promoting sustainable tourism policies and reducing energy intensity to promote long-term economic growth *(Hassen Toumi 2019).*
- In addition, the results show a short-run causality between GDP and tourism growth. This indicates that changes in tourism growth are associated with short-term changes in GDP. Specifically, it suggests that increases in tourism growth lead to increases in GDP in the short run *(Dritsakis 2004).*
- Electricity consumption has neither long-run nor short-run causality with GDP and Tourism growth. Similarly, tourism

growth has neither long-run nor short-run causality in GDP and electricity consumption.

6.2. Policy Implication

Considering the Government's sustainable hydropower development and its importance in economic growth, this study provides the following recommendations for relevant agencies and policymakers:

I. This study illustrates that Bhutan's substantial reliance on hydropower exposes the nation to risks related to seasonal changes in water supply and potential disruptions in energy production. Bhutan also imports electricity though not significantly during the lean seasons. To ensure the country's energy security during a low discharge period, there should be an arrangement to augment the power supply within the country to avoid importing power from neighboring countries at high prices. Therefore, in pursuit of meeting the power demand during the low discharge period and to ensure uninterrupted power supply during regional/global grid collapse, Bhutan needs to explore alternative renewable energy such as grid-tied solar power and wind energy, and small hydropower plants (Baumann, Florian, 2008).

II. Further, Bhutan must probe opportunities to access other energy market mechanisms and purchase and sell power from the energy exchange in India and regional markets (Davis, 2009). The export electricity volumes will grow significantly after the commissioning of the projects that are under construction.

III. Bhutan's policies and institutions have also been critical in driving its economic growth. The country's unique development philosophy, embodied in the concept of GNH, places the well-being of its citizens and the environment at the center of its policies rather than solely focusing on economic growth. This approach has helped ensure that economic growth's benefits are shared equitably and that the environment is protected, which has helped create a sustainable and inclusive economy. Thus, any new policies should strongly emphasize the conservation of the environment and the sustainable use of resources. This focus on sustainability is essential in facing numerous environmental challenges, such as climate change, deforestation, and biodiversity loss (Ura, K., Alkire, S., Zangmo, T., & Wangdi, K. (2012)).

IV. The economy of Bhutan is significantly influenced by tourism, which also significantly impacts the country's growth and the welfare of its citizens. Bhutan's primary source of foreign exchange comes from the tourism industry. The study evidence shows both long-run and short-run causality on GDP and Tourism Growth, suggesting that the tourism sector can be a long-run economic growth factor in Bhutan. Thus, Bhutan may focus on promoting a sustainable tourism policy as "high-value low volume" to promote long-term economic growth *(Tourism Council of Bhutan 2022).*

6.3. Study Limitations

- One of the limitations of this study is the lack of sufficient time-series data. The number of observations for 20 years is less to conduct an empirical analysis to ascertain the relationship between three endogenous variables and may limit the significance of the results.
- The study did not separate the data periods or use a break dummy for analysis when the electricity consumption pattern and foreign exchange earnings changed around 2010 and 2011. This may result in bias in the estimation results

- The study focuses exclusively on the foreign exchange earnings for tourism sector growth. Consequently, the study may fail to capture the broader economic context. This narrow scope may result in an incomplete understanding of the tourism sector's overall growth and performance.
- In this regard, further analysis through panel data models or cluster analysis is highly recommended as a direction for future research.

6.4. Abstract (Korean)

본 논문은 시계열분석기법을 통하여 부탄의 경제성장과 전력부문간의 관계를 분석한 연구이다. 부탄은 전력 생산의 대부분을 수력에 의존하고 있어 계절별 변동성이 크다는 특징을 가지고 있으며 동시에 전력생산량이 강수량에 크게 의존하고 있다. 이는 부탄 내 에너지 수요와 공급을 조정하는데 많은 어려움을 만든다. 또한 경제발전을 위한 에너지공급정책에도 한계로 작용하고 있다.

본 연구에서는 부탄의 에너지부문 중 전력 부문에 중점을 두고, 2001 년부터 2022 년까지의 전력 생산, 전력 소비, 전력 수출 및 수입 등 전력 부문 자료와 부탄의 국내총생산(GDP) 및 관광산업 지표 등 경제성장 지표 자료와의 장기적 균형관계를 공적분 분석, VECM, VAR, 회귀모형 및 상관관계분석 등 시계열분석기법을 활용하여 분석하였다. 이와 함께 전력 생산의 월별 변동성 및 생산량과 강수량과의 관계 역시 시계열분석을 통하여 분석하였다.

본 연구의 분석결과 전력생산이 부탄의 국내총생산과 장기적인 균형관계가 있음을 확인하였으며, 계절성 및 강수량과의 상관관계도 확인하였다. 본 연구의 결과는 부탄의 경제발전에 필요한 에너지공급 시스템 구축시 직면하는 문제들을 파악하고 해결하는 데 도움을 줄 것이다. 분석에서 나타난 시계열적 특성에 초점을 맞추어 부탄의 경제발전 및 효과적인 에너지시설 투자를 위한 정책 수립에 가초자료로 사용될 수 있을 것이다.

키워드: 키워드: 전력, 수력, 국내총생산(GDP), 계절성, 시계열분석
학번: 2021-24950

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