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Transition from Fossil Fuels to Renewables: A Comparative Analysis Between Energy-Rich and Energy-Poor Economies

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Abstract

The transition from non-renewable to renewable energy sources has emerged as a pressing global issue, driven by concerns over climate change, resource depletion, and the need for sustainable development. This study compares Canada, an energy-rich nation, and Bangladesh, an energy-scarce country, to understand the structural, institutional, and market factors driving their respective renewable energy transitions. Using univariate time-series models (ARIMA, ETS, and Prophet) for energy demand forecasting and extensive literature-based policy evaluation, the paper examines trends in energy production, consumption, and trade from 1990 to 2024. Our analysis indicates that Canada's vast reserves of both renewable and non-renewable energy sources, its diversified energy portfolio, and carbon-pricing framework support a stable decarbonization pathway, with renewables projected to account for more than 20% of total supply by 2030. However, regional disparities and political resistance from the established energy sector continue to delay transition outcomes. On the other hand, Bangladesh has limited renewable and non-renewable energy sources, with its primary energy resource being natural gas reserves. Consequently, its heavy reliance on imports (over 75% of primary energy) and institutional bottlenecks expose its energy system to commodity-price volatility, undermining energy security and slowing renewable investment. Despite these challenges, targeted solar programs and concessional financing have modestly increased the penetration of renewable energy. The analysis highlights that commodity market fluctuations, technological innovations (such as smart grids and energy storage), and market-based policy instruments critically shape each country's transition trajectory. A coordinated policy linking market stabilization, innovation investment, and social inclusion is essential for achieving a just and secure low-carbon transition in both countries.

Keywords: renewable energy transition; energy demand forecasting; Canada; Bangladesh; energy security; energy policy; commodity market mechanism; energy storage; fossil fuels

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1. Introduction

1.1. Background and Context of the Study

Fossil fuels currently dominate the global energy landscape, driving economic activity across all sectors. This dependence on fossil fuels has resulted in significant environmental consequences. A vast body of research establishes a causal link between fossil fuel combustion and global warming [1–7]. Global energy-related carbon emissions in 2019 reached

33.4 Gt CO_2, accounting for approximately three-quarters of total carbon emissions worldwide [8]. These emissions contribute substantially to global warming and climate change, posing a severe threat to the planet. Furthermore, the finite nature of fossil fuels, coupled with their uneven geographical distribution and volatile prices, necessitates a global transition from non-renewable to renewable energy sources. Global annual renewable capacity increased by almost 50 percent in 2023 to nearly 510 GW [8].

The rapid growth of renewable energy in recent years has several reasons: the uncertain price and supply volatility of fossil fuels, the environmental impact of fossil fuel production and consumption, and concerns about the exhaustion of fossil fuels [9]. Nonetheless, it is imperative that the world move toward replacing fossil fuels, and renewable energy is the most promising option. Not all economies and regions are progressing at the same rate, which is not unexpected. Different economies face distinct issues, problems, and resource bases, so they require different policies and procedures to transform their energy sectors. The paper examines such potential transformations for energy-rich and energy-poor economies.

Globally, fossil fuels remain the principal source of energy. In 2021, 29.5, 27.2, and 23.6 percent of energy came from oil, coal, and natural gas, respectively, totaling 83.6 percent from fossil fuels [10]. Per capita energy supply continues to increase. The modern renewable energy transition has its origins in early human use. Still, a significant shift began with the 1973 oil crisis, which spurred governments' interests and private investments in renewable energy. This was further driven by the environmental movements in the last half of the 20th century [11].

Currently, renewable energy constitutes nearly one-quarter of global primary energy consumption. Renewable energy sources accounted for 29.1 percent of global electricity generation in 2022 [12]. Renewable energy is contributing faster to electricity generation than fossil fuels. Not all renewable sources contribute at the same rate. Wind energy has exhibited the fastest growth during the last two decades, followed by solar energy (Figure 1).

However, significant disparities in energy production and access persist among nations, particularly between developed and underdeveloped nations [13]. Different countries are endowed with varying renewable and non-renewable energy resources, and not all nations have a similar capability of renewable energy transition. Consequently, the trend in energy consumption varies across different economies and regions (Figure 2). In this study, we plan to address the difficulties and challenges of the renewable energy transition faced by a developed, energy-rich country, namely Canada, in contrast to a developing country, Bangladesh, which is inherently energy-deficient but populous and experiencing consistent economic growth.

Energy resources behave like core tradable commodities, subject to price volatility, trade flows, and investment patterns, with macroeconomic consequences. For Canada, energy commodities account for 28 percent of merchandise exports and 10 percent of GDP [14]. In contrast, Bangladesh has a high (approximately 65%) import dependence for power, which transmits global energy price shocks into domestic inflation, current account pressure, and utility balance sheets [15,16]. Given this scenario, this comparative study examines how the interplay between abundance and scarcity generates different commodity market exposures and, in turn, other paths for the renewable energy transition. Since these exposures operate through markets, we first clarify how cost trends and price volatility shape adoption and policy.

Historically, renewable energy faced a cost disadvantage because electricity markets price energy based on private generation costs rather than the full social value. Over the past decade, rapid learning curve effects, larger installation scales, and falling technology

costs have substantially narrowed that gap. In 2023, 81 percent of newly commissioned renewable power projects delivered electricity at a cost lower than that of the lowest-cost fossil alternative, rising to 91 percent in 2024 [17,18]. The global average LCOEs (levelized costs of electricity) decreased by 12 percent for solar PV, 7 percent for offshore wind and hydropower, and 3 percent for onshore wind [17]. Beyond lowering average costs, renewables hedge fossil fuel price volatility and import bill risk [17]. Fossil price shocks affect output, employment, and inflation, although the size and symmetry of these effects vary across economies [19,20].

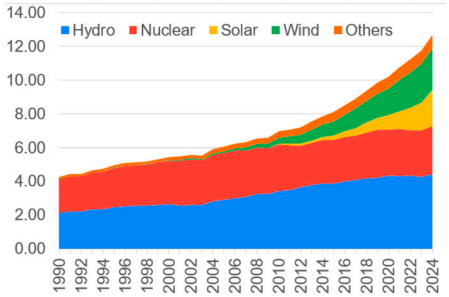


Figure 1. Different renewable energy generation (PWh) worldwide during the last three and a half decades (Data Source: [21,22]).

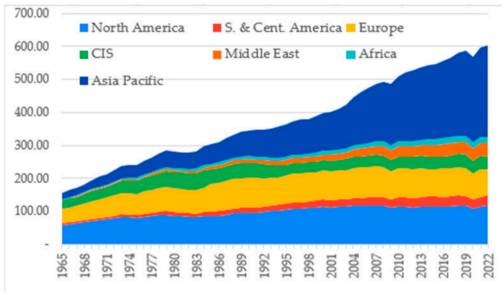


Figure 2. Trends in total energy consumption in different regions of the world (Data Source: [22]).

Recent scholarship highlights that technological innovation and market mechanisms are increasingly pivotal in accelerating global renewable energy transitions. Emerging technologies, such as grid-scale energy storage, smart grids, digital metering, and artificial intelligence-based demand management systems, enable greater flexibility in integrating intermittent renewables [23]. At the same time, market-oriented policies like carbon pricing, green bonds, and competitive renewable auctions are reshaping investment incentives and cost structures [24,25]. For a comprehensive study of the potential for renewable energy transition, it is essential to examine how technological innovation and market design interact with national resource endowments and policy frameworks. Accordingly, this paper also considers the role of such mechanisms in shaping the distinct transition pathways of Canada and Bangladesh. The renewable energy transition in an energy-rich and an energy-poor economy is expected to differ [25]. As such, this paper will explain the differences in the energy transition from three dimensions: resource endowment, institutional capacity, and exposure to commodity markets, using Canada and Bangladesh as case studies.

1.2. Research Objectives and Scope

We compare Bangladesh, an energy-deficient, populous, and developing country, with Canada, an energy-rich, sparsely populated, and developed country, through the lens of commodity market dynamics. We examine how price formation and volatility,

trade, foreign exchange and logistics exposure, investment incentives, and macroeconomic adjustments shape our renewable energy transition paths, alongside short- to medium-term demand projections for each country. Specifically, our research objectives are:

i. *Trends and Forecasts (until 2035)*: We analyze and forecast the structural trends in energy consumption and the production mix of both renewable and non-renewable energy sources in each country up to 2035, applying various univariate time-series models: Auto Regressive Integrated Moving Average (ARIMA); Error, Trend, Seasonality (ETS); and Prophet.
ii. *Commodity market mechanisms:* We compare four commodity market mechanisms that condition transition feasibility, cost, speed, and welfare: (a) price formation, volatility, and risk pass-through; (b) trade flows, import dependence, and supply vulnerabilities; (c) investment patterns, subsidies, and political-economy instruments; and (d) macroeconomic adjustment and structural change.
iii. *Renewable energy transition potential:* We evaluate the renewable transition potential of each country by synthesizing the findings from the first two objectives, moving beyond a purely resource-endowment view to one that incorporates market structures, financial capabilities, and governance.
iv. *Policy implications:* We derive policy recommendations that address the distinct commodity-market challenges in an energy-exporting developed economy and an energy-importing developing economy, targeting strategies for a secure and sustainable renewable energy transition.

The rest of the paper is organized as follows: Section 2 discusses Bangladesh's energy situation. Section 3 focuses on Canada's energy situation. Section 4 provides the methodological details, while Section 5 examines the renewable energy transition potential of the respective countries. Section 6 concludes and provides some policy recommendations.

2. Energy Situation in Bangladesh

Bangladesh's rapid population growth and high economic growth have made it one of the world's most energy-hungry economies [26,27]. Energy is considered one of the main driving forces of economic growth and development. While energy promotes economic growth, it also causes environmental problems by producing pollutants and generating greenhouse gases that contribute to global warming [28]. Bangladesh's energy sector remains heavily reliant on fossil fuels, particularly natural gas, imported oil, and coal, which account for most of its electricity production. As of 2024, less than 5 percent of the country's electricity comes from renewable sources, primarily solar and one small hydroelectric dam [29]. Although the government has set targets to increase renewable energy capacity, progress has been slow. In this section, we present the energy situation in Bangladesh, focusing on supply and demand, and the potential for transforming toward greater renewable energy production and use.

However, Bangladesh's energy dependence cannot be understood solely in terms of generation shares. As domestic natural gas reserves decline and domestic coal supplies are limited, the country is increasingly relying on imported fuels, particularly LNG and coal, to meet rising electricity demand. This reliance ties power generation costs to international commodity prices and foreign-exchange availability. When global fuel prices surge, utilities must absorb higher import bills, while tariff adjustments often lag due to the complexity of subsidy structures and political economy constraints. As a result, global price shocks transmit into domestic inflation, current-account pressures, and periodic electricity rationing. Understanding these commodity-market exposures is therefore essential for evaluating future renewable energy transition options.

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In what follows, Section 2.1 describes the current fossil fuel-based supply and infrastructure, including the increasing role of LNG imports. Section 2.2 presents demand patterns across sectors and links them to macroeconomic growth. Section 2.3 evaluates the potential for renewable scale-up, encompassing solar, wind, waste-to-energy, hydro, and tidal energy. In contrast, Section 2.4 outlines the key policy and institutional reforms necessary for a renewable energy transition.

2.1. Energy Supply in Bangladesh

Traditionally, the people of Bangladesh relied on firewood for cooking and heating their homes. Total energy supply (TES) encompasses all energy produced in or imported into a country, minus that exported or stored [25]. It represents all the energy required to supply end users in the country. Some of these energy sources are used directly, while most are transformed into fuels or electricity for final consumption. Natural gas has become the predominant energy source in recent years, as it is the only energy source available in Bangladesh. The remaining energy is imported from various countries. Figure 3 illustrates the total energy supply (both domestic and imports) from different energy resources. As Bangladesh is an energy-deficient economy, it relies substantially on imports, and all imported energy resources are consumed.

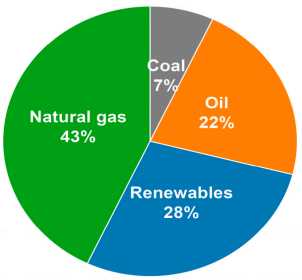


Figure 3. Total primary energy supply (percent) by sources in 2021 (Data Source: [25]).

The supply of most energy forms continues to increase in Bangladesh. Figure 4 below illustrates the trend of the supply of various energy forms. Among these, natural gas, biofuel, and waste are domestic, while the rest are imported.

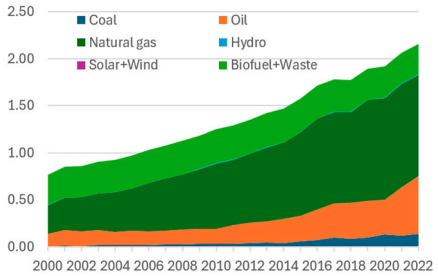


Figure 4. Trend of different energy supplies (Exajoules) over the last two decades (Data Source: [25]).

Natural gas is the only indigenous fossil fuel in Bangladesh. Natural gas exploration in Bangladesh began in the late 1800s, and several small gas fields were discovered occasionally. However, major natural gas extraction and supply to consumers did not happen until the 1980s, when natural gas reserves were at their highest. Natural gas production continued to increase until 2018, when the reserve was depleted to a point where sustained production at the existing high level became impossible (Figure 5). Production continued to increase after the turn of the century, but the reserves were being depleted sharply. Shetol et al. [30] conclude that Bangladesh's existing gas reserves will be depleted within a decade unless new reserves are discovered. With several explorations, both onshore and

offshore, the possibility of natural gas reserve growth is low. In recent years, production has slowed down primarily due to low reserves.

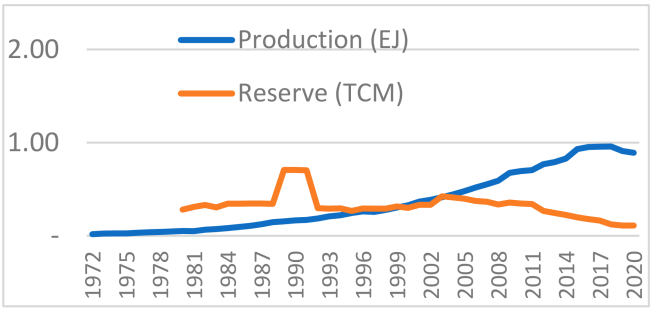


Figure 5. Natural gas production and reserve in Bangladesh (Data Source: [22]).

Natural gas was discovered by the Burmah Oil Company in 1955, and a test for commercial extraction was conducted in 1959. The Chhatak Cement Factory first used the natural gas produced at an early stage. In the same area, the Fenchuganj Fertilizer Factory started using natural gas from the Sylhet gas field. The first power generation from natural gas was achieved by the Siddhirganj Power Plant, which commenced operations on a small scale around the same time [31]. The scale of use remained small and limited to a few factories [32].

With the shortage of biomass fuel, increasing urbanization, and rising incomes and living standards, demand for natural gas increased, and eventually natural gas began to be extracted from more gas fields and piped to the capital city, Dhaka, for domestic and other industrial use [33]. Natural gas is cleaner than other fossil fuels, such as oil and coal, and produces less carbon dioxide per unit of energy released. For an equivalent amount of heat, burning natural gas produces about 30 percent less carbon dioxide than burning petroleum and about 45 percent less than burning coal. Figure 5 below illustrates the annual production of natural gas and its reserves since 1980.

As shown, natural gas production continues to increase, reaching a peak in 2017 and then declining (Figure 5). This is primarily due to the exhaustion of reserves, as reflected during the last two decades. The maximum reserve was estimated in the 1990s and has continued to decline since then. As of 2020, Bangladesh's natural gas reserve is estimated at only 0.1 TCM [22].

Most of Bangladesh's gas reserves are small and fragmented, having been discovered by different companies at different times. In 1993, there were 27 gas fields in the country with an estimated total reserve of 0.352 TCM, which increased to 0.76 TCM by 2011 and 0.768 TCM by 2017 [22]. Since then, the reserve continued to decline [21,22]. Many estimates predicted that Bangladesh's natural gas reserves would be exhausted within a decade unless substantial new gas fields were discovered offshore or elsewhere.

Commodity Market Implications of Natural Gas Depletion: The depletion of Bangladesh's natural gas reserves has significant implications for the commodity market, extending beyond concerns about energy security. As domestic production declines, Bangladesh has transitioned from energy self-sufficiency to dependence on imports, fundamentally altering its exposure to global commodity price volatility. The country established its first Floating Storage Regasification Unit (FSRU) in 2018, initially importing LNG at prices ranging from $6 to $8 per million British thermal units (MMBtu), which then spiked to $15 to $20 per MMBtu during the 2022 Russia-Ukraine conflict [34]. This sharp price increase directly affects the Bangladesh Power Development Board's financial sustainability, as fuel costs account for 60–70 percent of total power generation expenses. Each $1 per MMBtu increase in LNG prices translates to approximately BDT 12–15 billion in additional annual

import costs, straining foreign exchange reserves and necessitating either tariff increases or expanded fiscal subsidies [35,36]. The transformation of the commodity market from domestically priced gas to import-dependent LNG, therefore, represents a structural shift in Bangladesh's macroeconomic vulnerability.

In addition, Bangladesh's energy commodity supply chains exhibit multiple vulnerability points. LNG import terminal capacity constraints create queue delays during peak demand periods. Port congestion during the monsoon season disrupts coal unloading, disrupting fuel availability for baseload thermal plants. Insufficient buffer stocks increase vulnerability to global supply disruptions, as evidenced by the cancellation of spot LNG cargos during winter 2022–2023, which triggered emergency load shedding [35,37].

Taken together, Bangladesh's supply structure of natural gas, the only fossil fuel it has, reflects a gradual shift from domestic gas to imported fuels, increasing both price and foreign exchange risk. International price fluctuations or exposure to a sudden surge in prices put substantial strain on importability, resulting in dual pressure on the expansion of renewable capacity. On the one hand, it encourages increased renewable production; on the other hand, it puts a substantial strain on the government's capacity to implement such measures.

2.2. Energy Demand in Bangladesh

Bangladesh's energy demand can be viewed through several lenses. The growth of per capita energy consumption, driven by rising incomes and higher living standards, plays a significant role. The structural transformation of the economy, shifting away from production-based and toward service-based, also contributes to increased energy demand. As Bangladesh is inherently an energy-deficient economy, its import dependence, global energy prices, and government subsidies all influence energy demand.

2.2.1. Growth in Total and per Capita Energy Consumption

To understand the pressures on Bangladesh's energy system, it is essential to examine how total and per capita energy consumption have evolved in tandem with the country's expanding economy and population. As mentioned before, Bangladesh is one of the most energy-hungry countries in the world. Since independence, total primary energy consumption (TPEC) increased from 0.06 Exajoules in 1972 to 1.79 Exajoules in 2022, representing a 50-year increase of almost 30 times [22]. The growing population, shifting lifestyles, rising per capita income, declining indigenous energy supply, and increasing reliance on imported fossil fuels pose a significant challenge to energy security [9]. With limited domestic energy sources available, Bangladesh needs a comprehensive strategy to meet its growing energy demand. Persistently plagued by serious environmental concerns, including severe droughts, floods, air pollution, and contaminated water supplies, resulting from its heavy dependence on fossil fuels, the Bangladesh government is currently formulating policies to promote the greater utilization of lower-carbon energy sources [38].

Per capita and total energy consumption in Bangladesh have increased since the country's independence in 1972 (Figure 6). The downward trend for both series in 2020 is due to the COVID-19 pandemic, which may be considered an outlier. As an energy-deficient country, this poses a unique challenge as it must rely almost entirely on imports.

Examining Bangladesh's energy consumption mix, we find that the largest increase is in natural gas, the only domestic fuel expected to expire soon. Natural gas accounts for around 75 percent of the commercial energy consumption in Bangladesh (Figure 7).

Bangladesh was primarily an agricultural economy, with a significant share of its GDP coming from the farming sector (59.61% in 1972), steadily declining to 11.61 percent by 2021–22 [39]. The economy has undergone a significant shift in its production sectors,

transitioning from agriculture to manufacturing and services, which has contributed substantially to rising energy demand. This demand continues to grow and evolve in tandem with economic development [40]. Interestingly, the growth in per capita energy use, from 0.09 Gigajoules in 1972 to 10.1 Gigajoules in 2019, exceeds that of total energy use [22].

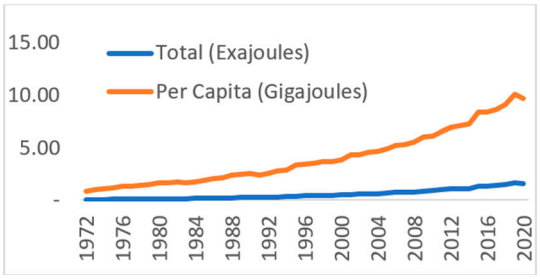


Figure 6. Primary energy consumption, total and per capita, Bangladesh (Data Source: [22]).

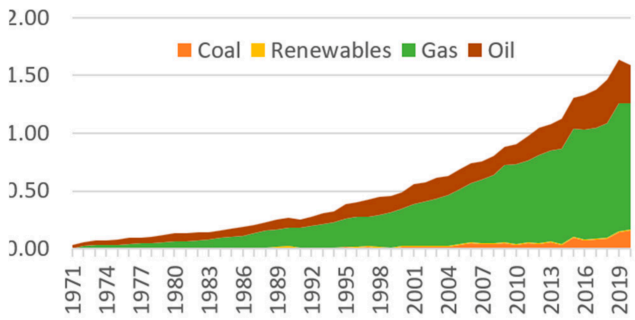


Figure 7. Energy consumption (Exajoules) by source in Bangladesh (Data Source: [22]).

With Bangladesh's rapid economic growth, its energy requirements are expected to continue increasing. Amin et al. [41] recently highlighted that industries face a constraint due to inadequate electricity supply. In fact, load-shedding [electricity rationing] is a well-known phenomenon in Bangladesh. The challenge of securing adequate energy to support economic growth is a concern for a country like Bangladesh, which is highly dependent on imported energy and is becoming increasingly reliant on imports.

2.2.2. Sectoral Demand and Structural Transformation

The natural gas consuming sectors in Bangladesh are (i) Power generation, (ii) Industrial use, (iii) Fertilizer production, (iv) Captive power generation, (v) Domestic household use, (vi) Commercial or business use, and (vii) Transportation of motor vehicles (CNG—compressed natural gas). The power and industrial sectors are the largest consumers of natural gas, accounting for 43% and 17%, respectively [31]. Nonetheless, per capita, primary commercial energy consumption in Bangladesh remains among the lowest in the world.

Intra-sectoral transformation in energy use contributed significantly to increasing energy demand. For example, increased mechanization in the agriculture sector boosts energy demand [40]. In recent years, machinery used in agricultural practices, such as irrigation, land preparation, intercultural operations, and threshing, has become widespread [42]. This trend, as noted by Hossen et al. [42], underscores how technological advancements within a single economic sector can lead to substantial increases in overall energy requirements.

The use of energy in the industrial sector has also been transformed by replacing biological energy [human power] with mechanical energy supplied through fossil fuels and electricity. Much construction, manufacturing, and transportation has now been automated, replacing human and animal power with mechanical power [43]. This process is ongoing, and the rate of increase is expected to accelerate even further in the future.

Energy use is a key indicator of social, economic, and infrastructural development, as well as of the standard of living. The extent of energy consumption is often related to economic development (GDP growth) and a society's lifestyle [44]. Although the relationship between energy consumption and economic growth has not been without dispute, it is well accepted in the scientific community that they are interlinked. The demand for energy is expected to continue increasing as Bangladesh's economy continues to develop. Over the past few years, total energy consumption in Bangladesh has increased by over 10 percent annually [45]. Electricity consumption per capita in Bangladesh in 2019 was 488 kWh, compared to the worldwide average of 3316 kWh [10], which is only 15 percent of that average. Economically well-off countries consume more energy than poor countries. For example, in 2019, Canada's per capita primary energy consumption was 388.24 gigajoules, whereas Bangladesh's was 36.89 gigajoules [22]. This clearly indicates that, with Bangladesh's rapid economic growth, energy demand will continue to rise.

Along with increases in GDP, the energy consumption pattern changes. Mujeri et al. [46] observe that in developing countries, energy consumption rises rapidly when per capita income reaches between $1000 and $10,000. Accordingly, Bangladesh's energy demand is expected to increase rapidly, given that its current per capita income falls within this range. This situation is compounded by rising population density and rapid urbanization. The urban population increased from only 2.6 percent in 1911 to 28.0 percent in 2011, with a much higher rate in recent years [47], reaching 38.18 percent in 2020 [48]. Indeed, considering population density, nearly the entire country has become urban. The population density in Bangladesh is 1123 people per square kilometer, compared to 25 globally and 36 in the USA [48].

Electricity coverage has increased rapidly from 72 percent of the population to 97 percent during 2015–2020 [49]. In 2019–2020, nearly 92.2 percent of the total population was reported to have access to electricity [10]. However, such access is far from secure, as load-shedding and electricity rationing are regular phenomena in Bangladesh. Domestic electricity use, primarily for lighting, heating, cooling, and other purposes, remains the largest sector of consumption (Figure 8). This is an indication of the success of the rural electrification effort and a change in lifestyle.

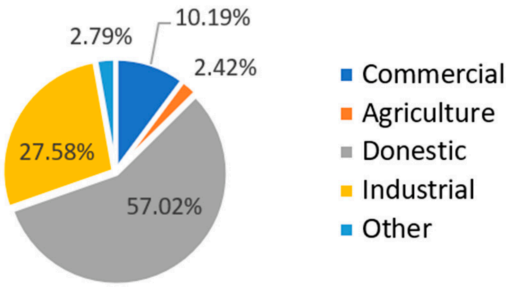


Figure 8. Electricity consumption in different sectors (Data Source: [50]).

The increasing demand for electricity is expected to continue in the years to come. Continuous increases in income and affordability, resulting in improved lifestyles, will require greater energy consumption. As a country develops, it typically transitions from an agriculture-based to an industry-based economy, and then to a service-based economy [27]. Bangladesh is on a trajectory of such development, and the trend is likely to continue, coupled with sustained increases in energy demand.

However, rising consumption alone does not fully explain Bangladesh's energy vulnerability. Because most marginal electricity now depends on imported LNG and coal, demand growth directly amplifies exposure to global price volatility and foreign-exchange constraints.

2.2.3. Import Dependence and Commodity-Market Exposure of Energy Demand

Bangladesh's power sector import dependence reached 65 percent in FY2024-25, encompassing imported LNG (26% of gas supply), coal (nearly 100% of coal consumption), and petroleum products for furnace oil generation [34]. This commodity exposure led to severe price shocks during the 2022–2024 global energy crisis. LNG costs tripled from $6–8 per MMBtu (2020–2021) to $15–20 per MMBtu (2022), while coal prices surged 150–200 percent, forcing the temporary closure of the Payra coal plant (1320 MW capacity) despite installed capacity exceeding demand [22,34].

Fiscal and Macroeconomic Impacts: The Bangladesh Power Development Board reported losses of BDT 382.89 billion (~$3.2 billion) in FY2023–24, primarily due to political resistance to tariff hikes and long-term take-or-pay IPP contracts that lock in fossil fuel use for decades [34]. Tariff increases of 17.5 percent (residential) and 21 percent (industrial) in 2023–2024 failed to cover costs, resulting in subsidies exceeding 2 percent of GDP and crowding out spending on health, education, and infrastructure [36].

Energy imports exceeding $2.6 billion annually depleted reserves from $48 billion (2021) to $20 billion (2024), as commodity price spikes coincided with the Russia–Ukraine conflict [36,51]. This illustrates a classic vulnerability for energy importers: import capacity constrained by foreign currency precisely when global prices rise.

Industrial Competitiveness Impacts: The 2023 energy crisis demonstrated cascading economic effects of commodity market vulnerabilities: 2245 GWh of unserved energy demand (10–12% load-shedding), Ready-Made Garment production declining 50 percent (affecting 80% of Bangladesh's $46 billion export earnings), and captive power costs running 30–50 percent premium over grid electricity [34,36]. These supply disruptions hinder the industrial transformation necessary for structural economic development, trapping Bangladesh in an energy-deficient development pathway where import dependence perpetually undermines its growth capacity.

Trade Balance Deterioration: Energy commodity imports significantly worsened Bangladesh's trade balance. With total merchandise imports of approximately $70 billion annually, energy imports ($2.6 billion in fuel plus $1.5 billion in refined petroleum products) represent 6 percent of the import bill but are characterized by high price elasticity of demand—industrial and power generation requirements are largely non-discretionary in the short term [51]. Combined with volatile RMG export earnings sensitive to load-shedding disruptions, energy commodity import dependence creates structural current account vulnerabilities that constrain development financing and lead to increased external debt accumulation.

2.3. Significance of Renewable Energy Transition

Transforming Bangladesh's energy sector from non-renewable to renewable sources is crucial on both the scarcity and environmental fronts. Bangladesh is inherently deficient in fossil fuels, such as coal, oil, and natural gas. Bangladesh's natural gas supply is expected to run out soon, as depicted in the energy supply subsection. On the second front, from a global warming perspective, Bangladesh, although not a significant contributor, repeatedly confronts the impacts of climate change–including heatwaves, tropical cyclones, floods, and droughts [52]. Therefore, it is prudent to become involved in clean energy production and consumption as much as possible. This subsection will examine the potential for different renewable energy production in Bangladesh. Several researchers have explored the potential from engineering, social, and economic perspectives [53–65].

Although Bangladesh is not a significant greenhouse gas emitter, its geographic location exposes it to disproportionately higher costs of global climate change, resulting in frequent flooding, cyclones, and droughts [52]. However, its CO_2 production has

continued to increase. From 1972 to 2017, per capita CO_2 production increased from 0.05 tons to 0.50 tons [10]. Much of the CO_2 emissions comes from agriculture, but the energy sector is playing an increasingly important role. From 2010 to 2020, coal consumption in Bangladesh increased from 0.03 Exajoules to 0.15 Exajoules [66], a 400% increase over the decade. Because of a rapid rise in energy demand, Bangladesh has had to rely on every possible energy source. Recently, amid growing concern about the environment, several studies [53,56,57,67–70] have focused on the potential for renewable energy in Bangladesh. Over the past several years, efforts to produce and use renewable energy have grown.

Research and development to examine the potential of renewable energy in Bangladesh to meet its energy demand are ongoing. Siddique et al. [60] provide a review of the renewable energy sector in Bangladesh, and Mahmud and Roy [62] identify barriers to accelerating renewable energy. Bangladesh has varying potential for different renewable energy sources, including solar, wind, biomass, hydro, tidal, geothermal, waste, ocean wave, etc. [53–57].

Bangladesh has the potential for a renewable energy transition, but it has made modest progress in this direction. Technological advancements, combined with social and economic motivations, have contributed to the shift toward renewable energy and a reduction in fossil fuel use. This subsection examines various renewable energy sources, including solar, wind, biomass, hydro, hydrogen, nuclear, tidal, and others.

2.3.1. Solar

Bangladesh has made significant strides in developing and adopting solar technology in recent years. It exhibits semi-tropical weather, as it is situated in the northern hemisphere, within 20.30–26.38 degrees north latitude and 88.04–92.44 degrees east longitude. On average, it receives sunlight for more than 70% of the year [71]. The average sunshine hours are 6.69, 6.16, and 4.81 in winter, summer, and monsoon, respectively [72]. Bangladesh receives 4–6.5 kWh/m^2 of solar radiation daily [73]. Therefore, there is considerable potential to expand solar energy in Bangladesh, and, as we have seen before, it has expanded significantly. Solar energy is used in two ways: thermal route—heat from solar energy to use for various purposes, like home heating, water purification, power generation, etc., and photovoltaic route—used for lighting, pumping, and power supply in many rural areas, where grid electricity is either not available or not reliable if available [56,74].

Most of the solar energy in Bangladesh is generated and used through solar home systems (SHSs), which use rooftop solar panels to convert sunlight into electricity for household use. By 2018, the system had provided over 4.1 million SHS. The total solar P.V. capacity installed was 163 MW [75]. The SHS Program was economically justifiable from both national and global perspectives, with an EIRR of 20 percent without considering global emission-reduction benefits and 25 percent with them, based solely on savings in kerosene/grid electricity costs for lighting [75]. It provided electricity services that were adopted by rural households cost-effectively and with net benefits to all participants except kerosene dealers, while also reducing kerosene consumption by 4.4 billion liters and reducing greenhouse gas (GHG) emissions by 9.6 million tons. The SHS program expanded until 2013, then slowed, primarily due to grid electricity availability and the government's shortage of loan programs [75]. This indicates that a sustained support system is required. Commercial and residential buildings also feature rooftop solar systems to meet their electricity requirements. In rural areas, solar water heating systems, solar-powered drinking water systems, solar irrigation, and solar charging systems are becoming popular [56].

Solar energy is the most abundant and promising renewable energy resource for Bangladesh (Table 1). It has the highest potential for providing energy through two routes:

thermal and photovoltaic. Although Bangladesh is a subtropical country and home heating is not a general requirement, the thermal route can provide heating during winter, water purification, and power generation. The photovoltaic route is more important for Bangladesh, as it can produce electricity that can be used for nearly anything—from lighting to powering equipment. In recent years, the SHS has gained popularity among households, and numerous national and international organizations have emerged to promote solar energy development in Bangladesh [63]. Several solar park projects have been completed, while others are ongoing, and some are still in the planning stage [76]. However, there is still room for continuous improvement, and solar energy production is expected to grow further.

Table 1. Renewable energy database in Bangladesh as of 2023.

Technology	Off Grid (MW)	On-Grid (MW)	Total (MW)
Solar	377.15	909.16	1286.31
Wind	2	60.9	62.9
Hydro	0	230	230
Biogas to electricity	0.69	0	0.69
Biomass to electricity	0.4	0	0.4
Total	380.24	1200.06	1580.3

Source: National Database of Renewable Energy, Bangladesh Sustainable and Renewable Energy Association (BSREA) National Database of Renewable Energy—The Bangladesh Sustainable and Renewable Energy Association [76].

2.3.2. Wind

Wind energy is one of the world's fastest-growing renewable energy production systems. However, in Bangladesh, the potential of wind energy is relatively limited, except in some coastal areas [54,56]. Bangladesh has a coastline of over 700 km, with potential for wind energy development. Some efforts have been made to harvest wind energy in the southeastern coastal area (Feni and Kutubdia districts). However, episodic natural calamities (such as cyclones), insufficient wind speeds during calm weather, and inadequate investment capacity make it unfeasible to implement large-scale wind energy harvesting in Bangladesh. An extensive, highly technical survey conducted by USAID and the United States Energy Research Laboratory, in collaboration with the Government of Bangladesh, estimated that wind energy alone could meet the country's 10 percent renewable energy target [77]. However, such studies did not consider many risk factors, and the country's wind energy production remains in its infancy; the 10 percent renewable energy production target is far from reality. Moreover, further research on physical ability, considering all risk factors, and the economic feasibility is needed before concluding the true potential of wind energy in Bangladesh.

2.3.3. Biomass

Historically, the people of Bangladesh relied on bio-energy sources for heating (cooking), transport, and other purposes. Before independence in 1971, only about 3 percent of Bangladeshis had access to electricity. The country was primarily rural and agriculture-based, utilizing energy from plant sources (fuelwood), animal sources (draft power), and manual labor (for all agricultural activities). Even today, Biomass remains a prominent source of energy in most developing countries, especially for rural populations [78]. Biomass fuels are principally supplied from trees around homesteads and/or other secondary plantations and natural forests.

The overexploitation of forest resources has made biomass fuel scarce, and the changing lifestyles of most of the population have increased demand for fossil fuels [79]. Some non-bio energy sources were used in marine transportation (river current, wind sail) and in coal-fired steam engines for railway and marine transportation. With the world's primary energy source shifting from coal to liquid oil, Bangladesh began modernizing its energy infrastructure to use oil and gas.

Historically, Bangladesh has used biomass fuel, which is renewable, storable, and transportable. It remains a vital energy source for rural populations, particularly for cooking and heating. However, its importance is waning primarily due to limited availability and changing lifestyles. Bangladesh has significant biomass resources due to its year-round congenial growing conditions, characterized by a warm, humid climate that supports rapid plant growth. Biomass sources include agricultural, forest, animal, and human manure, as well as municipal solid waste [80,81]. Despite a dramatic reduction in natural forest areas, forest biomass remains significant due to plantation forests, trees established through agroforestry or social forestry, and tree plantations around homesteads. Both animal manure and municipal solid waste continue to increase due to the commercial farming of animals and poultry, as well as the rise in urbanization. Halder et al. [80] argued that biomass energy resources have both advantages and disadvantages. Still, with the use of appropriate technology and policy, biomass resources can make a significant contribution to meeting the future energy challenge in Bangladesh. Masud et al. [82] seconded the argument, stating that biomass has the capacity to contribute to the adaptability of the UN's Sustainable Development Goal 7, an aspiration to ensure affordable, reliable, sustainable, and modern energy for all people.

2.3.4. Hydro

Bangladesh is a land of rivers, which carry over 1.4 trillion cubic meters of water every year [60]. However, the river flow is not conducive to the development of hydroelectric dams, as the country is relatively flat and a dam can flood a considerable area upstream, leading to water shortages downstream. In addition, the water flow is uneven. During the monsoon season, the rivers become filled with water and sometimes overflow their embankments. However, during the dry season, the rivers lack sufficient water to generate hydroelectricity. Bangladesh's primary hydropower facility is the Kaptai Hydroelectric Power Plant, with a total capacity of 230 MW, consisting of two 40 MW and three 50 MW turbines [35].

Since Bangladesh does not have a water flow system to build large-scale hydroelectricity production capacity, it can resort to a mini [small-scale] hydroelectricity facility [55]. Globally, small-scale hydropower has become prevalent and acceptable due to its simplicity, low cost, reliability, and environmental sustainability [83,84]. In Bangladesh, both the Bangladesh Power Development Board and the Sustainable Rural Energy project under the Local Government and Engineering Department examined the potential for a mini-hydro facility. The table below shows the potential sites identified by Sustainable Rural Energy [85,86]

2.3.5. Geothermal

Bangladesh has limited potential for geothermal energy exploration, as it lies outside active tectonic plates. However, further investigation is needed. There are a few thermal gradient sites in Bangladesh where geothermal energy can be harnessed to generate electricity [87,88]. However, in-depth knowledge is required to assess geothermal energy. The government approved a 200 MW geothermal project in Thakurgaon and Habiganj [89]. The government and the private sector should make greater efforts to evaluate the potential of geothermal energy to enable its effective utilization.

2.3.6. Tidal Energy

Tidal energy is produced from the natural tide—surge and fall of the ocean water level due to the tidal effects. Bangladesh has access to the Bay of Bengal, which receives semi-diurnal tides. Arafat and Chowdhury [53] state that Bangladesh has a 740-kilometre coastal belt with a regular tidal range of between two and eight meters. Given the difference in water levels between the rise and the fall on a diurnal basis, Bangladesh can potentially harvest substantial energy from low-head and medium-head tidal flow technologies [53]. As the coastal area of Bangladesh is uneven and there are plenty of lagoons and embankments for protecting people and resources from coastal cyclones, it can produce tidal energy in three different ways: (1) general tidal streams—using the diurnal variation in water levels, (2) barrages—keeping the water inside the embankments to produce hydroelectricity during the fall and filling then during the rise, and (3) tidal lagoons—using the natural lagoon areas, where no artificial embankment is needed [89,90].

The development of tidal energy is still in its infancy. Although theoretical potential exists in many of the world's oceans, only a few tidal energy production plants have been built. The biggest ones are in South Korea, France, the United Kingdom, and Canada. Nonetheless, this is an area of power generation that the world has not yet fully explored. Given the limited resource capacity, Bangladesh is unlikely to be able to produce much of this energy in the near future.

Additionally, there are natural challenges. The Bay of Bengal is highly prone to tropical cyclones. Singh [91], using data from 129 years, observed that both the frequency and severity of tropical cyclones in the Bay of Bengal are increasing.

Given all the different options for renewable energy production, Bangladesh can easily adopt solar energy, which it has already expanded significantly. Solar power and some wind power are likely to continue growing. The other options—hydro, geothermal, and tidal—need substantial initial investment, which Bangladesh may not be able to afford at this time. However, as time passes, the situation will change, and with the increase in income at both the individual and national levels, Bangladesh must explore other renewable energy options.

2.3.7. Nuclear Energy

Bangladesh does not have nuclear energy, although efforts to produce such energy began several decades ago, even before the country was established. The region, being energy-deficient, began nuclear energy exploration in 1961, with a site selected in 1963 [92]. The country planned a nuclear power plant with approximately 2 GW of capacity [either one or two plants, for a total of 2 GW]. Both the political situation and public perception fluctuated at different times, exhibiting rollercoaster-like behavior [93]. Finally, construction is underway, and after several postponements, the plants are expected to begin production in late 2025. However, no one can say for sure, unless the production process begins. The cost of establishment is expected to be much higher than in many competitive countries [94,95].

Bangladesh's renewable energy progress remains constrained by the limited diffusion of enabling technologies, such as battery storage, smart inverters, and digital grid controls. The country lacks the advanced grid management infrastructure necessary to integrate variable solar and wind power effectively. Pilot projects, such as the Infrastructure Development Company Ltd. (IDCOL) solar microgrid program and the JICA-supported smart-metering demonstration initiative, illustrate nascent technology adoption but reveal scalability challenges related to finance and regulation [96]. The wider deployment of storage-integrated solar systems, smart microgrids for rural electrification, and data-driven grid monitoring could significantly strengthen Bangladesh's capacity to integrate renewables and enhance supply reliability.

2.4. Energy Policy in Bangladesh

The government of Bangladesh has established the Sustainable and Renewable Energy Development Authority with the aim of generating a significant amount of electricity from renewable sources [97]. With the shift in privatization policies of the energy sector, several non-governmental organizations have emerged in recent years. In 2019, over 13 million solar energy beneficiaries in Bangladesh were primarily from the private sector [69]. Even in many remote parts of the country, installing a solar home system is noticeable. Bangladesh can harness wind energy as another renewable source, particularly in coastal areas. Although there are only a few wind energy facilities in Bangladesh, primarily operated by the private sector, the potential for further improvement exists.

Despite its potential, renewable energy has not significantly impacted Bangladesh's total energy production and consumption. In 2020, the share of renewable energy remained below one percent, while natural gas accounted for over 68 percent. This suggests that renewable energy can play a significant role in the future. Still, it will not be able to make a substantial contribution to the energy challenge in Bangladesh in the near future.

The government of Bangladesh planned to supply electricity to all citizens by the end of 2021, and it has taken various initiatives to increase electricity generation and improve its distribution system [50]. The government identified insufficient energy availability as a significant constraint on GDP growth and overall economic development. The primary objective of the 2004 energy policy was "*To provide energy for sustainable economic growth so that the economic development activities of different sectors are not constrained due to a shortage of energy*" [32]. In the Seventh Five-Year Plan (fiscal years 2015/16 to 2019/20), the government aimed to adopt a balanced approach between increasing supply through new investments and managing demand through policy interventions. With support from international financial institutions, such as the World Bank and the Asian Development Bank, it planned to deploy utility-scale solar, wind, and biomass plants at selected locations wherever possible, with a target of 10 percent renewable energy production capacity [98]. Interestingly, in the following plan, the focus was on power generation, claiming that capacity exceeded demand and that the share of renewables remained below 1%. The total production from renewable sources increased [99].

Domestic energy supply receives complements from imported energy, including liquefied natural gas (LNG). The Government of Bangladesh's stated policy objectives are to make the gas sector financially viable, improve its efficiency and the quality of supply, and increase private-sector participation and investment. The government of Bangladesh has given continuing attention to the sector's overall development through survey, exploration, exploitation, production, transmission, and distribution, and will allocate adequate resources to develop gas infrastructure.

A critical political-economy challenge in Bangladesh's energy sector is the extensive subsidy regime for fossil fuels, particularly for natural gas, electricity, and fertilizers [100]. These subsidies, while intended to ensure affordability and social stability, create significant market distortions. They place a heavy burden on the national budget, diverting public funds from critical investments in infrastructure, health, and education. Furthermore, they artificially lower the cost of fossil fuels, reducing the price competitiveness of renewable alternatives and discouraging private investment in the green energy sector [46]. Phasing out these subsidies is politically sensitive but economically imperative, as their fiscal cost exacerbates the macroeconomic vulnerabilities created by high import bills. Amin et al. [101] suggested lowering fossil fuel subsidies to foster economic development and environmental sustainability in Bangladesh.

Beyond the abovementioned traditional subsidy reform, market-based instruments are emerging as viable complements to policy mandates. Competitive renewable energy

auctions, net-metering schemes, and the gradual development of carbon credit markets could enhance cost transparency and attract private investment. Coupled with incentives for battery storage and smart-grid infrastructure, such reforms would shift Bangladesh's transition from a subsidy-driven to a market-driven model of clean growth [102]. These steps align with the government's Integrated Energy and Power Master Plan (2023), which emphasizes technological modernization and financial sustainability.

3. Energy Situation in Canada

Canada has a large land mass, a small population, and one of the world's largest and most diverse energy sources. Its rivers carry about seven percent of the world's freshwater—a tremendous source of hydroelectric power. It has the fourth-largest proven oil reserves and the third-largest uranium reserves (Table 2). Canada is rich in energy resources and a leader in developing and implementing innovative technologies for producing and using energy. Its production and consumption systems place significant emphasis on the evolving electricity mix. In fact, wind and solar photovoltaic (P.V.) energy are Canada's fastest-growing sources of electricity generation [103]. Traditional coal-fired electricity plants are being dismantled to reduce greenhouse gas (GHG) emissions. In the electricity system, cogeneration has increased energy-efficient practices and reduced GHG emissions in areas such as the oil sands. Ongoing developments in areas such as grid-scale electricity storage, carbon capture and storage, hydrogen, and electric and alternative-fuel vehicles have the potential to further transform the energy system.

Table 2. Global energy rankings for Canada.

Energy	Reserve Capacity	Production	Export
Crude oil	4	4	3
Uranium	3	2	2
Hydroelectricity	4	3	-
Electricity	8	7	2
Coal	18	15	8
Natural gas	15	5	6

Data Source: [104].

On average, a Canadian household spent $4943 in 2023 on energy to heat and cool its home, as well as to operate its appliances and cars [104]. The energy CPI is more volatile and grew faster than the total CPI. Aside from costs, many other Canadians benefit indirectly from energy sector developments through activities such as manufacturing steel and pipe, supplying mining equipment to oil sands plants and coal mines, and transporting these goods to where they are needed [104]. Canada is fortunate to have a strong and diverse energy sector, but, like most countries, it faces several energy challenges.

The energy sector achieved a significant milestone in 2019 with the establishment of the Canadian Center for Energy Information (CCEI). Housed at Statistics Canada, the CCEI brings together Canada's existing energy information in one location, facilitating access to products such as the Energy Fact Book. For over ten years, the Energy Fact Book has provided a solid foundation for Canadians to understand and discuss significant developments across the energy sector [103].

3.1. Energy Supply in Canada

As mentioned in the previous subsection, Canada is blessed with large quantities of diverse energy sources, including hydro, wind, solar, ocean (tidal and wave), biomass,

uranium, oil, natural gas, coal, oil sands/bitumen, and coal-bed methane (Table 2). It is an "energy superpower" on the world stage. It is the world's sixth-largest energy producer [103]. It is the third-largest hydroelectric power-generating country, after China and Brazil, and the fourth-largest oil producer, after the US, Russia, and Saudi Arabia. Additionally, it is the fifth-largest natural gas producer, alongside the US, Russia, Iran, and China. It is the second-largest uranium producer in the world after Kazakhstan [105].

Canada has some of the world's largest and safest nuclear-generating stations and several crucial nuclear research facilities. It is one of the few countries in the world that is not only energy-rich but also fully capable of increasing its energy production in an environmentally and economically sustainable manner. These resources, combined with Canadians' intellectual and technological skills, have made Canada's domestic and export energy sector one of its biggest economic drivers. The energy sector provides significant employment and economic opportunities, contributing significantly to the lifestyle that Canadians have come to enjoy and expect. For example, in 2006, industry accounted for 5.9 percent of the national GDP, fueled by energy production and generation, with over 345,000 people employed in the oil and gas and electricity sectors alone [106]. Canada's energy sector is substantial in terms of both the quantity produced and traded, as well as its contribution to the country's GDP. In 2023, the energy sector contributed 10.3 percent to Canada's GDP and employed 697,000 people [106]. Among different provinces, Alberta alone employs over 150,000 workers. Canada, with only 0.5 percent of the world's population, produces a substantial amount of energy. Interestingly, it is rich in all forms of energy.

Because of its abundance of energy resources, Canada produces, uses, and exports a diverse portfolio of energy, commonly known as the "energy mix". The following table (Table 3) shows Canada's energy mix in 2021. There may be some variations from one year to the next. Still, the overall distribution of energy remains relatively unchanged, except that the more environmentally friendly energy sources are increasing slowly. For example, the share of coal production is decreasing substantially. The target is to eliminate coal in the next 10 to 20 years. At this time, natural gas production is increasing alongside all renewable energy sources, including wind, solar, and others. Although the transition process is not dramatic, the movement is in the right direction.

Table 3. Canada's energy production and supply mix, 2021.

	Production	**Supply**
Coal	4%	2%
Oil	41%	33%
Natural gas	27%	41%
Natural gas liquid	4%	
Hydro	5%	11%
Uranium	16	
Nuclear		8%
Biofuel and waste		4%
Other renewables	3%	1%
Total percent	100%	100%
Total (PJ)	27,057	12,442

(Data source: [104]).

Canada's energy production and domestic supply are not the same, as it exports nearly all forms of energy it produces. So, the domestic supply is calculated as

Total Energy Supply = Production + Imports — Exports + Stock Changes.

In 2022, Canada's energy supply mix was 76 percent fossil fuel (2, 41, and 33 percent coal, natural gas and oil, respectively) (Table 3), 16 percent renewable and eight percent nuclear, compared to the global energy mix of 81 percent fossil fuel (28, 23, and 28 percent, coal, natural gas, and oil, respectively), 14 percent renewable and five percent nuclear [103].

The energy sector is also a major contributor to several provincial treasuries and, potentially, to territorial treasuries. In 2005, petroleum companies and electrical utilities contributed over $3 billion in royalties, bonuses, fees, dividends, and taxes to Canadian provinces and territories, which support critical programs such as health and education.

Canadian energy production, particularly in the non-renewable sector, faces significant challenges. While Canada's conventional energy sources, such as oil, natural gas, and coal, still have substantial potential to meet demand over the short to medium term, these non-renewable energy sources are becoming increasingly challenging to find and more costly to extract. Therefore, new sources must be developed [107]. As the world has turned its attention to the critical issue of climate change, it is increasingly essential to create, transport, and use energy resources in an environmentally responsible manner. Many stakeholders, communities, and Aboriginal people are seeking increased opportunities to provide input into energy policy and resource management.

3.1.1. Fossil Energy Supply in Canada

Canada has three primary fossil energies—coal, oil, and natural gas. Over time, due to climate change and environmental concerns, coal production has been declining steadily. Indeed, the Government of Canada is in the process of phasing out the extensive use of coal for electricity production. Canada holds vast reserves of fossil fuels, particularly in the western provinces. The most prominent resource is crude oil, particularly in the form of oil sands, with Alberta serving as the hub of production. In 2021, Canada was the sixth-largest primary energy-producing country in the world, with over 80 percent of its energy coming from fossil fuels [103]. Crude oil is by far the most significant primary energy source in Canada. The energy sector contributes over 10 percent of the country's GDP and employs more than 500,000 people [103]. It has a vast amount of primary energy reserves in various forms.

Oil is the primary source of energy and a major contributor to Canada's export earnings (Figure 9). Although not all provinces have oil resources, some areas are richer than others. Oil production in Canada continued to increase, driven by sustained international crude oil prices and technological advancements in oil sands extraction. New technology, successfully employed in shale gas developments (including horizontal drilling and multi-stage fracture stimulation), has been successfully used in several projects in Alberta and Saskatchewan. Canada now focuses more on its unconventional oil production. By the end of this decade, oilsands production is expected to account for nearly 90 percent of Canadian oil production [108]. The shift towards unconventional production has long been anticipated, as 97 percent of Canada's proved oil reserves are in the form of oil sands.

Canada's fossil energy sector receives substantial support from the Government, primarily through subsidies [109]. The energy sector also generates substantial income for resource-rich provincial and federal governments. However, in response to recent environmental concerns, the government has decided to reduce subsidies on the fossil energy sector [110]. Canada has agreed to phase out coal, which substantially contributes to human health [111]. New processes and efficiency improvements are also helping curb

the expected demand for natural gas per barrel of oil sand produced. With significant reserves in Alberta, British Columbia, and Saskatchewan, Canada is among the world's top five natural gas producers, with output exceeding 15 billion cubic feet per day in recent years [22]. In contrast, coal production has declined due to environmental policies and decreased domestic demand; however, Canada continues to export coal, particularly metallurgical coal used in the steelmaking process.

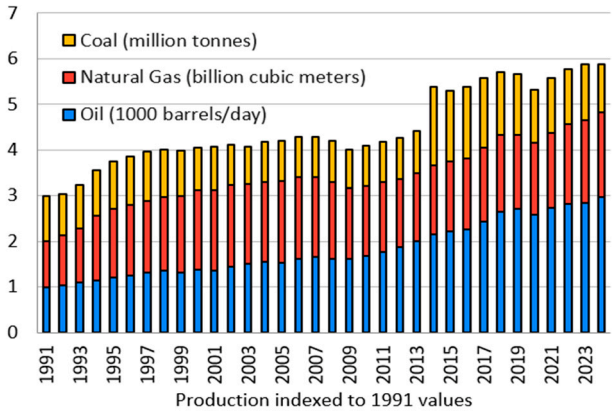


Figure 9. Fossil fuel (coal, oil, and natural gas) production in Canada, 1991–2024, indexed to 1991. (Data Source: [21,22]).

Canada's natural gas industry began to take off in the mid-20th century, driven by discoveries in Alberta and British Columbia. Today, Canada possesses one of the largest natural gas reserves in the world [22], primarily located in the Western Canadian Sedimentary Basin, which spans Alberta, British Columbia, and Saskatchewan. Unconventional sources, such as shale gas and tight gas, have become increasingly important due to advancements in horizontal drilling and hydraulic fracturing [112,113].

Canada is a major exporter of natural gas, with the United States being its primary destination. In 2024, Canada produced over 194 billion cubic meters of natural gas [35], with the majority originating from Alberta and northeastern British Columbia. Ghosh and Islam [114] used a theoretical model to find that Canada's entry into the LNG market benefits Canadian firms. The industry has tried to export its natural gas to the international market beyond the USA with little success. Only recently did the shipment of LNG to Asia from one of its plants begin (Kitimat). Several LNG projects are in development or under construction. These projects aim to diversify Canada's export markets and enhance energy security for international partners. However, LNG infrastructure development faces challenges, including high costs, regulatory hurdles, and concerns from Indigenous communities and environmental groups. The first LNG shipment from Canada to Asia was on 30 June 2025 [115].

The fossil fuel industry is Canada's largest source of greenhouse gas (GHG) emissions, contributing significantly to the country's climate footprint. Oil sands production (Figure 10) is energy and water-intensive, raising concerns about air and water pollution, habitat disruption, and Indigenous rights. The future of fossil energy in Canada is uncertain but evolving. While global demand for oil and gas is expected to persist for decades, particularly in developing economies, there is growing pressure to reduce carbon emissions. Canada's fossil energy industry is exploring ways to adapt, including investing in cleaner extraction technologies, transitioning to hydrogen production, and implementing carbon capture systems. There is a growing movement toward diversification and innovation in the clean energy sector. Public opinion, investor preferences, and international climate

commitments are pushing Canada to rethink its reliance on fossil fuels and invest in a more sustainable energy future.

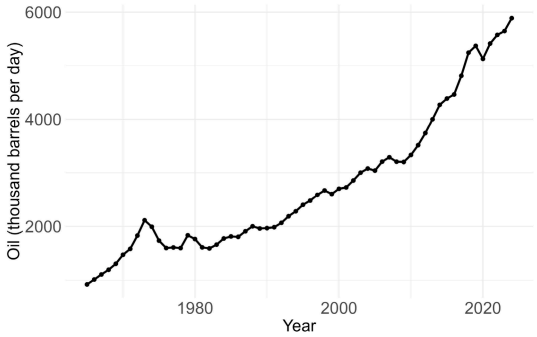


Figure 10. Oil production trend in Canada (Data source: [21,22]).

Fossil energy has long been a pillar of Canada's economy and energy system [116]. While the country remains a major player in global oil and gas markets (Figure 10), it faces mounting challenges related to environmental sustainability and climate change. Balancing economic interests with environmental responsibility will be critical as Canada navigates the transition to a low-carbon future. The evolution of its fossil energy supply will shape not only the nation's economic trajectory but also its role in the global effort to combat climate change.

Two ways to reduce GHG emissions from Canada are to reduce coal production and increase natural gas production as a transition fuel [117]. Among the three fossil fuels, coal is the worst for contributing to GHG emissions. Canada recognized this almost half a century ago and has attempted to reduce coal production [118–120]. The target is to eliminate coal-fired electricity plants by 2030. However, progress is slow, and the sector may not realize its objectives by 2030 [118]. Nonetheless, the trajectory is in the right direction, and at some point, Canada's GHG emissions will decline.

The country's total coal production has been declining since the 1990s, following a period of increase in the 1970s and 1980s (Figure 11), in response to the world's energy crisis. The trend continues in the right direction with a more rapid decline in recent years.

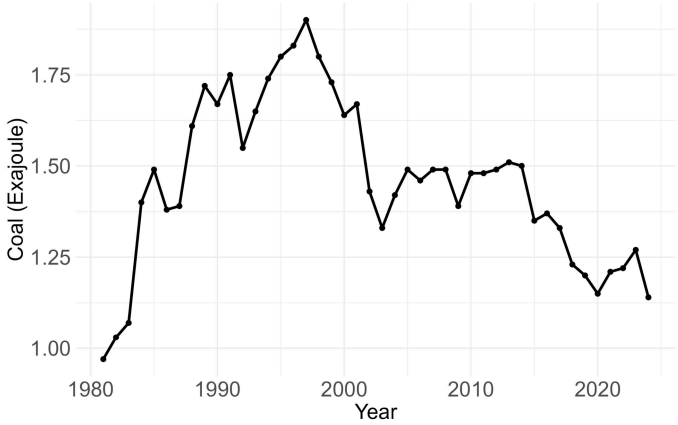


Figure 11. Coal production in Canada (Data source: [21,22]).

Canada is one of the world's leading producers of natural gas, with vast reserves that play a crucial role in both the national economy and the global energy market. As the world increasingly seeks cleaner energy alternatives, natural gas is positioned as a transitional fuel, offering a lower-carbon alternative to coal and oil. In Canada, the production and export of

natural gas have undergone significant evolution over the past few decades (Figure 12), driven by technological advances, market demand, and environmental considerations.

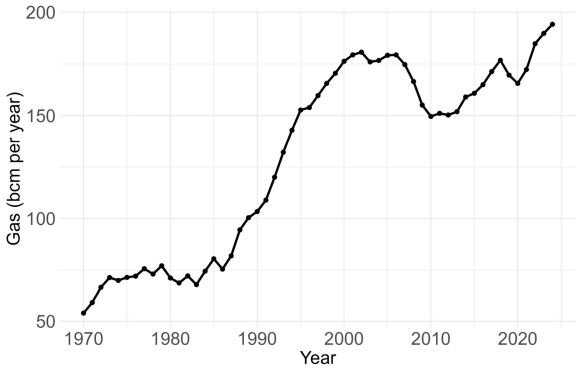


Figure 12. Natural gas production in Canada (Data source: [21,22]).

As the world transitions to net-zero emissions, natural gas in Canada may serve as a bridge fuel, supporting energy reliability and economic development. In contrast, renewable energy capacity continues to expand [18]. However, this will require ongoing investment, robust regulation, and meaningful engagement with Indigenous communities to ensure sustainable development.

Commodity Market Dynamics of Canada's Fossil Fuel Exports: Canada's fossil fuel production fundamentally shapes its commodity market position and macroeconomic performance. The value of energy commodity exports was $199.1 billion CAD in 2024, representing 28 percent of total merchandise exports and 10.3 percent of GDP, making energy Canada's dominant export sector [103,121]. Export capacity includes crude oil at 4.1 million barrels per day (MMb/day) and natural gas at 8.5 billion cubic feet per day (Bcf/day), with 95 percent of exports by value destined for the United States market [122]. This concentration creates monopsony vulnerabilities, despite Canada's energy abundance, as the country functions as a price-taker in the integrated North American energy commodity market. The completion of the Trans Mountain Pipeline expansion in May 2024 added 590,000 barrels per day (bbl/day) of capacity for Pacific tidewater access, with the first LNG shipment to Asia scheduled for 30 June 2025, marking the initiation of market diversification efforts [123,124].

However, regional price differentials persist due to infrastructure bottlenecks. Western Canadian Select (WCS) crude traded at $15–20 per barrel discounts to West Texas Intermediate (WTI) through 2024, while AECO natural gas prices ($1–2.50 per MMBtu) remained substantially below Henry Hub ($2–4 per MMBtu), reflecting commodity market inefficiencies costing producers billions annually in foregone revenues [22]. Despite energy self-sufficiency exceeding 100 percent, eastern refineries (in Quebec and the Atlantic provinces) import foreign oil at Brent pricing due to the absence of pipeline connectivity to western production, resulting in regional price disparities that increase consumer costs [125].

3.1.2. Renewable Energy Supply in Canada

Canada, with its vast natural resources and commitment to environmental sustainability, is a global leader in renewable energy production. The country's energy landscape is undergoing significant transformation as it shifts from traditional fossil fuels to cleaner, more sustainable energy sources [126]. The development and expansion of renewable energy technologies such as hydroelectricity, wind, solar, and biomass are central to Canada's strategy to reduce greenhouse gas emissions, promote economic growth, and ensure energy security (Figure 13).

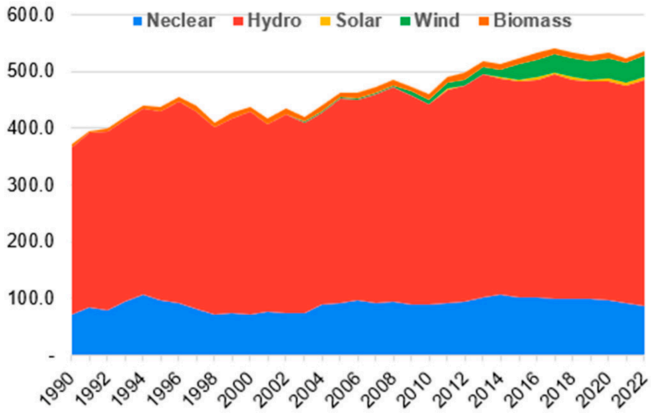


Figure 13. Canada's renewable energy generation capacity (TWh) (Data Source: [33]).

Canada's renewable energy supply is dominated by hydroelectric power, which accounts for nearly 60 percent of the country's total electricity generation [126]. The abundance of rivers and lakes, particularly in provinces like Quebec, British Columbia, Manitoba, and Newfoundland and Labrador, has made hydroelectric power a cornerstone of Canada's energy strategy. Large-scale hydroelectric dams provide reliable, low-cost electricity and play a key role in reducing the nation's carbon footprint.

Wind energy is the second-largest source of renewable electricity in Canada, accounting for approximately six percent of the country's total generation [126]. Wind farms are primarily located in Ontario, Quebec, and Alberta, where government policies and favorable wind conditions support their development. The growth of wind power has been rapid over the past two decades, driven by technological advancements and increasing investments from both the public and private sectors.

Solar energy is growing steadily, although it remains a minor contributor to Canada's electricity supply (Figure 13). It is most prevalent in Ontario, which benefits from a combination of solar-friendly policies and relatively high radiation. As solar panel technology becomes more efficient and affordable, it is expected to play an increasingly important role, particularly in distributed energy systems and remote communities.

Biomass and bioenergy also contribute significantly to Canada's renewable energy portfolio, particularly in regions with substantial forestry and agricultural industries. Biomass energy is derived from organic materials, including wood waste, agricultural residues, and landfill gas. It provides a valuable opportunity for waste reduction while generating heat and electricity.

Canada has committed to achieving net-zero greenhouse gas emissions by 2050 [127]. To achieve this goal, federal and provincial governments have implemented a range of policies and incentives to promote renewable energy development. These include carbon pricing, renewable portfolio standards, feed-in tariffs, and investments in clean energy infrastructure.

Despite the progress, several challenges remain. Integrating variable renewable energy sources, such as wind and solar, into the grid necessitates substantial investments in energy storage, grid modernization, and transmission infrastructure [120,128]. Moreover, energy projects must be developed in partnership with Indigenous communities, respecting land rights and ensuring mutual benefit.

Nevertheless, the renewable energy transition presents numerous opportunities [129]. Canada can create thousands of green jobs, attract international investment, and develop new export markets for clean technologies. Moreover, renewable energy can provide a reliable and affordable power supply to remote and northern communities, many of which currently rely on expensive and polluting diesel generators.

Canada's renewable energy supply is vital to its move to a sustainable, low-carbon economy [129]. Hydro power remains the backbone of its clean energy system, with wind second and solar growing from a small base [130]. The growth of wind, solar, and biomass signals a diversified, resilient energy future. With continued investment, supportive policies, and a commitment to innovation, Canada is well-positioned to lead the global shift toward renewable energy and climate resilience [120]. However, industrial structure and winter heating loads make the oil and gas bases macro-relevant even as non-emitting supply grows.

3.2. Energy Demand in Canada

3.2.1. Sectoral Demand and Energy Intensity

Canada, with its vast geography and diverse climate, is one of the world's highest per capita energy consumers [22]. Several factors, including economic growth, industrial activity, weather conditions, population trends, and technological advancements, impact energy demand in Canada. Understanding how and why Canadians consume energy is crucial for shaping effective policies on energy production, sustainability, and climate change.

Canada's total energy demand in 2020 was 11,059 petajoules, which can be divided among four major sectors: industrial, transportation, residential, and commercial/institutional [130]. The industrial sector is by far the largest consumer, accounting for over 50 percent of the country's total energy use (Table 4). This includes energy-intensive industries such as oil and gas extraction, mining, pulp and paper, and manufacturing. The transportation sector follows, consuming about 20 percent, mainly in the form of gasoline and diesel fuels.

Table 4. Canada's energy demand by sector in 2020. (Data Source: [130]).

Sector	Percent
Industrial	53
Transportation	20
Residential	14
Commercial	13

In the residential and commercial sectors, energy is primarily used for heating, specifically for space and water heating, due to Canada's cold climate [131]. Electricity, natural gas, and heating oil are the primary energy sources for these sectors. In recent years, electricity demand has remained relatively stable, while natural gas use has grown due to its affordability and efficiency.

Provinces vary in their reliance on fossil fuels. For example, Alberta and Saskatchewan are heavily dependent on oil and gas, whereas Quebec and British Columbia utilize more hydroelectricity. This regional variation shapes provincial policies and public attitudes toward energy development [125].

Over the past two decades, energy intensity (energy use per unit of GDP) in Canada has improved, reflecting gains in energy efficiency [106]. Federal and provincial programs promoting building retrofits, appliance standards, electric vehicle adoption, and industrial efficiency have helped slow demand growth. However, population growth and economic development continue to exert upward pressure. Electrification of heating and transportation is expected to increase electricity demand in the coming decades.

Canada's energy demand reflects both its natural resource wealth and its ambitions for a cleaner, more sustainable future. While the country faces challenges in aligning high energy consumption with climate targets, it also has the tools and opportunities to lead

in the global renewable energy transition. Although energy use has both positive and negative aspects, in all its sectors, energy intensity continues to improve (Table 5). Strategic investments in clean technology, infrastructure, and policy will be essential to meeting future energy needs while reducing environmental impact [120].

Table 5. Average percentage change in energy use and energy intensity in different sectors, average of 2000–2022 (Data Source: [103]).

	Energy Use	Energy Intensity
Residential	+6	−30
Commercial	+21	−5
Passenger Transport	−14	−17
Freight Transport	+24	−7
Industrial [forestry, mining, manufacturing, construction]	+21	−3
Industrial [without upstream mining]	−15	−29

3.2.2. Commodity Markets and Macroeconomic Interdependencies

Canada's energy commodity exports create profound macroeconomic interdependencies that both support and constrain economic performance. Energy commodity exports contributed $169.8 billion to GDP in 2024 (21.7% of goods exports). Still, interprovincial disparities create structural conflicts: Alberta's energy-driven economy versus the eastern provinces, which face manufacturing competitiveness challenges from CAD appreciation driven by energy exports—classic Dutch Disease dynamics [121,132]. When global oil prices fluctuate between $70 and $ 90 per barrel WTI, Canadian producers maintain relatively stable revenue streams through long-term contracts, pipeline commitments, and proximity to US Gulf Coast refineries, providing substantial insulation from global commodity price volatility compared to import-dependent economies like Bangladesh [22,133].

However, this price stability paradoxically reduces the competitiveness of renewable energy in the short term. Canada's $30 billion CAD in annual fossil fuel subsidies (2024) keep conventional energy artificially cheap relative to clean alternatives, despite a carbon pricing of $80 per ton of CO_2 [130,134]. Subsidy components include $21 billion for Trans Mountain Pipeline federal ownership and financing, $7.5 billion from Export Development Canada for LNG and oil sands projects, and $2.4 billion for carbon capture and storage (CCS) projects—effectively reducing producer costs and stabilizing domestic commodity prices at significant fiscal expense [133]. These subsidies persist despite G20 commitments to phase out "inefficient" fossil fuel subsidies by 2025, reflecting regional political economic pressures from Alberta and Saskatchewan, where the energy sector contributes over 150,000 jobs and substantial provincial revenues [135].

Electricity trade with the United States reveals additional commodity market interdependencies: Canada exported 45.9 TWh while importing 19.2 TWh in 2023, resulting in a net export value of $3.1 billion CAD [122]. These cross-border flows necessitate regulatory coordination and impose constraints on unilateral Canadian energy policy, particularly for provinces with significant export dependencies, such as Quebec's hydroelectricity to New England and Manitoba's exports to the US Midwest [125].

3.2.3. Environmental Concerns and Conflicts

Canada, known for its vast natural landscapes and abundant resources, faces growing environmental concerns that reflect the tension between economic development and ecological protection. As a developed country with a resource-based economy, Canada faces

complex environmental challenges, including climate change, biodiversity loss, Indigenous land rights, and industrial pollution. These challenges often give rise to conflicts between governments, industries, Indigenous communities, environmental groups, and the public. Nonetheless, Canada has the highest environmental performance index among G7 countries, indicating that it has the highest energy self-sufficiency, economic development, and environmental performance potential [136].

Canada is one of the world's highest per capita greenhouse gas (GHG) emitters, primarily due to its reliance on fossil fuels for energy and transportation. The oil sands in Alberta are a significant contributor to national emissions, and although the country has set ambitious targets (reaching net-zero emissions by 2050), progress toward this goal remains slow. Increasing wildfire activity, extreme weather events, and melting permafrost are visible consequences of climate change across the country.

Canada has some of the world's most extensive intact forests, but logging, particularly in provinces such as British Columbia and Quebec, has raised concerns about habitat loss and declining biodiversity. Old-growth forests, which are crucial for carbon storage and species protection, are being cut at unsustainable rates in certain regions, resulting in public protests and legal challenges [137].

Industrial activities, including mining and oil and gas extraction, have caused significant water contamination in certain areas [138,139]. For example, tailings ponds from oil sands operations pose long-term risks to surrounding ecosystems and communities [140]. Agricultural runoff and urban wastewater also contribute to water quality issues in lakes and rivers, including Lake Winnipeg and the Great Lakes [141].

One of the most significant environmental conflicts in Canada involves the rights of Indigenous peoples to their traditional lands. Many natural resource projects—including pipelines, mining operations, and logging—occur on unceded or contested Indigenous territory. While some Indigenous communities support development for economic reasons, others oppose it due to environmental and cultural concerns [142]. Major pipeline projects such as the Trans Mountain Expansion (TMX) and Coastal GasLink have sparked nationwide debates [143,144]. Proponents argue that these projects are essential for job creation and energy security, while opponents point to the risks of oil spills, increased emissions, and violations of Indigenous consent. Protests and legal actions have delayed several such projects, underlining the deep divisions they cause. Environmentalists and some First Nations oppose the destruction of ancient forests, arguing that conservation should take priority over short-term economic gain [145].

Balancing economic interests with ecological sustainability is no easy task, but it is essential for Canada's long-term health and global climate commitments. Canada's environmental concerns and conflicts reflect the country's complex relationship with its natural environment. While it benefits from immense ecological wealth, it also faces significant pressures from development, climate change, and political divisions. Addressing these challenges requires collaboration across sectors and a commitment to justice, sustainability, and respect for nature, as well as the rights of Indigenous peoples.

Commodity Market, Political Economy, and Transition Barriers: The political economy conflicts surrounding Canada's energy infrastructure highlight how commodity market dependencies create barriers to renewable energy transition. The $34.2 billion Trans Mountain Pipeline investment represents the most significant federal energy infrastructure commitment in decades, signaling continued prioritization of fossil fuel commodity export capacity despite net-zero 2050 commitments [122,123]. This juxtaposition—$30 billion in fossil fuel subsidies alongside $35 billion in clean energy investment in 2024—illustrates political economy tensions between regional economic dependencies and national climate commitments [134,146].

Canada attracted $35 billion USD in clean energy investment in 2024, ranking 8th globally, facilitated by Investment Tax Credits offering 15–30 percent for renewable generation and storage, 30 percent for clean technology manufacturing, and 37.5–60 percent for CCUS projects [103,146]. The Canada Growth Fund ($15 billion capitalization) and Infrastructure Bank commitments represent innovative public financing approaches. However, renewable procurement momentum slowed dramatically in Alberta: only 50 MW of new wind/solar deals through August 2024, down from 1000 MW in 2023, following provincial approval moratoriums [147]. This demonstrates how subnational political control over commodity resources fragments national energy markets and hinders the transition to renewable energy, despite the presence of federal financing mechanisms.

The energy sector's contribution of 10.3 percent of GDP, 697,000 jobs, and the dependence of provincial economies (Alberta and Saskatchewan) on commodity revenues generate political-economy resistance that fragments national policy coherence [103,121]. Managing the decline of a sector that contributes $199 billion in export earnings requires coordinating energy-sector restructuring with broader economic diversification, leveraging energy revenues to finance clean technology industries that can replace commodity export earnings [103,132].

3.3. Significance of Renewable Energy Transition

Transitioning to renewable energy is a goal for many government policies; however, significant investment is required to ensure a smooth change [48]. According to Stringer and Joanis [148], previous research has demonstrated that the renewable energy transition is feasible at the national scale in Canada; however, it may not be equally feasible across provinces. The transition to renewable energy sources in Saskatchewan, focusing on a framework known as Strategic Environmental Assessment (SEA) is used to explore the risks, capacities, and challenges that exist in certain institutions and governance; there are opportunities to determine not only the energy security concerns but also implement distributed generation and address the economic impact that may occur when transitioning away from a fossil-fueled run economy [149]. Results have shown that there needs to be clear transition goals and objectives, along with strategies and tools to implement them, and, most importantly, a complete commitment to these objectives [149]. They further state that clarity and responsibility are needed to ensure proper implementation and to manage complexity when creating a new assessment for transition-based SEA.

Climate change, specifically CO_2 emissions, is a significant global concern because it impacts people, resources, and critical environmental systems [150]. Global leaders are implementing various energy policies to reduce emissions, promote economic development, and ensure environmental sustainability [150]. Canada is a country that heavily relies on grey energy sources such as fossil fuels [151]. Canada produces 17.7 million tons of carbon emissions, ranking 34th in environmental performance [150]. In fact, as of 2020, Canada's electric power system accounted for 9 percent of Canada's Greenhouse gas (GHG) emissions, of which 53 percent came from Alberta alone [152].

Canada, a nation with abundant fossil fuel reserves, faces a critical juncture in its energy sector, particularly given its commitment to achieving net-zero emissions across the economy by 2050 [153]. While currently a leading producer of hydropower, diversifying its energy mix beyond non-renewable sources is essential. The country's energy supply is dominated by non-renewable sources, with fossil fuels accounting for 75 percent of total primary energy production in 2022 [126]. However, the adverse environmental impacts of fossil fuel combustion, including greenhouse gas emissions and air pollution, pose a significant threat to Canada's efforts to mitigate climate change and meet its commitments under the Paris Agreement. The Intergovernmental Panel on Climate Change [154] emphasized the need for a rapid transition to renewable energy sources to limit global warming

to 1.5 °C above pre-industrial levels. Canada has substantial renewable energy potential, with the Canadian Renewable Energy Association [155] estimating that the country could generate up to 64 percent of its electricity from renewable sources by 2050. Hydroelectricity already accounts for 60 percent of Canada's electricity generation, while other renewables contribute only 6.2 percent [156]. Transitioning to renewable energy sources, such as wind and solar, offers a compelling solution. These resources are abundant in Canada, with wind and solar capacity experiencing significant growth [103,157]. By embracing this modification to renewables, Canada can enhance its energy security, mitigate the impacts of climate change, and unlock new economic opportunities associated with renewable energy technologies.

Commodity Market Policy and Transition Barriers: Canada's transition to renewable energy is hindered by commodity market dynamics that continue to favor fossil fuels, despite the country's substantial renewable energy potential. A $30 billion annual subsidy regime keeps conventional energy artificially inexpensive, creating a policy paradox: while carbon taxes aim to internalize environmental costs, subsidies externalize production costs, weakening the price signals needed to spur clean energy investment [133,158]. Although carbon pricing reached $80 per ton of CO_2 in 2024 and is set to increase to $170 by 2030, its effectiveness is undermined by ongoing fiscal supports, which erode the relative cost advantage of renewables [159].

Canada's domestic fossil fuel production offers price stability that, paradoxically, dampens short-term incentives to transition—especially compared to import-reliant economies. Long-term contracts and proximity to U.S. markets buffer Canadian producers from global oil price volatility, reducing immediate economic pressures for change [22]. Yet, this stability conceals long-term risks: a decline in global fossil fuel demand could render over $150 billion in oil sands investments stranded. At the same time, continued reliance on commodity cycles reinforces Dutch Disease effects that limit manufacturing competitiveness [131].

Despite these barriers, Canada holds significant advantages for renewable deployment. With 60 percent of electricity already sourced from hydropower, the country possesses a clean energy base that few nations can match. Clean energy investments reached $35 billion in 2024 yet remain concentrated in supportive provinces—Ontario and Quebec account for over 70 percent of wind and solar capacity, while Alberta's momentum stalled following recent policy reversals [146,160].

However, to counter these regional disparities and accelerate the renewable energy transition beyond simple resource availability, Canada is increasingly deploying targeted technological innovations and market mechanisms. The federal Smart Grid Program has played a key role in modernizing grid infrastructure, funding utility-scale pilots that integrate variable renewable energy sources with advanced grid automation [161]. The rapid scaling of energy storage complements this technological push, a critical enabler for grid stability in a net-zero future; notably, the Oneida Energy Storage project (250 MW) in Ontario represents a shift from planning to commercial execution, supported by the province's historic procurement of 2.5 GW of storage capacity [162]. On the market side, the government has introduced the Clean Technology Investment Tax Credit (ITC) to actively de-risk private capital and lower the levelized cost of storage and clean energy technologies [163]. These mechanisms are designed to overcome the previously identified infrastructure limitations, ensuring that the market, rather than just policy mandates, drives the deployment of smart grids and storage solutions.

The impacts of the renewable energy transition on marginalized individuals and communities can be complex and uneven. Sovacool et al. [164] identified four dimensions of injustice in the renewable energy transition: distributive justice (costs and benefits), procedural justice (due process), cosmopolitan justice (global externalities), and recognition

justice (concerns for vulnerable groups). The renewable energy transition can have both positive and negative effects on the social, economic, and environmental aspects of communities, including indigenous peoples, which are shaped by history, treaty rights, geography, and existing inequalities. Many renewable energy projects, such as hydroelectricity projects, are in rural areas or on Indigenous lands, where individuals often have limited control or participation in decision-making, thereby violating procedural justice [165,166]. Indigenous people often bear the risks and challenges associated with many projects but receive little benefit, a violation of distributive and recognition justice [167,168]. In some renewable energy projects in Canada, Indigenous ownership can reach up to 50 percent, marking a promising step toward more equitable and just participation and toward improving energy justice [169]. Some Indigenous communities have started their own renewable energy production facilities [170]. Some Indigenous communities have begun developing renewable energy sources in their Territories to break free from colonial ties, move towards energy autonomy, establish more reliable energy systems, and reap the long-term financial benefits of clean energy [171]. Unfortunately, such cases are scarce, as defending the rights of all Indigenous people is complex due to the vagueness and ambiguity surrounding Indigenous national sovereignty and self-determination [168,172].

The global shift toward renewable energy cost competitiveness presents a strategic opportunity that Canada has yet to fully capitalize on. In 2023, 81 percent of new global renewable capacity produced electricity at a lower cost than its fossil counterparts, rising to 91 percent in 2024 [12,18]. Global levelized costs of electricity (LCOE) declined by 12 percent for solar PV, 7 percent for offshore wind, and 3 percent for onshore wind [17]. As renewables increasingly outcompete fossil fuels on cost alone, Canada's renewable energy transition hinges less on technological capacity and more on aligning market institutions such as subsidies, carbon pricing, and investment frameworks with its climate ambitions [173].

3.3.1. Solar Energy

Canada, known for its vast landscapes and diverse energy resources, is increasingly turning to renewable energy to meet its environmental and economic goals. Among these renewables, solar energy is gaining momentum as a clean, sustainable, and accessible source of power [153]. Solar energy installations in Canada continued to increase until 2015, after which they slowed down, but reached a peak in 2021 (Figure 14). From 2023 to 2024, solar energy production in Canada increased by 8.2 percent [22].

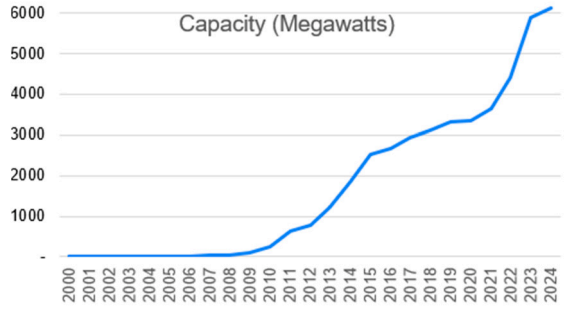


Figure 14. Solar power capacity in Canada. (Data Source: [21,22]).

Although Canada is not the sunniest country in the world, its advancing technology, declining costs, and growing climate awareness have positioned solar energy as a key player in the country's energy transition, and production is expected to continue to increase [174]. British Columbia aspires to have net-zero energy by 2032 [175]. Canada has certain advantages when it comes to solar energy, as it is abundant and has significant solar potential in most of the southern part of the country and in the western part of Prince

Edward Island [176]. There are over 43,000 solar photovoltaic systems across Canada that supply electricity to commercial, residential, and industrial rooftop areas [176].

3.3.2. Wind Energy

Wind energy is one of the fastest-growing sources of renewable electricity in Canada. With its vast open landscapes and strong wind resources, Canada is well-positioned to harness wind power to generate clean, reliable energy. As global efforts to reduce carbon emissions intensify, wind energy is playing an increasingly important role in helping Canada transition to a low-carbon economy. Although annual installations vary, the cumulative total wind energy capacity continues to increase (Figure 15). From 2023 to 2024, wind energy in Canada grew at a rate of 8.2 percent [22].

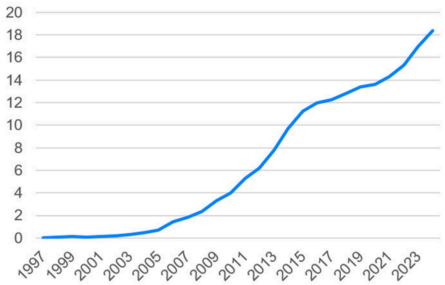


Figure 15. Wind power capacity (GWh)in Canada, 1997–2023 (Data Source: [21,22]).

Canada, the second-largest country in the world, spans a vast area with significant wind energy potential. Wind power systems are generally viable where annual average wind velocity exceeds 15 km/h [177]. Despite considerable seasonal variations in wind and temperature, particularly extreme winter temperatures, adequate wind resources exist throughout Canada for wind power generation. Socio-economic aspects play a significant role in implementing the wind energy production projects. The market size, remoteness, transmission facilities, grid connection, local acceptance, installation and maintenance costs, and energy storage capabilities are among the key challenges. An environmentally friendly form of energy production may not be acceptable to everyone [178].

In Canada, wind energy has experienced rapid growth since 2008, accounting for approximately 5 percent of the country's overall electricity generation [179,180]. Canada, the second-largest country in the world, has a vast landmass and varying capacities across its regions. Ontario and Quebec together produce over 66 percent of Canada's total wind energy (Figure 16). However, one small province, Prince Edward Island, produces over 95 percent of its electricity from wind.

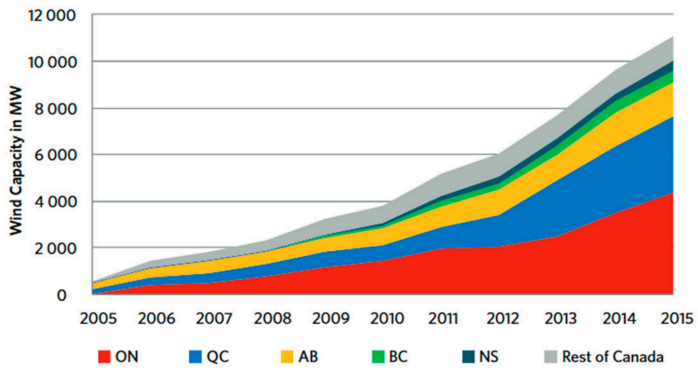


Figure 16. Wind energy capacity (megawatts) in Canada—a breakdown by provinces (Source: [125] used with permission).

In Canada, there is potential for a continuous increase in wind electricity generation. Canada's geography, especially the Prairies and coastal regions, offers consistent and powerful wind currents that are ideal for large-scale wind farms [181]. The four principal advantages of wind energy are: clean and renewable; abundant and sustainable; low operating costs; job creation; and economic growth. However, despite these advantages, wind energy has several issues, including intermittency, impact on wildfires and landscapes, community composition, competition with hydroelectricity, and transmission infrastructure [182]. The federal government has played a significant role in promoting wind energy through various programs. Examples include feed-in tariffs and renewable energy targets in Ontario, carbon pricing across Canada, green infrastructure funding, and Indigenous partnerships [183].

The future of wind energy in Canada is promising. With global and domestic pressure to reduce emissions, wind power is expected to expand rapidly. According to the Canadian Renewable Energy Association [155], wind and solar together could make up 30–35 percent of Canada's electricity by 2050.

3.3.3. Biomass

Biomass energy refers to the use of organic matter, such as wood chips, pellets, crop waste, and even animal manure, to generate heat, electricity, or transportation fuels. Biomass can be burned directly, converted into biogas, or processed into liquid biofuels such as ethanol and biodiesel. Biomass energy is a vital yet often underappreciated component of Canada's renewable energy portfolio. Derived from organic materials such as wood, agricultural residues, and municipal waste, biomass provides a sustainable means of producing electricity, heat, and biofuels. In a country as rich in forests and agricultural land as Canada, biomass presents a unique opportunity to support rural economies, reduce waste, and contribute to national climate goals [184].

Unlike fossil fuels, biomass is renewable, as new crops or forests can regrow to replace what is used. While burning biomass releases carbon dioxide, the emissions are generally offset by the carbon absorbed by the plants during their growth, making the process carbon-neutral when sustainably managed.

Canada is one of the world's leading producers and consumers of biomass energy, primarily due to its extensive forest sector (Figure 17). Canada is investing in advanced biofuels and biochemical technologies to produce cleaner alternatives for aviation, shipping, and heavy industries. It is expected to remain a crucial component of Canada's clean energy strategy, particularly in rural, remote, and industrial settings. With improved efficiency, emissions controls, and sustainable sourcing, biomass can complement other renewable energy sources, such as wind, solar, and hydro.

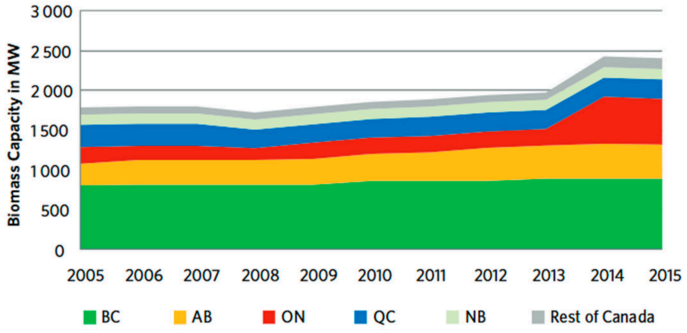


Figure 17. Biomass energy capacity (megawatt) in Canada—a breakdown by provinces (Source: [125]. Used with permission).

3.3.4. Hydro

Hydroelectricity, or hydro energy, is the backbone of Canada's electricity system. Thanks to its abundant rivers, lakes, and elevation changes, Canada has become one of the world's largest producers of hydroelectric power (Table 1). As a clean, renewable, and reliable energy source, hydro energy plays a key role in helping Canada reduce greenhouse gas emissions and transition to a sustainable energy future. Canada is the second-largest producer of hydroelectricity in the world, after China. As of 2024, over 60 percent of Canada's electricity comes from hydro power, making it the dominant source of renewable energy in the country [184]. Among the Canadian provinces, Quebec and British Columbia are home to massive hydropower projects. Manitoba, Newfoundland, and Labrador also rely heavily on hydro. Nonetheless, the production capacity remains relatively stable, with a moderate increase (Figures 18 and 19).

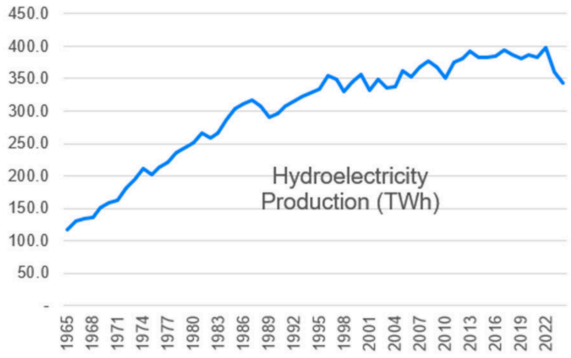


Figure 18. Hydroelectricity production in Canada (Data Source: [21,22]).

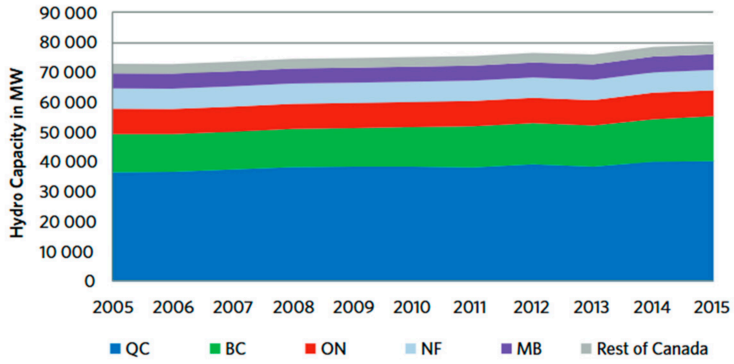


Figure 19. Hydroelectricity production (megawatt) in Canada—a breakdown by provinces (Source: [125]. Used with permission).

Canada's hydroelectricity projects are aging and face challenges from various fronts, including ecosystem disruptions, indigenous land claims, greenhouse gas emissions, and high maintenance costs. Nonetheless, hydro will remain a cornerstone of Canada's energy system, but future projects are expected to focus more on community partnerships, environmental sustainability, and respect for Indigenous rights.

Hydro energy has powered Canada for over a century and remains central to its clean energy leadership. With its ability to provide large-scale, low-emission, and reliable electricity, hydro plays a key role in meeting national climate goals. However, to maintain public trust and sustainability, future hydro development must be balanced with ecological protection and meaningful Indigenous engagement. By doing so, Canada can continue to lead the world in clean, responsible energy production.

3.3.5. Geothermal

In Canada, geothermal energy remains underdeveloped, despite the country's vast geothermal resources. As Canada seeks to reduce emissions and diversify its renewable energy mix, geothermal energy presents a promising, though challenging, opportunity [185].

Geothermal energy is derived from the natural heat of the Earth's interior. It can be accessed in several ways: (1) shallow geothermal systems (also called ground-source heat pumps) for residential and commercial heating and cooling; (2) deep geothermal systems for producing electricity by using hot water or steam to drive turbines and (3) direct-use applications, such as heating greenhouses, fish farms, or industrial facilities [185,186]. Geothermal energy is a reliable, renewable source that has a very low environmental footprint when developed responsibly. Canada has significant geothermal potential—especially in British Columbia, Alberta, Yukon, and Saskatchewan [187,188]. Increased interest in low-carbon heating systems, as part of Canada's push for net-zero emissions by 2050, could further boost demand for geothermal heating in urban and suburban areas [185].

Geothermal energy in Canada is still in its early stages, but its future looks promising [189]. As technology improves, costs decrease, and climate policies become more ambitious, geothermal is expected to play a supporting role in Canada's clean energy transition. Particularly in provinces like Saskatchewan and Alberta, geothermal energy can help repurpose oil and gas expertise, create new jobs, and decarbonize heat and electricity [188].

Though underutilized, geothermal energy represents a robust and sustainable resource beneath Canada's surface. With the right mix of investment, research, and policy support, geothermal could help Canada achieve its clean energy goals while providing reliable power and heating—especially in remote and resource-rich regions. Unlocking this potential will require collaboration between governments, Indigenous communities, industry, and researchers.

3.3.6. Tidal Energy

As the world moves toward cleaner energy solutions, tidal energy, the power generated from the natural rise and fall of ocean tides, offers a predictable and sustainable source of renewable electricity. With its vast coastlines and strong tidal currents, Canada is uniquely positioned to become a global leader in tidal power [190–193]. While the technology is still emerging, it holds great promise for contributing to Canada's clean energy goals, especially in coastal and remote communities.

Tidal energy harnesses the gravitational forces of the moon and sun, which create the daily movement of tides in oceans and bays. This energy can be captured using several technologies, including (1) tidal stream turbines—underwater turbines that operate like underwater windmills in fast-moving tidal currents, (2) tidal barrages—dams built across tidal estuaries that trap water at high tide and release it through turbines, and (3) tidal lagoons—man-made enclosures that work similarly to barrages, but with potentially less environmental disruption [89].

Unlike wind and solar, tidal energy is highly predictable, making it a reliable option for enhancing grid stability and supporting long-term planning. Canada is home to one of the most powerful tidal zones in the world: the Bay of Fundy, located between Nova Scotia and New Brunswick. This bay experiences tidal ranges of up to 16 m, the highest on Earth [193]. Tidal energy has not yet been widely commercialized in Canada, and the number of operational projects remains relatively small [190].

Tidal energy in Canada is still in the early stages of commercial development, but its long-term potential is substantial. As technology improves and costs fall, tidal power could play a complementary role alongside wind, solar, and hydro in Canada's renewable energy mix. For coastal provinces like Nova Scotia and British Columbia, tidal energy

offers a unique opportunity to generate clean power while supporting local economies and Indigenous energy sovereignty [192].

3.3.7. Nuclear Energy

Nuclear energy has been a cornerstone of Canada's electricity system for over 50 years. As the country seeks to decarbonize its energy grid and meet its climate targets, nuclear power, particularly with the emergence of new technologies like small modular reactors (SMRs), is receiving renewed attention [194]. With a strong domestic industry, an established safety record, and significant uranium resources, Canada is the sixth-largest producer of nuclear energy, accounting for approximately 4% of the world's nuclear energy production [194]. The largest nuclear energy-producing and consuming countries are the USA, China, France, Russia, and South Korea (Figure 20).

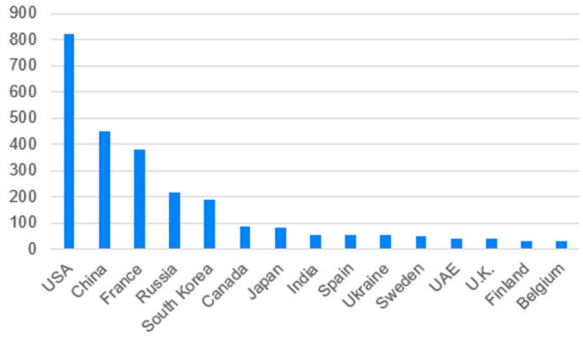


Figure 20. Leading countries in nuclear energy consumption (TWh) worldwide in 2024. (Data Source: [195]).

Canada began developing nuclear technology in the 1940s and launched its first commercial nuclear power station in the early 1970s [196,197]. Today, nuclear energy accounts for approximately 15 percent of Canada's electricity, with over 60 percent of this energy used in Ontario, where it serves as a primary power source. Canada operates 19 nuclear reactors, primarily in Ontario, with additional reactors located in New Brunswick and Quebec [198]. It is the birthplace of the CANDU reactor (CANada Deuterium Uranium), a unique technology that uses natural (unenriched) uranium and heavy water. Canada is also one of the world's top producers and exporters of uranium, with significant mining operations in Saskatchewan [197,198]. Canada's nuclear energy production has remained stable in the last two decades (Figure 21) [199,200].

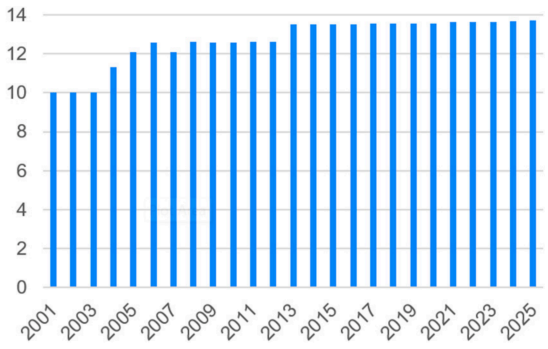


Figure 21. Operable nuclear power capacity (TWe) in Canada from 2000 to 2024 (Data Source: [201]).

Ontario and New Brunswick are the only two provinces in Canada that operate nuclear power plants. Nuclear generation accounted for 58 percent of Ontario's total generated electricity in 2016, and 30 percent of the total in New Brunswick [194]. In both

provinces, it was the largest source of electricity generation. From 2005 to 2016, total nuclear generation in Canada increased by 10 percent. No new nuclear facilities were built during this time. Refurbishments and improvements at existing nuclear facilities in Ontario and New Brunswick were responsible for the increase. However, the overall capacity remains more or less the same in recent years (Figure 21) due to rotational maintenance.

Nuclear energy is a vital part of Canada's clean energy strategy [202]. With its low-carbon footprint, reliable output, and potential for innovation through SMRs, nuclear power can help Canada meet its climate commitments while supporting economic growth. However, its future depends on addressing public concerns, managing waste responsibly, and ensuring safe and cost-effective deployment. If implemented correctly, nuclear energy will continue to be a robust and sustainable contributor to Canada's energy future [199–202].

3.4. Energy Policy in Canada

Canada's energy policy framework represents a complex governance and public administration challenge, fundamentally shaped by two persistent tensions. First, there is an ongoing competition between economic development tied to resource extraction and environmental protection, which mandates rapid decarbonization. More specifically, it has vast fossil fuel reserves, with its economy heavily dependent on this sector. Simultaneously, it always positioned itself internationally as a proponent of ambitious climate commitments, from its early ratification of the Kyoto Protocol to its more recent obligations under the Paris Agreement to achieve net-zero emissions by 2050 [203,204].

Second, the distribution of energy authority spans multiple levels of government, requiring sophisticated coordination among federal, provincial, territorial, and Indigenous authorities. This intricate constitutional division of powers creates systematic challenges for policy coordination, as energy-consuming provinces with larger populations can elect federal governments that favor consumers. In contrast, energy-producing provinces exercise constitutional authority over natural resources to resist such policies [205].

Recent policy developments provide crucial insights into these dynamics. The 2025 restructuring of federal carbon pricing, the completion of the Trans Mountain Pipeline expansion, and the finalization of the Clean Electricity Regulations demonstrate both the adaptive capacity and inherent limitations of Canada's federal system in managing the transition to renewable energy [134]. These developments reveal a pattern of policy effectiveness that varies dramatically across economic sectors, with notable success in decarbonizing electricity contrasting sharply with persistent challenges in reducing emissions from oil and gas.

Market mechanisms complement Canada's energy policy. Carbon pricing, clean-fuel standards, and innovation-funding programs provide clear price signals that accelerate private investment in clean technologies [206]. The synergy between technological readiness and market liberalization distinguishes Canada's transition trajectory from that of energy-scarce economies such as Bangladesh, where institutional and financial barriers remain pronounced.

3.4.1. Energy-Environment Competition

Policy Architecture and Constitutional Framework:

Canada's contemporary climate policy framework is anchored by the Canadian Net-Zero Emissions Accountability Act (2021), which establishes legally binding interim targets, including a 40–45 percent reduction below 2005 levels by 2030 and net-zero emissions by 2050. This legislation represents a significant institutional innovation, establishing independent oversight mechanisms through the Net-Zero Advisory Body and requiring comprehensive emissions reduction plans with mandatory progress reporting [207].

The federal carbon pricing system underwent fundamental restructuring in March 2025, representing a significant departure from the comprehensive approach implemented since 2019 [158]. The government eliminated the consumer-facing fuel charge, effective 1 April 2025, by setting federal fuel charge rates to zero and removing the requirement for provinces and territories to maintain consumer-facing carbon pricing [159]. Prior to this restructuring, the system reached $80 per ton of CO_2 in 2024 and was scheduled to increase by $15 per ton annually, reaching $170 per ton by 2030 [159].

This policy shift reflects persistent implementation challenges that arise when federal environmental policies intersect with provincial constitutional authority and regional economic interests. The elimination of consumer-facing carbon pricing while maintaining industrial carbon pricing systems represents a strategic recalibration that prioritizes federal authority over large emitters while accommodating provincial resistance to broad-based carbon pricing. Nonetheless, Canada's energy sector remains robust in CO_2 production. The electricity production sector continues to outperform others, driven by increases in fossil fuel production and renewable electricity generation (Table 6).

Table 6. Sectoral Greenhouse Gas Emissions in Canada (Mt CO_2eq).

Economic Sector	2005	2023	Change 2005–2023 (%)
Oil and Gas	194.5	208.0	+6.9
Transportation	156.2	156.6	+0.3
Electricity	115.9	48.8	−57.9
heavy industry	86.8	78.3	−9.8
Buildings	82.3	82.7	+0.5
Total National	759.0	694.0	−8.6

Source: Greenhouse Gas Emissions data [207].

The Two-Track Pattern of Policy Effectiveness

The empirical evidence reveals stark differences in policy effectiveness across economic sectors, with emissions outcomes varying dramatically based on structural characteristics. Analysis of greenhouse gas emissions data demonstrates a clear pattern of policy impact across the Canadian economy.

The electricity sector achieved remarkable decarbonization, with emissions declining from 115.9 million tons of CO_2 equivalent in 2005 to 48.8 million tons of CO_2 equivalent in 2023, a decrease of nearly 58 percent. This transformation was primarily driven by Ontario's provincially mandated phase-out of coal, which resulted in the elimination of coal-fired electricity generation between 2005 and 2014 [208]. Success reflects the structural advantages of government intervention in sectors dominated by Crown corporations and regulated utilities, which are directly susceptible to government mandates (Table 7).

Table 7. Renewable Energy Capacity Growth in Canada.

Technology	2019 Capacity (GW)	2014 Capacity (GW)	Growth (%)
Wind	13.4	18.0	+34.3
Solar (Utility-scale)	2.1	4.0	+90.5
Solar (On-site)	0.5	1.0	+100.0
Energy Storage	0.11	0.33	+200.0

Source: [160].

Conversely, the oil and gas sectors present fundamentally different implementation challenges. Emissions from this sector increased from 194.5 million tons of CO_2 equivalent in 2005 to 208.0 million tons of CO_2 equivalent in 2023, representing a 6.9 percent increase despite the implementation of comprehensive federal climate policies. The transportation sector exhibited similar resistance to policy intervention, with emissions remaining relatively stable at approximately 157 million metric tons of CO_2 equivalent in 2023 [207].

This differential effectiveness reflects distinct characteristics of economic sectors and their susceptibility to government intervention. Electricity systems, dominated by provincial utilities and Crown corporations, present clear regulatory pathways for government action. Oil and gas production, characterized by private ownership, global market integration, and significant regional economic dependence, presents far more complex implementation challenges that resist direct government control [205].

Renewable Energy Policy Implementation

Federal renewable energy policies have achieved substantial deployment outcomes, though implementation has varied significantly across technologies and regions. The Clean Technology Investment Tax Credit offers a 30 percent refundable tax credit for renewable technologies implemented until 2034, while the Clean Electricity Investment Tax Credit provides additional support for generation projects that meet emission intensity thresholds of no greater than 65 tons of CO_2 per gigawatt-hour [103].

Provincial approaches to renewable energy policy implementation reveal significant variation in effectiveness. Quebec's renewable energy auction system has achieved some of the lowest prices for wind and solar power in North America, demonstrating successful policy design that leverages competitive market mechanisms. Alberta's Renewable Electricity Program facilitated significant wind and solar development through long-term contracts, though policy momentum has varied with changes in provincial government priorities [209].

The Canada Infrastructure Bank's commitment of over $3 billion to clean energy projects represents an innovative approach to addressing private sector investment gaps, though implementation has been slower than initially anticipated. This experience illustrates the broader challenges of translating federal policy intentions into operational outcomes within Canada's complex institutional environment [210].

3.4.2. Interjurisdictional Conflict and Cooperation

Constitutional Constraints and Federal-Provincial Dynamics

Canada's federal system presents fundamental implementation challenges for a coherent energy policy, stemming from the constitutional division of powers outlined in sections 91 and 92 of the Constitution Act, 1867. Provinces maintain constitutional jurisdiction over natural resources under Section 92A, while the federal government holds authority over interprovincial trade, international commerce, and matters of national concern. This division creates overlapping jurisdictions and institutional friction, which significantly complicates policy implementation [128].

The constitutional framework enables energy-consuming provinces with larger populations to elect federal governments that favor energy consumers. In contrast, energy-producing provinces can exercise constitutional authority over natural resources to resist federal policies that may constrain development. This structural dynamic creates persistent implementation challenges, as federal climate policies must navigate provincial resistance from jurisdictions whose economies heavily depend on fossil fuel production [128,211,212].

Clean Electricity Regulations Implementation

The development and finalization of the Clean Electricity Regulations (CER) illustrate the complex negotiation processes required for implementing federal environmental policy within Canada's federal system. Initially proposed to require electricity systems

to achieve net-zero emissions by 2035 [213], these regulations exemplify the complexities of implementing federal environmental policy within Canada's federal system. The regulations faced significant opposition from several provinces, particularly Saskatchewan and Alberta [205,214].

The final regulations, enacted in December 2024, represent substantial federal accommodation to provincial concerns [213]. The emissions intensity limit was revised from the originally proposed 30 tons of CO_2 per gigawatt-hour to 65 tons, with additional flexibility through offset credits. The timeline for achieving net-zero was extended from 2035 to 2050, with emission restrictions not taking effect until 1 January 2035 [213].

Alberta's Electric System Operator concluded that the regulations pose significant risks to reliability and affordability, projecting $30 billion in additional costs and 35% higher wholesale electricity prices between 2035 and 2050. Saskatchewan has rejected the regulations as unconstitutional, while Alberta has announced its intention to launch a constitutional challenge [215].

Indigenous Rights and Energy Development

Indigenous consultation requirements, established through Supreme Court decisions and the United Nations Declaration on the Rights of Indigenous Peoples Act (2021), introduce additional layers of complexity in implementing energy projects [216]. The federal government's commitment to free, prior, and informed consent has significantly empowered Indigenous communities to influence decisions related to energy development. Yet, implementation remains challenging due to complex governance structures and varying community perspectives. The Energy Council of Canada acknowledges that the risks faced by Indigenous communities and individuals have been underappreciated and emphasizes this to bring it to the public's attention [217].

International Constraints and Policy Implementation

Canada's energy policy operates within international constraints that limit domestic policy flexibility and complicate implementation. However, the United States–Mexico–Canada Agreement (CUSMA) does not include energy provisions that affect Canadian policy options, particularly the proportionality clause, which requires Canada to maintain energy export levels to the United States during supply shortages, which was previously present in NAFTA [218].

Cross-border electricity trade relationships with the United States create both opportunities and constraints for policy implementation. Quebec exports significant hydroelectric power to New England, while Manitoba exports to the US Midwest, requiring regulatory coordination between Canadian and American authorities. These relationships create interdependencies that affect domestic energy policy choices and limit unilateral Canadian action.

The completion of the Trans Mountain Pipeline expansion in May 2024 highlights ongoing federal support for fossil fuel infrastructure, despite climate commitments. The project, which cost over $34.2 billion and increased capacity from 300,000 to 890,000 barrels per day, represents the most significant federal investment in energy infrastructure in decades [123]. This juxtaposition, namely federal financing of major hydrocarbon infrastructure alongside renewed commitments to net-zero, illustrates the deep structural contradictions that continue to define Canada's energy policy landscape.

Together, the evidence across Sections 3.4.1 and 3.4.2 reveals a policy architecture marked by impressive institutional sophistication but constrained by systemic fragmentation. It has achieved world-leading decarbonization in sectors under direct regulatory oversight, such as the electricity sector. However, entrenched provincial autonomy, fossil-fuel dependence, and uneven federal–provincial coordination continue to limit the scope and speed of its economy-wide renewable energy transition. This highlights that gover-

nance coherence, rather than technological capacity, remains the decisive factor in Canada's pathway to net zero.

The foregoing exposition of the energy situation in Bangladesh and Canada reveals that Bangladesh has limited potential, whereas Canada has substantial potential for a renewable energy transition. Nonetheless, both countries strive to move forward with more renewable energy production and use. Of course, the potential, policies, and discourse are expected to be different based on resource endowments and the policies and procedures followed. The underlying theory and assumption are that the trajectory of the renewable energy transition remains the same as it existed in the past.

4. Methodology

The methodology of this paper includes a literature review, secondary data collection, and statistical analysis. We conducted an extensive review of the literature to examine the energy situation in Canada and Bangladesh. Comprehensive database searches through the university library, which is connected to the consortium of libraries in the province. The university's library system has access to 333 databases covering all subject areas. For our specific areas, we used various relevant keywords and key phrases. A single keyword or key phrase can yield numerous outcomes, including both relevant and irrelevant documents. We refined the search using more appropriate keywords to obtain more targeted literature and then applied our judgment to determine the relevance of the selected literature. This type of literature search was a continuous process from the project's inception through its completion and the writing of the final draft.

The library system often documents peer-reviewed and other scholarly articles. However, for a comprehensive review of the renewable energy transition literature, we need to consider non-peer-reviewed sources, including government and private industry reports, government policy documents, and reports and publications from advocacy groups. We used Google search for soft literature, which yielded many unpublished but worthwhile literature on policies, procedures, and arguments. These include research reports, government documents, policy briefs, and other departmental publications. As this is an academic article, we have avoided biased and unscientific documents. Consequently, newspaper editorials, op-eds, and similar electronic publications, such as blog posts or social media posts (e.g., Facebook or Instagram), are excluded.

Energy data are typically annual and often exhibit long-term trends driven by economic growth, policy changes, technological advancements, and external factors such as GDP, population, and energy prices. We collected secondary data from several sources, including various issues of the Statistical Review of World Energy published by the Energy Institute [previously published by the British Petroleum (BP)], the International Energy Agency (IEA), the International Renewable Energy Association (IRENA), Statistics Canada, the Bangladesh Bureau of Statistics (BBS), Statista, and others. As most of the energy data we have used is annual, seasonality is minimal compared to monthly or daily data; however, autocorrelation, non-stationarity, and nonlinear patterns are standard. In this paper, we applied the ARIMA (Auto Regressive Integrated Moving Average), ETS (Error, Trend, Seasonality), and Prophet models to forecast energy production and consumption for the period from 2025 to 2035, based on historical data from 1965 to 2024. The spreadsheet was downloaded from the Energy Institute website https://www.energyinst.org/statistical-review/resources-and-data-downloads (accessed on 11 September 2025). Annual oil, coal, natural gas production and consumption, as well as nuclear, hydro, solar, and wind generation, from 1965 to 2024 for both Canada and Bangladesh were retrieved, where applicable. Only available historical data were used to fit the three univariate time series models, and forecasts were made for the period from

2025 to 2035. The three models were chosen for their flexibility, power, and convenience. The built-in R (R Studio, desktop version 2023.12.1+402) functions auto.arima() and ets() automatically pick the optimal models for us.

ARIMA models [219] forecast future values based on past observations, incorporating autoregressive (AR), differencing (I) for stationarity, and moving-average (MA) components. It is well known that ARIMA models are effective for modeling univariate nonstationary time series with trends and autocorrelation. The general ARIMA(p, d, q) model can be expressed as

$$\phi(B)(1-B)^d y_t = c + \theta(B)\varepsilon_t,$$

where

- $\phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_p B^p$ is the AR polynomial;
- $\theta(B) = 1 + \theta_1 B + \theta_2 B^2 + \cdots + \theta_q B^q$ is the MA polynomial;
- B is the backshift operator: $By_t = y_{t-1}$;
- $\varepsilon_t \sim N(0, \sigma^2)$ is white noise;
- d is the degree of differencing.

Alternatively, the ARIMA model can be expressed explicitly as

$$y_t{}' = c + \sum_{i=1}^{p} \phi_i y_{t-i}{}' + \sum_{j=1}^{q} \theta_j \varepsilon_{t-j} + \varepsilon_t$$

where $y_t{}' = (1-B)^d y_t$ is the differenced series. For annual data, parameters like (p, d, q) are tuned to capture trends without seasonal components.

The ETS model [220,221] is a generalized, state-space formulation of exponential smoothing. It provides a systematic way to model time series by combining: (1) error: additive (A) or multiplicative (M); (2) trend: none (N), additive (A), damped additive (Ad), multiplicative (M), or damped multiplicative (Md); (3) seasonality: none (N), additive (A), or multiplicative (M). It is a generalized, state-space formulation of exponential smoothing. Below are some popular ETS models.

1. The ETS (A, N, N) model is equivalent to Simple Exponential Smoothing (additive error, no trend, no seasonality). The observation equation is $y_t = \ell_{t-1} + \epsilon_t$ with the state (transition equation consisting of only the level component: $\ell_t = \ell_{t-1} + \alpha\epsilon_t$ where α ($0 \le \alpha \le 1$) is a smoothing parameter controlling how much weight is given to the most recent error.
2. ETS (A, A, N) corresponds to Holt's Linear Trend model (additive error, additive trend, no seasonality). The observation equation is $y_t = \ell_{t-1} + b_{t-1} + \epsilon_t$ with the state (transition) equations, i.e., level (smoothed value) and trend (slope) updates: $\ell_t = \ell_{t-1} + b_{t-1} + \alpha\epsilon_t$ and $b_t = b_{t-1} + \beta\epsilon_t$. Both α and β are smoothing parameters ($0 \le \alpha \le 1, 0 \le \beta \le 1$).
3. ETS (A, A, A) is equivalent to Holt–Winters' seasonal model with additive error (additive error, additive trend, and additive seasonality). The observation equation is $y_t = \ell_{t-1} + b_{t-1} + s_{t-m} + \varepsilon_t$ with level, trend and seasonal updates:

$$\ell_t = \ell_{t-1} + b_{t-1} + \alpha\epsilon_t, \;\; b_t = b_{t-1} + \beta\epsilon_t \text{ and } s_t = s_{t-m} + \gamma\varepsilon_t,$$

   where α, β and γ are smoothing parameters ($0 \le \alpha \le 1, 0 \le \beta \le 1, 0 \le \gamma \le 1$), and m is the seasonal period.
4. ETS (A, A, M) is mathematically equivalent to Holt–Winters' model with additive errors and multiplicative seasonality (additive error, additive trend, and multiplicative

seasonality). The observation equation is $y_t = (\ell_{t-1} + b_{t-1})s_{t-m} + \varepsilon_t$ with level, trend, and seasonal updates:

$$\ell_t = \ell_{t-1} + b_{t-1} + \alpha\frac{\varepsilon_t}{s_{t-m}}, b_t = b_{t-1} + \beta\frac{\varepsilon_t}{s_{t-m}} \text{ and } s_t = s_{t-m} + \gamma\frac{\varepsilon_t}{\ell_{t-1} + b_{t-1}},$$

where α, β and γ are smoothing parameters ($0 \le \alpha \le 1$, $0 \le \beta \le 1$, $0 \le \gamma \le 1$), and m is the seasonal period. All these parameters can be estimated using the maximum likelihood methods.

5. ETS (M, A, A) is mathematically equivalent to Holt–Winters' model with multiplicative errors and additive seasonality (multiplicative error, additive trend, and additive seasonality). The observation equation is $y_t = (\ell_{t-1} + b_{t-1} + s_{t-m})(1 + \varepsilon_t)$ with level, trend, and seasonal updates:

$$\begin{aligned}\ell_t &= \ell_{t-1} + b_{t-1} + \alpha(\ell_{t-1} + b_{t-1} + s_{t-m})\varepsilon_t,\\ b_t &= b_{t-1} + \beta(\ell_{t-1} + b_{t-1} + s_{t-m})\varepsilon_t \text{ and}\\ s_t &= s_{t-m} + \gamma(\ell_{t-1} + b_{t-1} + s_{t-m})\varepsilon_t,\end{aligned}$$

where α, β and γ are smoothing parameters ($0 \le \alpha \le 1$, $0 \le \beta \le 1$, $0 \le \gamma \le 1$), and m is the seasonal period.

For damped trend models, replace b_{t-1} with ϕb_{t-1} where $0 < \phi < 1$ is the damping parameter. The "ets()" function in the R package "forecast" (desktop version 2023.12.1+402) automatically identifies the best model by evaluating all possible combinations of error, trend, and seasonal components (up to 30 models) and selecting the one with the lowest information criterion (e.g., AICc).

The Prophet model [222], developed by Meta AI, is a time-series forecasting tool designed for robust, flexible modeling of time-series data that includes trends, seasonality, and holidays. Prophet is an additive model that decomposes a time series into: (1) trend: a piecewise linear or logistic growth curve to capture long-term changes; (2) seasonality: annual or multi-year cycles (if present); (3) holidays/events: user-defined impacts of specific events (e.g., policy changes); (4) exogenous regressors: external variables like GDP or oil prices. Bayesian methods estimate model parameters. While the Prophet model handles univariate series well, its accuracy improves with the inclusion of relevant external variables.

Mathematically, the Prophet model decomposes a time series as follows:

$$y(t) = g(t) + s(t) + h(t) + \varepsilon_t.$$

- $y(t)$: Observed value at time t.
- $g(t)$: Trend component (piecewise linear or logistic).

Piecewise Linear Trend (default):

$$g(t) = \left(k + \sum_{i:t_i<t} \delta_i\right)t + \left(m + \sum_{i:t_i<t} \gamma_i\right)$$

where k is the base growth rate, δ_i is the change in growth rate at the changepoint t_i, m is the base offset, γ_i is the offset adjustment for continuity.

Logistic Trend (for bounded exponential growth):

$$g(t) = \frac{C}{1 + \exp\left(-\left(k + \sum_{i:t_i<t} \delta_i\right)\left(t - \left(m + \sum_{i:t_i<t} \gamma_i\right)\right)\right)}$$

where C is the carrying capacity.

- $s(t)$: Seasonal component (yearly, weekly, etc.) is modelled with a Fourier series:

$$s(t) = \sum_{n=1}^{N} \left(a_n \cos\left(\frac{2\pi n t}{P}\right) + b_n \sin\left(\frac{2\pi n t}{P}\right) \right)$$

where P is the period (e.g., 365.25 for yearly, 7 for weekly), N is the number of Fourier terms. Multiple seasonalities (e.g., yearly, weekly) can be included.

- $h(t)$: Holiday component (optional) can be modelled as

$$h(t) = \sum_{i \in \text{holidays}} \kappa_i \cdot I(t \in D_i)$$

where κ_i is the effect of the holiday i and D_i is the date for the holiday i.

- ε_t: Additive error, assumed $N(0, \sigma^2)$.

The "prophet()" function in the R package "prophet" can be used to fit the Prophet model. Unlike "auto.arima()" and "ets()", which automatically select the best model by testing multiple parameter combinations, the Prophet model does not automatically switch to a different model class. Instead, it uses a single, flexible additive model framework that automatically tunes its parameters (e.g., trend flexibility, seasonality strength, and holiday effects) to fit the data. It achieves this through a Bayesian approach and optimization techniques. Users can further fine-tune the model by adjusting parameters (e.g., 'changepoint.prior.scale' to adjust trend flexibility) or by adding custom seasonality/holidays [223,224].

ARIMA, ETS, and Prophet are the most suitable and widely used univariate models for energy data, each with distinct strengths. ARIMA is a classic model that can handle stationarity through differencing. The auto.arima() function in R automatically determines the best order. ETS (Error, Trend, Seasonality) is effective for data with trends and seasonality, often outperforming ARIMA in such cases [225]. Prophet is excellent at capturing non-linear trends and changepoints (e.g., shale boom, renewable acceleration), though it may not always be the most accurate model. Muhlehner et al. [226] conclude, based on a comprehensive analysis, that each model has its distinct advantages and shortcomings.

ARIMA, ETS, and Prophet models are selected for their robust flexibility and powerful forecasting capabilities. Despite the absence of intra-year seasonality in annual data, these models effectively capture long-term trends through their distinct components. ARIMA leverages autoregressive and moving-average terms to model trends and dependencies; ETS employs exponential smoothing for trend forecasting; and Prophet uses piecewise linear trends with automatic changepoint detection. Each model's ability to adapt to trending patterns makes it well-suited for annual energy data, ensuring accurate and reliable forecasts. Details of the forecasting methods and results are in the Supplementary Materials.

5. Transition Potential—A Comparative Analysis

The world is seeking a transition to renewable energy, regardless of whether it is a developed or developing country, a rich or poor nation, a resource-rich or resource-poor region, or a northern or southern one. However, not all economies have the same or similar capability for moving from non-renewable to renewable energy. Challenges to the renewable energy transition have been addressed from several directions [227,228], as well as for specific regions or countries [229–233]. Fabra and Reguant [234,235], upon an extensive theoretical and practical analysis, find that the renewable energy transition is a balancing act. They identify that determining the most effective way of operationalizing

the transition is the most challenging. Finding a cost-effective policy option is neither necessary nor sufficient for energy transition; rather, the policy option must be feasible, fair, effective, and credible, which requires a balancing act [234,235]. Yang et al. [236] presented the external and connotative aspects of renewable energy transition, including its mechanisms and effects. They also explained the mechanisms, including technological innovation, market mechanisms, policy arrangements, and cultural factors. The ramifications are social, economic, and ecological effects [236]. Pereira et al. [13] compared the transition potential between developed and developing countries.

Transition from fossil fuel to renewable energy also depends on several market factors, i.e., (1) price dynamics, (2) trade flows, (3) investment patterns, (4) government supports, and (5) macroeconomic implications of fossil and renewable energy. However, the impacts of those factors are neither linear nor unidirectional. Fabra and Reguant [235], upon analyzing electricity price variability and renewable energy generation in six European countries [Germany, France, Poland, Slovakia, the Czech Republic, and Estonia], observed that the relationships are non-linear and country and period specific.

One of the most critical hurdles for transitioning to renewable energy was the higher cost. Given the same market price for electricity from fossil fuels and renewables, the latter is at a disadvantage, as the market price does not reflect its actual social value [237]. Nonetheless, renewable energy is becoming increasingly cost-competitive with technological advances. In 2023, 81 percent of renewable energy capacity additions resulted in cheaper electricity than fossil alternatives [17]. In a year, this figure jumped to 91 percent [18]. The global average levelized cost of electricity (LCOE) from solar PV decreased by 12 percent, while the LCOE for offshore wind and hydropower decreased by 7 percent, and the LCOE for onshore wind decreased by 3 percent [17]. Renewable energy reduces exposure to volatile fossil-fuel import bills, lowers average electricity system costs, and avoids the damaging impacts of high electricity prices on consumers and industry [17]. Energy price risk significantly influences the adoption of renewable energy, acting as both a driver and a potential inhibitor, depending on how it is perceived and managed. Changes in oil prices affect actual economic activity and employment [19]. Changes in oil prices or volatility had a limited impact on the economies [20]. The oil price shock did not affect the economic output of inflation in Nigeria [238].

In our case, as mentioned before, we compare the transition potential of two economies: one energy-rich, such as Canada, and the other energy-poor, like Bangladesh, to contribute to this literature.

5.1. Bangladesh—A Case of Limited Potential

As the global shift toward renewable energy intensifies in response to climate change, countries like Bangladesh face unique challenges. Despite growing awareness of environmental degradation and the urgent need to reduce greenhouse gas emissions, Bangladesh's transition to renewable energy remains limited in both scope and impact. Economic constraints, high population density, limited natural resources, and infrastructural deficiencies all contribute to the country's struggle to embrace a fully renewable future.

Bangladesh faces a significant challenge due to being one of the most densely populated countries in the world [239,240]. This poses a significant barrier to large-scale solar farms or wind turbine installations, which require vast tracts of land. Land is already under pressure from housing, agriculture, and industry, leaving little room for utility-scale renewable projects. Unlike countries with consistent wind patterns or large mountainous regions for hydroelectric projects, Bangladesh lacks the natural conditions for reliable wind and hydropower development. The flat deltaic topography and variable wind speeds make large-scale wind power inefficient and unfeasible in most areas.

Bangladesh is deficient in all three fossil fuels: coal, natural gas, and oil. It only has some natural gas. However, as a growing economy, it consumes all three fossil fuels. It is expected that the demand for consuming fossil fuels in Bangladesh will continue to grow (Figure 22; Appendix A Tables A1–A4). Although coal is the dirtiest fossil fuel, its consumption in Bangladesh is expected to increase, as forecasted by all three models: ARIMA, ETS, and Prophet models (Figure 22). Since the forecasts from all three models are consistent, we can rely on the estimates being robust. Upon out-of-sample validation (e.g., using data from 1965–2010 to fit the models and observations from 2011–2024 to evaluate goodness-of-fit), all models yield similar results. For brevity, we will not further elaborate on the minor differences among the models. The forecast details are in the Appendix A. Additionally, since all three models yield similar results, we have included only the ARIMA results for the renewable energy forecasts (Appendix A Table A5).

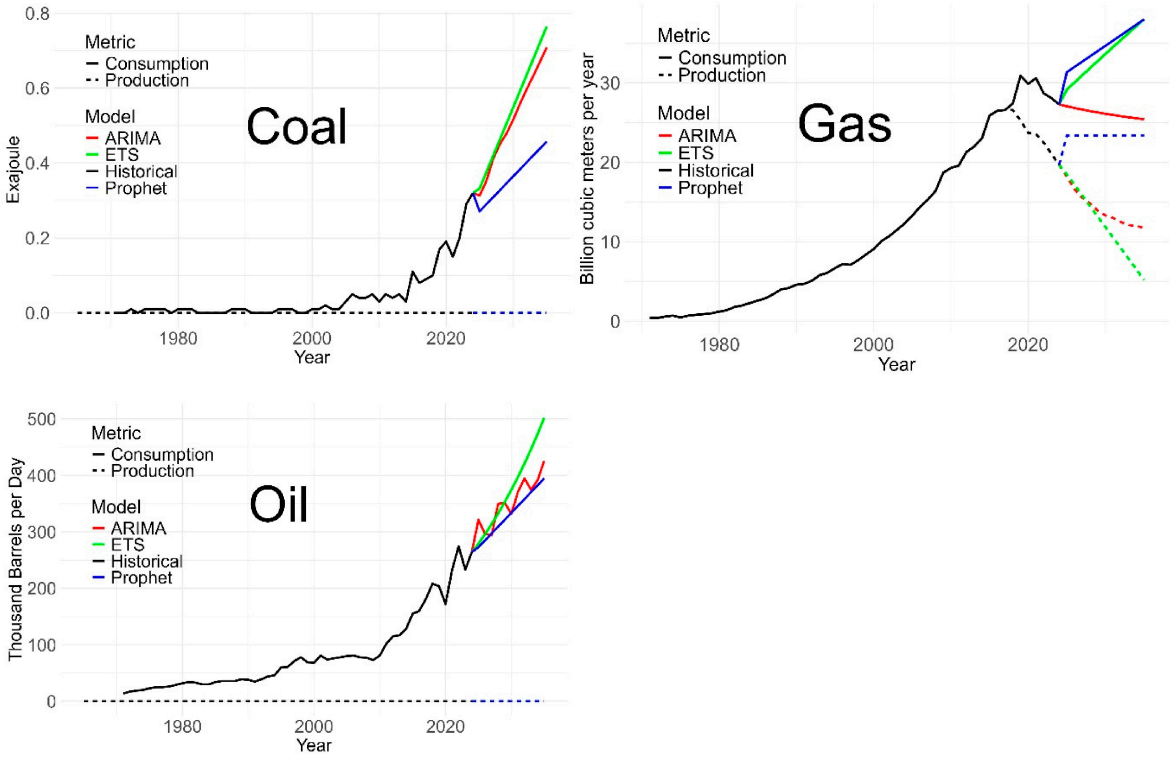


Figure 22. Coal, natural gas, and oil production (dashed line) and consumption (solid line) in Bangladesh, historical data and forecast 2025–2035. Different colors present different forecast methods. (Data source: [21,22]).

Historically, production and consumption of natural gas in Bangladesh were similar, as the country neither imported nor exported it. However, the reserve has started to decline, and production has followed suit. The country has begun increasing reliance on imported natural gas in the form of LNG. The forecast for natural gas production and consumption remains highly variable (Figure 22; Appendix A Table A3), as both sides contain substantial uncertainty. The future trend of natural gas production depends on future discoveries, and future consumption depends on both domestic production and imports. In recent years, Bangladesh has started importing LNG by establishing a floating regasification plant.

Figure 22 illustrates the increasing disparity between coal production and consumption in Bangladesh. Bangladesh lacks quality coal. The small amount it has [241] is of lower quality, but it imports a substantial amount of coal due to high energy demand. It produces a limited amount of coal from its Barapukuria coal mine in the north, whose economic and power-generation capacity is small. Much of the coal it uses is imported [241,242]. Recently,

Bangladesh commissioned a coal-fired power plant near the Sundarbans. Even though the claim is for using clean coal [coal dust] for a lower environmental footprint, reviews suggest otherwise. Samiullah et al. [243] report that coal-fired power plants can cause thermal pollution, chemical contaminants, acidification, habitat disruption, and endocrine disruptors through degraded water bodies and aquatic ecosystems, suggesting the need for rigorous monitoring and strict restrictions.

As discussed earlier, natural gas is the only indigenous fossil fuel Bangladesh has, which is being depleted at a drastic rate. By 2023, 71 percent of the natural gas reserve will have already been produced, leaving only 29 percent remaining [244]. Our forecast shows a similar trend (Figure 22), and by 2035, natural gas may be completely exhausted, leaving no economic reserves (Appendix A Tables A2 and A3). The difference between production and consumption is to be met by imported LNG. While Canada has started producing LNG [115,245], Bangladesh has already begun importing LNG, and future LNG imports are expected to continue increasing [27,244].

Oil is another fossil fuel that Bangladesh is entirely dependent on imports. Despite being energy-poor, especially in fossil fuels, energy demand continues to increase due to economic growth and an improving standard of living (Appendix A Table A4). Therefore, attention must be paid to the potential for developing renewable energy sources.

Developing and deploying renewable energy technologies requires significant capital investment, technical expertise, and infrastructure, which Bangladesh currently lacks [246,247]. While international aid and private sector investment have contributed to some progress, the pace remains slow due to limited financial resources, bureaucratic delays, and a lack of local manufacturing capacity for renewable equipment.

The country's aging, fragmented electricity grid is ill-equipped to handle variable, decentralized power sources such as solar and wind. Integrating renewable energy into the national grid would require significant upgrades and investment, which adds to the financial burden. Like most developing countries, Bangladesh's energy sector is highly subsidized, disproportionately benefiting the wealthy. Removing energy subsidies would benefit the economy by increasing GDP [244]. The magnitude of the impact, however, depends on how the budgetary savings from removing the subsidy and the increased revenues from natural gas are reallocated to the economy. Government subsidies for natural gas and coal have kept fossil fuel prices artificially low, making them more attractive than renewables in the short term. This distorts the energy market and reduces incentives for renewable investment [100].

Despite these challenges, Bangladesh has made progress in certain areas, particularly in the implementation of solar home systems (SHS). Over six million rural households now have solar panels, making Bangladesh a global leader in off-grid solar. These systems have helped improve access to electricity in remote areas and reduce reliance on kerosene [50,63]. Other initiatives, such as rooftop solar installations for commercial buildings and pilot biogas projects in rural areas, show that renewables can be effective on a small scale in specific contexts. However, scaling these up to meet national energy demands remains a significant hurdle [50].

Ironically, while Bangladesh is one of the least responsible for global carbon emissions, it is among the most vulnerable to the impacts of climate change—rising sea levels, extreme weather, and temperature increases. Yet, its dependence on fossil fuels may deepen in the short term, as the country prioritizes economic development and energy security over environmental concerns.

Recently, under substantial pressure from the Government and private organizations, there has been an impetus to produce renewable energy as much as possible, primarily through the installation of solar panels [29,58]. A forecasting model, based on ARIMA,

shows an exponential increase (Figure 23), but that is unrealistic. Among the three renewable energy sources, only solar energy is growing rapidly. This is simply because the forecast demonstrates the recent trend. Bangladesh has limited space for solar panels due to its high population density. Nonetheless, the potential for further increase exists, albeit to a limited extent (Appendix A Table A5).

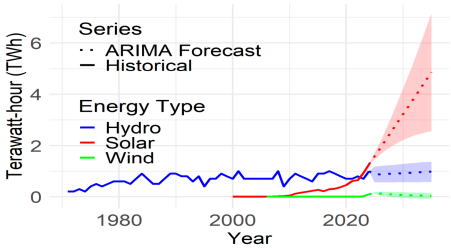


Figure 23. Renewable Energy Production (hydro, solar, and wind) in Bangladesh. Historical trend (solid line) and ARIMA forecast (2025–2035, dashed line) with 95% confidence band. Different colors present different energy types. (Data source: [17,22]).

Bangladesh's path to renewable energy is marked by structural limitations that restrict its potential for a large-scale transition [63]. Although it has demonstrated leadership in certain areas, such as rural solar home systems, broader adoption of renewables is hindered by land constraints, limited resources, financial barriers, and infrastructural weaknesses. Without significant international support, technology transfer, and long-term planning, Bangladesh is likely to remain a case of limited potential in the global renewable energy movement—despite its urgent need for sustainable solutions.

5.2. Canada—A Case of Enormous Potential

Canada is one of the world's most resource-rich and technologically advanced countries, positioning it exceptionally well to lead the global transition to renewable energy [248]. With vast land, abundant natural resources, low population density, and a strong policy framework, Canada has the geographic, economic, and political capacity to become a renewable energy powerhouse. It has significant fossil energy reserves and production facilities. It is rich in all three fossil fuels: crude oil, natural gas, and coal [245].

Coal production and consumption increased until the late 1990s but have since declined. On the other hand, both natural gas and oil production and consumption continue to grow (Figure 24). Coal mining was closely linked to Canada's economic and social development [248]. Several factors have contributed to the recent decline and potential elimination of coal production in Canada. Increasing production costs resulting from the exhaustion of surface mining, lower global prices due to increased substitution by oil and natural gas, and environmental concerns are cited as the major ones [249,250]. Our forecast indicates that coal production will continue to decline at a smaller scale than consumption (Figure 24; Appendix A Tables A6 and A7). Consumption is expected to decrease to zero by as early as 2030, which is precisely the expected result [251].

Both oil and natural gas production and consumption are expected to continue to increase (Figure 24; Appendix A Tables A8–A11). Canada is building new and expanding existing pipelines to increase oil exports and has begun its first shipment of LNG in July 2025 [252]

The energy situation in Canada is like that of Norway, except that Norway's economy is based on oil and natural gas rather than coal [253]. With the reduction in coal production, such similarity becomes even closer. Norway has successfully transitioned its energy sector from non-renewable to renewable sources. It produces all its electricity from renewable sources, primarily hydroelectric, with additional contributions from wind, thermal, and

solar [254]. In addition to its oil and gas exports, it exports electricity generated from renewable sources.

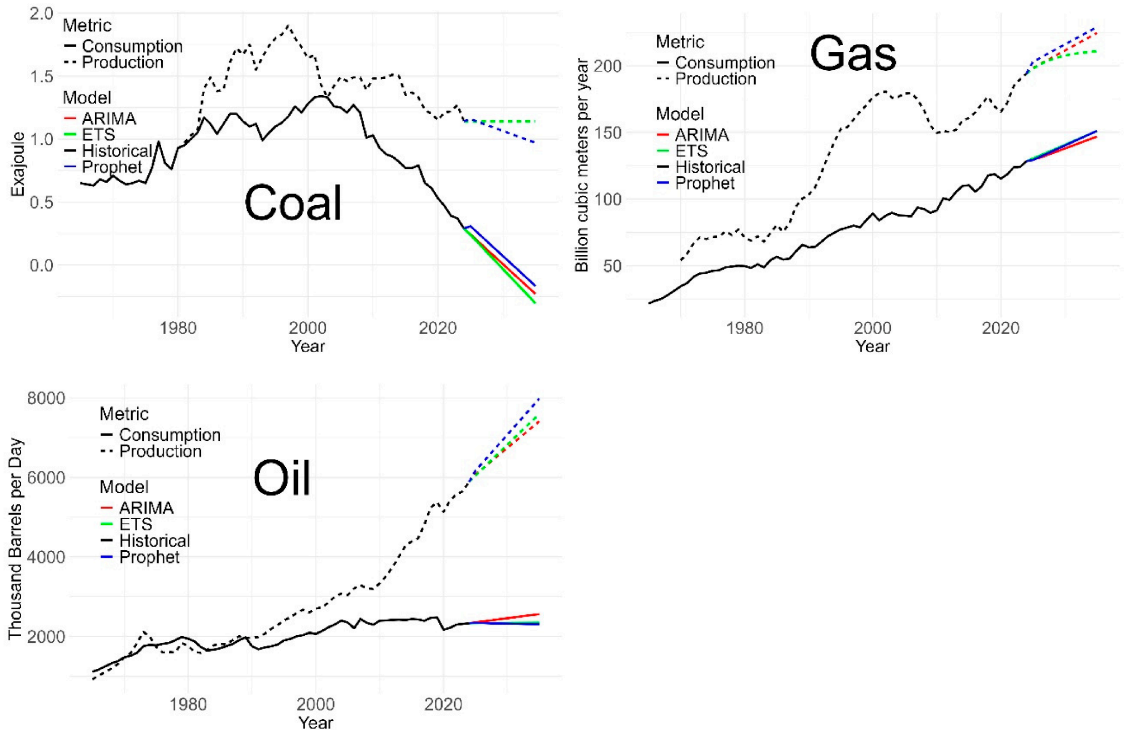


Figure 24. Coal, natural gas, and oil production (dashed line) and consumption (solid line) in Canada, historical data and forecast 2025–2035. Different colors present different forecast methods. (Data source: [21,22]).

Like Norway, Canada has enormous potential to produce renewable energy, and it is increasingly vital for meeting climate targets and building a sustainable energy future. Canada already generates over 65 percent of its electricity from renewable sources, with hydropower being the dominant contributor [103]. The remaining energy mix includes nuclear, natural gas, and a small but growing share of wind, solar, biomass, and tidal power. As of 2024, Canada is actively expanding its clean energy infrastructure through public investment, Indigenous partnerships, and private innovation [119,120,129].

Canada's vast land, with its variable topography and weather patterns, offers a diverse range of renewable energy-producing capacities. Some regions, particularly Quebec and British Columbia, have significant hydropower potential. Rivers such as the St. Lawrence, Peace, and Nelson are good sources of large hydroelectric power capacity. The Prairie provinces, like Alberta, Saskatchewan, Manitoba, and Ontario, have vast open land with substantial opportunity for wind and solar power. The maritime provinces in the east and British Columbia's coast in the west offer an excellent facility for offshore wind energy. However, its cold weather and variable sunlight between winter and summer pose substantial challenges. Its extensive forests and agricultural sector produce large amounts of organic waste suitable for bioenergy. Coastal provinces like Nova Scotia and British Columbia are exploring tidal and geothermal energy sources, which represent untapped future resources.

Canada has a well-developed energy sector with the engineering, manufacturing, and technological infrastructure needed to support a large-scale renewable transition. From smart grids and battery storage to electric vehicles and hydrogen research, Canada has the tools to support clean energy innovation. The Canada Electricity Advisory Council

forecasts a continuous increase in electricity production until 2050 [255]. This is a highly optimistic scenario, but not impossible.

The federal government has committed to achieving net-zero emissions by 2050 and has introduced carbon pricing, clean energy subsidies, and a Clean Electricity Standard. Provinces such as Quebec and British Columbia have also implemented aggressive climate policies to support renewable energy development [256]. Many renewable energy projects in Canada are co-developed with Indigenous communities, offering economic development opportunities and respecting traditional knowledge and sovereignty. This collaborative model strengthens social support for clean energy while fostering equity [170].

As a G7 nation, Canada has a responsibility to lead on climate action. A shift to 100 percent renewable energy would drastically reduce emissions from electricity, buildings, transportation, and industry. Canada could become a global exporter of clean energy, including hydrogen, renewable electricity, and critical minerals used in battery and solar panel production. Job Creation and Economic Diversification Renewable energy development can create tens of thousands of jobs, especially in rural and Indigenous communities, while reducing reliance on volatile fossil fuels [255].

Canada's renewable energy is almost entirely domestically sourced, with negligible impact from other governments. It is immune to global fuel price shocks and increasingly cost-competitive with fossil fuels. Despite its enormous potential, Canada must overcome several barriers:

(i). **Fossil Fuel Dependence**: The oil and gas sector remains economically significant, particularly in Alberta and Newfoundland. Renewable energy transition presents complex challenges, including employment displacement in fossil fuel industries, heightened risks of energy poverty, and an uneven distribution of transition costs and benefits across social groups [257]. A just renewable energy transition [just transition] is a planned movement toward renewable energy production and use that integrates equity, economy, environment, and human well-being. The implementation of Canada's Truth and Reconciliation Commission (TRC) report and the signing of the Paris Agreement in 2015 emphasized the concept of just transition. Since then, the energy transition has become a significant opportunity for reconciliation with Indigenous peoples and for deeper reflection on the power dynamics involved. The renewable energy transition often conflicts with the land rights and cultural survival of Indigenous peoples [258]. The TRC calls for meaningful consultation, building respectful relationships, and obtaining the free, prior, and informed consent of Indigenous peoples before proceeding with economic development projects, and ensuring that Indigenous peoples have equitable access to job opportunities, training, and education in the corporate sector [259]. A just transition will require retraining workers, managing economic impacts to maintain or improve equity, and involving Indigenous peoples [170]. Transitioning to renewable energy does not mean eliminating fossil fuels; instead, following Norway's model [260], Canada can continue to export fossil fuels while building renewable energy to become self-sufficient.

(ii). **Interprovincial Grid Limitations**: Canada's electricity grid is fragmented by province, limiting the interconnections needed to transfer renewable power across regions. It is more integrated with the US than it is with the other provinces, which is a concern for energy security. The current electric grid system is a patchwork of provincial systems, resulting in disparities: some provinces have surpluses while others face shortages. There is little inter-provincial trade in electricity to capitalize on each province's relative strengths and weaknesses in production, and no national strategy exists in this area of provincial jurisdiction [261]. Increased interprovincial trade and a

unified national grid can invest in transmission infrastructure, surplus diversion, and new clean capacity to achieve a cleaner, more prosperous future.

(iii). **Permitting and Bureaucracy**: Long timelines for environmental assessments and project approvals can delay renewable projects. Recently, the federal government announced plans to streamline the approval process for energy projects.

(iv). **Equity Concerns**: Ensuring that low-income, remote, and Indigenous communities benefit from the renewable energy transition requires inclusive planning and investment. Most energy projects are in remote and rural areas, but the benefits are disproportionately distributed to affluent areas, leaving local communities with little to gain. Policies need to be developed and implemented so that the local community sees the benefits and does not oppose the developments.

With the right policies, investments, and partnerships, Canada can become a global leader in renewable energy. By expanding wind and solar, modernizing its grid, phasing out fossil fuel subsidies, and supporting clean technology innovation, Canada could achieve 100 percent clean electricity well before 2050 [255]. Provinces like Quebec, British Columbia, and Prince Edward Island are already leading the way, demonstrating how regional solutions can contribute to a national clean energy vision.

Canada possesses enormous and diverse renewable energy potential, unmatched by many other countries. From hydropower and wind to bioenergy and emerging technologies, Canada has the resources, knowledge, and political will to move to a sustainable energy future. While challenges exist, especially in aligning provincial and federal agendas, paths toward clean energy are not only possible but also economically and environmentally necessary. By harnessing its renewable strengths, Canada can ensure a resilient, equitable, and carbon-free energy system for generations to come.

Our short-term (ten-year) forecast, based on ARIMA, paints a different picture (Figure 25, Appendix A Table A12). The general trend toward increased wind and solar energy production makes sense. The growing trend toward nuclear energy is also realistic, as discussions are underway to establish nuclear facilities across the country. However, the declining trend of hydro seems counterintuitive. In recent years, hydroelectricity generation has faced challenges due to low precipitation, and forecasts of a downward trend are the result of this recent decline. Canadian river flows have been declining, and eventually, the potential for developing hydroelectricity will diminish [262–264]. However, the potential for solar, nuclear, and wind is highly promising (Figure 25).

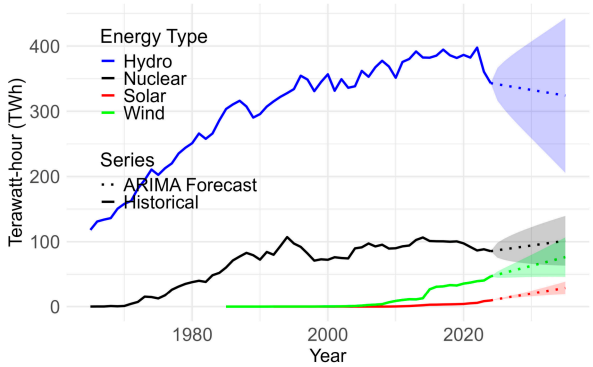


Figure 25. Renewable Energy Production (hydro, nuclear, solar, and wind) in Canada. Historical trend and ARIMA forecast (2025–2035, dashed lines) with 95% confidence band. Different colors present different energy types. (Data source: [17,22]).

As of 2021, only about 1% of the hydrogen produced globally comes from renewable energy sources [264]. Canada can become a leader in hydrogen production if it uses it effectively; the value is determined by several factors, such as geographical location, wind

potential, and topological constraints [265,266]. Canada possesses specific innate advantages for developing a sustainable hydrogen economy, including a robust livestock sector, a strong energy sector, and robust international relationships [265]. In fact, many of the provinces, such as Alberta, Quebec, and Ontario, have wind projects across the country [264]. To implement this, a robust framework is necessary to integrate hydrogen storage technologies across industrial applications, research and development, and international partnerships.

5.3. Commodity Market Dynamics and Transition Pathways

As we have alluded to before, market dynamics, especially energy price volatility (Figure 26), have complex effects on the transition from non-renewable to renewable sources. In general, fossil fuel prices are highly variable due to the inelastic nature of supply and demand, as well as their sensitivity to political and environmental fluctuations [267,268]. The historical and commonly held notion is that the price fluctuations of fossil fuels incentivize a transition toward renewables. Although there is widespread concern about the sustainability of renewable energy production, it is credited with mitigating energy price fluctuations, particularly in electricity prices [269].

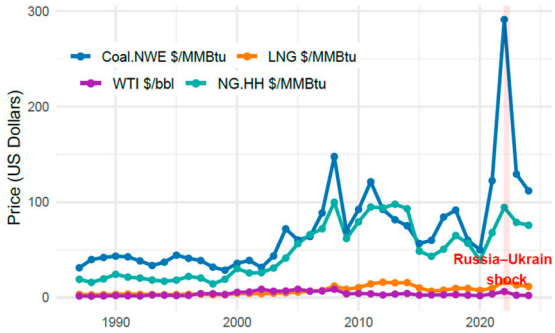


Figure 26. International price volatility of coal, oil, and gas based on annual data. The pink vertical line marks the year 2022, when Russia invaded Ukraine. (Data source: [21,22]).

Prices of oil, natural gas, and coal fluctuate over time, sometimes mildly, sometimes sharply. These fluctuations can occur daily, monthly, or annually and persist over extended periods, having significant implications for economies, energy security, and climate policy. Such volatility may come from both supply and demand [270].

The prices of WTI and Brent are highly correlated (r = 0.99), and similarly, coal NWE and coal US are highly correlated (r = 0.94); as such, we included only WTI and coal NWE. The coal price shows significant variability, especially in recent years, due to the Russia-Ukraine war (Figure 26). Fossil fuel price variability has a considerable influence on the pace, direction, and political feasibility of the renewable energy transition. Historically, a sharp increase in fossil fuel prices is credited with the inception of the importance of renewable energy adoption. This is true: a sudden increase in fossil fuel prices accelerates renewable adoption, but a sharp decline slows it [11]. The adoption of renewable energy may even increase the total energy price stability [237].

5.3.1. Price Competitiveness and Transition Incentives

Both countries face commodity price dynamics that fundamentally shape renewable energy transition trajectories, though with opposite incentive structures. Canada's domestic fossil fuel production provides price stability, which paradoxically reduces the competitiveness of renewable energy. Indeed, the $30 billion subsidy regime keeps conventional energy artificially cheap relative to clean alternatives, despite carbon pricing reaching $80 per ton of CO_2 in 2024 [133]. This creates a policy contradiction: carbon taxes theoreti-

cally internalize environmental costs, yet fiscal subsidies practically externalize production costs, diluting price signals that would otherwise drive transition investment.

Bangladesh faces inverse incentives. Import dependence creates extreme exposure to price volatility. As mentioned earlier, LNG costs more than doubled to $15–20 per MMBtu during the 2022 shocks, and coal prices also nearly doubled. In theory, that should have favored renewable investment, offering price stability and savings in foreign exchange [34]. However, upfront capital costs for renewable infrastructure clash with fiscal constraints from existing subsidy obligations (BDT 383 billion annually for BPDB losses). The absence of carbon pricing mechanisms in Bangladesh renders fossil fuels privately optimal, despite their social costs. At the same time, political resistance to tariff increases prevents cost-recovery pricing that could finance transition investments.

These price mechanism failures demonstrate commodity market characteristics—such as subsidies, tariff structures, and the effectiveness of carbon pricing—determine transition feasibility as much as technological capacity [233,234]. Canada possesses financial resources but lacks price incentives; Bangladesh has economic incentives but lacks financial capacity.

5.3.2. Trade Flows, Investment Patterns, and Capital Allocation

Investment flows reveal how commodity market structures create barriers to the political economy. Canada attracted $35 billion in clean energy investment (2024) through Investment Tax Credits and public finance, yet renewable procurement stalled in Alberta following provincial approval moratoriums—demonstrating how subnational political control over commodity resources fragments national energy markets [146,147]. The $34.2 billion Trans Mountain Pipeline investment, the most significant federal energy infrastructure commitment in decades, signals continued prioritization of fossil fuel commodity export capacity despite net-zero 2050 commitments [123].

Bangladesh's power sector FDI flows overwhelmingly to thermal generation (90% of pipeline projects are Chinese-financed coal and LNG plants), with minimal capital for renewables, despite official targets of 40% by 2041 [34]. Take-or-pay IPP contracts lock in fossil fuel commodity procurement for 20–25 years, creating stranded asset risks if renewables subsequently displace thermal generation. This path dependency reflects commodity market realities, including established import relationships (LNG suppliers in Qatar and Oman, coal from Indonesia), infrastructure already optimized for fossil fuels (LNG terminals and coal ports), and financing relationships that favor conventional technologies with proven revenue models.

5.3.3. Macroeconomic Adjustment and Structural Transformation

The general equilibrium effects of a renewable energy transition differ fundamentally between commodity exporters and importers. Canada's transition requires managing the decline of a sector contributing 10.3 percent of GDP, 697,000 jobs, and $199 billion in export earnings. This risks regional economic dislocation if not carefully sequenced [103,121]. Dutch Disease dynamics complicate this adjustment: energy exports historically appreciated the CAD by 30–40 percent during the 2000s oil booms, constraining manufacturing competitiveness [131]. Stranded asset risks in oil sands ($150 + billion invested capital) could trigger severe regional recessions in Alberta and Saskatchewan, absent robust just transition policies.

Bangladesh faces opposite challenges: energy scarcity constrains structural transformation from agriculture (11.6% of GDP in 2021–2022) to industry and services [271]. Load-shedding, which reduces Ready-Made Garment output by 50 percent in 2023, demonstrates how energy commodity import constraints directly undermine industrialization, a key factor for development [34]. The country's energy intensity is rising (79.0, indexed to

2015 = 100) amid rapid economic growth, creating a development trap in which industrial expansion requires greater energy imports. These imports deplete foreign exchange, forex constraints limit fuel procurement, and energy shortages curtail industrial output, creating a negative feedback loop that perpetuates underdevelopment.

Renewable energy investment offers Bangladesh import substitution benefits. Each gigawatt of solar capacity (with a capital cost of nearly $800 million) displaces approximately $100 million annually in LNG or coal imports at current prices, achieving payback within 8–10 years while providing energy security and resilience [12]. Macroeconomic modeling suggests that achieving a 40 percent renewable energy share by 2041 could reduce the trade deficit by 1.5–2 percent of GDP through import substitution, while also improving industrial productivity by 15–20 percent through a reliable electricity supply [36].

5.4. Comparative Potential—What Is at Stake

By comparing the energy consumption patterns, production levels, investment trends, and policy effectiveness in Canada and Bangladesh, we uncover valuable insights and lessons:

1. Energy Consumption and Production: Canada's energy consumption is significantly higher per capita than Bangladesh's, reflecting disparities in economic development and industrialization between the two countries. While Canada is a net exporter of energy, Bangladesh heavily relies on imported fossil fuels, posing challenges to its energy security and economic stability.
2. Investment and Policy Effectiveness: Canada has made substantial investments in renewable energy infrastructure, supported by various policy incentives and emission reduction targets. However, the effectiveness of these policies has been uneven across provinces and territories. In contrast, while ambitious, Bangladesh's renewable energy policies have faced implementation challenges due to financial constraints and infrastructure limitations.
3. Economic Implications: The renewable energy transition has divergent economic implications for the two nations. For Canada, the shift towards renewables has the potential to create new industries and jobs while reducing reliance on volatile fossil fuel markets. However, it also poses risks of economic disruption for established energy sectors. On the other hand, Bangladesh seeks energy security and affordability through renewable sources, which could alleviate the financial burden of importing fossil fuels.
4. Technological innovation and market mechanisms: In Canada, mature innovation ecosystems, such as those spanning energy storage, hydrogen, and digital grids, interact with transparent market frameworks to accelerate renewable energy transition [272]. Conversely, Bangladesh's limited technological base and underdeveloped market instruments constrain its ability to internalize environmental costs and attract private capital [273]. Bridging this divide requires technology transfer partnerships, innovation-focused finance, and regional cooperation to ensure inclusive progress toward net-zero targets.
5. Lessons Learned: Canada's gradual, decentralized approach to the renewable energy transition, which accounts for regional disparities and stakeholder interests, offers valuable lessons for managing complex energy systems. Conversely, Bangladesh's targeted policies and rural electrification through solar home systems provide insights into addressing energy access and affordability challenges in developing nations.
6. Given these various circumstances, Canada has substantial potential to transition to renewable energy, leveraging its natural resources, environmental conditions, and financial, institutional, and technological capabilities, as does Norway. In contrast,

Bangladesh has limited natural and ecological resources, as well as poor financial, institutional, and technological capabilities.

6. Conclusions and Policy Recommendations

6.1. Synthesis of Key Findings

This comparative analysis of Canada and Bangladesh demonstrates that the transition from fossil fuels to renewables is shaped not only by resource endowment but also by governance quality, institutional coordination, and policy coherence. Our econometric analysis and forecasts (Section 4) reveal that renewable-energy trajectories in both countries are characterized by asymmetrical transition potential: Canada possesses abundant renewable resources but faces governance inertia, whereas Bangladesh exhibits strong policy intent but limited financial and infrastructural capacity.

The comparative analysis further reveals fundamental commodity market dynamics that shape renewable energy transition pathways. Canada's energy abundance generates export revenues and fiscal capacity for transition investments; however, it also creates political-economy resistance from fossil-fuel stakeholders and Dutch Disease effects that undermine competitiveness. Bangladesh's energy scarcity exposes the economy to severe commodity price volatility and import dependence, which constrain structural transformation but create stronger economic incentives for renewable investment that remain unrealized due to capital constraints and governance challenges.

Forecasting results further indicate that Bangladesh's renewable energy share will grow steadily yet insufficiently under a business-as-usual scenario, primarily through increased solar installations (Appendix A Table A5), unless accelerated investment and institutional reforms are implemented. Conversely, Canada's renewable share, already exceeding 65 percent of electricity generation, is projected to plateau after 2030 due to persistent dependence on oil and gas and the absence of coherent federal–provincial coordination mechanisms. These projections underscore that policy and institutional variables, rather than technological or resource availability alone, determine the speed of transition.

In Bangladesh, Section 2 indicates that the dominance of natural gas (accounting for around 68 percent of primary energy) and reliance on imported fuels create fiscal and external sector vulnerabilities. Despite ambitious national targets, including a goal of five percent renewable energy by 2015, 10 percent by 2020, and 40 percent by 2041 [274], the country failed to meet early milestones due to limited investment capacity, bureaucratic overlap, and slow project implementation.

In Canada, Section 3 reveals that while electricity decarbonization has been highly successful (a 58% reduction in emissions since 2005), emissions from oil, gas, and transportation have remained largely static or increased. The federal system's constitutional fragmentation, combined with entrenched fossil-fuel political influence, constrains a unified transition pathway.

Across both contexts, the empirical findings reinforce a central conclusion: the renewable energy transition is not a linear technological substitution, but a socio-political transformation that requires coordinated institutions, stable financing for renewables, and ensuring public and political acceptance of the transition costs.

6.2. Comparative Reflections on Transition Pathways

The divergent paths of Bangladesh and Canada reflect differences in four structural dimensions: economic context, institutional capacity, financial resources, and political legitimacy.

Economically, Bangladesh faces the dual challenge of expanding energy access and decarbonizing its energy system simultaneously. Its low per capita electricity consumption

(less than 700 kWh annually) contrasts sharply with Canada's high consumption levels (over 14,000 kWh per capita), reflecting fundamentally different stages of development. For Bangladesh, the transition to renewables is both an environmental and developmental necessity. Canada, conversely, faces the challenge of decarbonizing a mature energy system heavily integrated with global hydrocarbon markets. Forecasts from Section 4 suggest absent major policy innovation, Canada's oil- and gas-sector emissions will continue to offset gains in other sectors, limiting net reductions.

Institutionally, Canada's federal structure enables policy experimentation but also produces interjurisdictional conflict, particularly between energy-producing and energy-consuming provinces. Bangladesh's centralized system allows more unified planning, but it suffers from limited institutional capacity and overlaps among agencies, such as SREDA and BPDB.

Financially, Bangladesh's energy transition is hindered by limited access to affordable long-term financing. Section 2.4 notes that green projects struggle to attract investment due to high perceived risks and long payback periods. In contrast, Canada's financial markets and institutions have greater access to capital, but investment flows remain concentrated in fossil fuel projects due to established infrastructure and entrenched interests. As noted in Section 3.4, the fossil fuel sector's lobbying power has further skewed federal investment patterns toward hydrocarbons, despite formal commitments to renewable energy transition [205].

Politically, both countries must navigate challenges to social acceptance. In Canada, opposition often arises from fossil-fuel-dependent communities concerned about job losses and regional inequities. In Bangladesh, resistance is more closely tied to the affordability and accessibility of energy. However, in both cases, public engagement and community participation emerge as crucial factors for building trust and sustaining momentum during the transition. Studies from other contexts, such as Germany's community energy cooperatives [275], demonstrate that public ownership and participation can significantly enhance the legitimacy and speed of renewable energy transitions. Together, these dimensions confirm that effective energy transition requires aligning economic priorities, governance structures, financial incentives, and citizen participation within coherent national strategies.

6.3. Policy Recommendations

Based on comparative analysis and drawing from successful international experiences, we propose differentiated policy recommendations tailored to each country's specific context and capabilities:

Bangladesh

Bangladesh's transition will succeed only if renewable expansion is integrated with economic stability and institutional reform. Based on our findings, we recommend the following policies:

1. Strengthen coordination through a National Energy Transition Authority (NETA).

As shown in Section 2.4, overlapping mandates among the Power Division, SREDA, and BPDB hinder effective planning and coordination. A dedicated NETA should coordinate renewable strategies, streamline approvals, and monitor progress. Morocco's centralized agency (MASEN) offers a valuable precedent for ensuring accountability and unified implementation [276]. A unified NETA would also harmonize tariff-setting, auction design, and renewable procurement schedules, creating predictable market signals for investors and reducing bottlenecks to private investment in the energy sector.

2. Scale solar energy through targeted, bankable programs.

Building on the success of Solar Home Systems (Section 2.3), Bangladesh should prioritize grid-connected solar parks, rooftop systems, and urban microgrids. Fast-track permitting, net-metering expansion, and blended financing mechanisms, like Vietnam's solar model [49], can accelerate capacity growth while minimizing fiscal strain.

3. Diversify energy supply and reduce import dependence.

Given the rising costs of LNG and oil imports, Bangladesh should expedite the exploration of onshore and offshore gas blocks under transparent Production Sharing Agreements, while utilizing natural gas as a bridge fuel during the transition to renewable energy. Strategic use of domestic resources will enhance short-term energy security and reduce exposure to volatile global markets.

4. Mobilize finance through innovative instruments.

Bangladesh Bank's green refinancing should be expanded to include risk-sharing facilities and concessional loans for renewable projects. Efforts should be made to ensure that it evolves into a tiered credit facility with transparent eligibility metrics. Establishing a Green Energy Fund, supported by development partners, can provide long-term financing for grid modernization and storage. Experiences from India and Kenya show that such dedicated funds attract private capital [277,278].

5. Upgrade grid infrastructure and storage capacity through a market-driven mechanism.

As noted in Section 2.3.4, system losses and weak transmission lines are key constraints on the integration of renewable energy sources. Beyond targeted infrastructure investments in smart grid systems, advanced metering, and battery storage that can enable large-scale integration of solar and wind energy, Bangladesh must create market incentives for their deployment [279]. The Bangladesh Energy Regulatory Commission (BERC) should implement Time-of-Use (ToU) pricing for industrial consumers to incentivize battery storage investment. Meanwhile, the Sustainable and Renewable Energy Development Authority (SREDA) should conduct reverse auctions for Solar-plus-Storage hybrid projects to determine the actual cost of firm renewable power.

6. Build human and technical capacity.

As discussed in Section 5, Bangladesh's energy transition depends on skilled manpower. Targeted programs in universities and vocational institutions, developed in collaboration with industry, can enhance local technical expertise and skills. Over time, this will reduce reliance on foreign contractors and enhance domestic innovation. Industry associations such as the Bangladesh Garment Manufacturers and Exporters Association (BGMEA) and local solar cooperatives have begun partnering with municipalities to pilot rooftop solar and storage systems, demonstrating how private-sector and community engagement can accelerate deployment while enhancing social acceptance [173].

7. Commodity market perspective.

As an energy-importing country vulnerable to severe energy price and foreign-exchange shocks, Bangladesh's transition priorities center on financial and structural reforms. As Ref. [41] suggested, its tariff restructuring should aim for cost-recovery pricing while maintaining protection for vulnerable households. This would foster economic growth and environmental sustainability. Additionally, a targeted import and export substitution strategy should prioritize the deployment of renewable energy. For example, an emphasis on the high-export-intensive sectors, such as ready-made garments (RMG) and manufacturing, would maximize foreign exchange earnings and achieve savings and industrial resilience. Ultimately, Bangladesh should strive to mobilize international climate

finance at concessional rates to bridge the investment gap and accelerate the development of sustainable infrastructure.

Canada

For Canada, the central barriers are political and institutional rather than technical or financial. Drawing on Sections 3 and 5, the following recommendations address these systemic issues:

1. Reform intergovernmental coordination for coherent climate policy.

As shown in Section 3.4, provincial control over natural resources creates fragmented policy outcomes. Canada should adopt a binding federal–provincial emissions framework that aligns renewable energy targets and transition timelines. Germany's federal climate law, which sets sectoral emission budgets and enforces corrective action, provides a relevant model [280]. A harmonized emissions and renewable-target framework would not only align policy goals but also reduce market fragmentation across provincial electricity markets, improving investment efficiency and cross-border electricity trading.

2. Curb fossil fuel influence in policymaking.

Long-standing industry lobbying has perpetuated hydrocarbon dependency [205]. Stronger lobbying disclosure rules, the exclusion of fossil fuel representatives from climate advisory bodies, and robust conflict-of-interest safeguards for policymakers would enhance transparency and credibility. Similar reforms in Norway and Denmark have strengthened public trust.

3. Revitalize community-based renewables through cooperatives.

Section 3.4 notes that energy authority is spread across multiple levels of government, requiring sophisticated coordination mechanisms between federal, provincial, territorial, and Indigenous authorities [281]. The federal government should create a Cooperative Energy Fund, reintroduce stable price incentives (e.g., feed-in tariffs or contracts for difference), and enable virtual net metering. Germany's REScoop federation demonstrates how community participation can accelerate the adoption of renewable energy [275]. Canadian industry groups and Indigenous communities have increasingly co-developed renewable projects, such as the ATCO–Piikani Nation solar partnership [281]. This illustrates how joint ventures between utilities, civil society, and local communities enhance legitimacy, foster local employment, and promote equitable participation in the transition [282].

4. Implement a Just Transition Strategy for regions heavily reliant on fossil fuels.

Resistance in Alberta and Saskatchewan reflects legitimate concerns about economic losses. A Just Transition Fund should support worker retraining, regional diversification, and Indigenous-led renewable projects. Spain's experience demonstrates that well-designed regional funds can build social consensus and maintain momentum [228].

5. Improve data transparency and progress monitoring.

Section 3.4 observes that incomplete data on community generation and emissions hinder evaluation. Canada should establish a national database that integrates indicators of renewable energy production, employment, and social equity to promote a more comprehensive understanding of these areas. Open data platforms, as utilized in the EU's Clean Energy Observatory, can enhance accountability and facilitate policy learning. A unified national data platform would also support price discovery and market valuation of renewable assets, encouraging participation from institutional investors through improved information symmetry.

6. Accelerate grid modernization and storage integration through innovation and market incentives.

Canada's transition progress depends on upgrading transmission capacity and balancing regional grids. Expanding energy storage infrastructure, AI-based demand management, and interprovincial smart grid connectivity will enhance flexibility and reliability. To achieve this through market incentives, the federal government should expand the eligibility of the Clean Technology Investment Tax Credit (ITC) to include not just physical storage assets, but also the 'soft costs' of smart grid interconnection and grid-management software, which currently constitute a significant barrier to entry. Second, provincial system operators outside of Ontario should replicate the 'Long-Term Request for Proposals' (LT1 RFP) model, establishing concrete procurement mandates for energy storage (e.g., specific GW targets by 2030) rather than treating it as a passive resource. Integrating these storage targets into provincial market rules will provide the long-term revenue certainly required to mobilize private capital.

7. Commodity market perspective.

As an energy exporter primarily to the U.S., Canada's transition effectiveness hinges on realigning fiscal and market incentives. First, reallocating the $30 billion in annual fossil fuel subsidies toward clean energy deployment would correct price distortions and accelerate the transition to renewable energy. Their export diversification should prioritize the development of renewable electricity export capacity and hydrogen production, leveraging Canada's clean power potential to sustain external competitiveness and to find alternative export markets, especially given the increasingly unpredictable policies of the current U.S. administration. Finally, regional equity mechanisms must ensure that resource-dependent provinces, notably Alberta and Saskatchewan, equitably benefit from national transition investments and avoid disproportionate adjustment costs.

6.4. Concluding Reflections and Future Directions

This study, employing forecasting and comparative analysis, presents new evidence that governance coherence, institutional adaptability, and inclusive finance are more significant determinants of transition success than resource endowment. For Bangladesh, empirical projections suggest that without substantial institutional reform and financial mobilization, the expansion of renewable energy will fall short of its target. For Canada, the forecasts confirm that progress in electricity decarbonization cannot compensate for continued growth in fossil fuels unless federal–provincial coordination is substantially strengthened.

Both countries exemplify how commodity market characteristics, such as price dynamics, trade flows, investment patterns, and macroeconomic linkages, mediate between energy systems and development outcomes. While Canada's transition is shaped by its exposure to export markets and fiscal flexibility, Bangladesh's path is constrained by its vulnerability to import prices and foreign exchange risk. Both cases illustrate how commodity-market mechanisms—through pricing volatility, trade dependence, and fiscal elasticity—mediate the scope and speed of transition. Integrating price-stabilization policies, targeted subsidies, and diversified trade portfolios within transition strategies can align market stability with decarbonization objectives. For both Bangladesh and Canada, the transition from fossil fuels to renewables must navigate these commodity market realities: for Canada, managing the decline of a significant export sector while diversifying the economy; for Bangladesh, breaking free from import dependence while financing the upfront costs of energy infrastructure. This comparative perspective highlights the commodity market's central role as both a constraint and a catalyst in national energy transitions.

In both cases, the structure and volatility of the commodity market have a fundamental influence on energy transition outcomes, determining fiscal space, investor confidence, and the pace of technological deployment. The broader implication is that policy design must evolve from fragmented, sector-based interventions to *more coordinated transition strategies*

that integrate fiscal, regulatory, and social dimensions. Future research should extend the time-series models introduced in Section 4 to incorporate behavioral and distributional variables such as income effects, employment, and regional disparities to better predict the feasibility of transitions and social equity outcomes.

Comparative lessons also highlight the value of cross-national learning. Canada's institutional experience with advanced technology and regulatory frameworks can inform Bangladesh's capacity-building efforts, while Bangladesh's rapid diffusion of decentralized solar systems offers insights for Canada's community-energy initiatives. Both countries can benefit from collaborative mechanisms for technology transfer, climate finance, and knowledge exchange under multilateral platforms such as the Clean Energy Ministerial.

A promising avenue of strategic cooperation lies in natural gas trade. Canada's emerging LNG export capacity through the new Kitimat terminal on the Pacific coast provides an opportunity to establish long-term supply partnerships with energy-importing economies such as Bangladesh. Such an arrangement could be mutually beneficial: Canada would diversify its export markets beyond North America, while Bangladesh would enhance short- to medium-term energy security by securing stable, predictable LNG supplies. Because natural gas is the least carbon-intensive of the fossil fuels, this North–South energy cooperation would provide a pragmatic pathway for transition. It will facilitate the gradual displacement of higher-emission fuels, such as coal, in Bangladesh, while allowing Canada to align its export strategy with global renewable energy transition objectives.

Another avenue of bilateral cooperation is for the Canadian Export Development Corporation to provide concessional financing for Bangladesh's renewable projects, creating export markets for Canadian cleantech (ranking 3rd globally in renewable energy patents) while accelerating Bangladesh's transition [12]. Redirecting even 10 percent of Trans Mountain's investment ($3.4 billion) to Bangladesh could install 8–10 GW of solar capacity, displacing 65 percent of imported fuel requirements, demonstrating how Canadian capital, combined with Bangladesh's deployment needs, could generate win-win outcomes in commodity markets that accelerate renewable energy transitions in both energy-abundant and energy-scarce contexts. Ultimately, industry innovation, civil society advocacy, and local participation are indispensable in translating policy ambitions into real progress; their collaborative roles ensure that transition pathways remain socially inclusive and regionally grounded [164].

The primary limitation of this study is its reliance on univariate time-series forecasting, which projects energy demand trajectories while treating policy, institutional, and market variables as exogenous. Future research could advance this framework by developing a formal mediation analysis that quantifies commodity market dynamics, including price volatility, trade dependence, and exchange rate risk, to influence transition speed through fiscal and investment channels indirectly. Applying multivariate time-series and Vector Autoregression (VAR) or Vector Error Correction (VEC) models, along with dynamic panel estimations with country-specific fixed effects, would capture the interdependence among energy, trade, and macroeconomic variables over time. Such methods could generate elasticity estimates to guide fiscal allocation, subsidy design, and market-stabilization strategies. Extending the ARIMA model to the Seasonal ARIMA with exogenous regressors (SARIMAX) model by including external regressors may also provide further insights.

Energy transitions are not linear technological substitutions but rather socio-political transformations that require coordinated institutions, aligned commodity-market incentives, and sustained financing. Our study demonstrates that commodity market realities, rather than mere resource endowments, determine the feasibility of transition. For Canada, managing the decline of a major commodity export sector while diversifying the economy and addressing regional equity. Bangladesh needs to break free from its dependence on

commodity imports while financing upfront infrastructure costs. International cooperation that fosters win-win outcomes in the commodity market can accelerate renewable energy transitions in both energy-abundant and energy-scarce contexts, while reducing global fossil fuel consumption and associated emissions.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/commodities5020009/s1. Supplementary materials on details of methods and forecasting results are available in a separate file.

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Abbreviations

The following abbreviations are used in this manuscript:

ADB	Asian Development Bank
AECO	Alberta Energy Company
AR	Autoregressive
ARIMA	Autoregressive Integrated Moving Average
BP	British Petroleum
BBS	Bangladesh Bureau of Statistics
BC	British Columbia
BDT	Bangladesh Taka
BERC	Bangladesh Energy Regulatory Commission
BPDB	Bangladesh Power Development Board
CAD	Canadian Dollar
CanREA	Canadian Renewable Energy Association
CAPP	Canadian Association of Petroleum Producers
CCEI	Canadian Centre for Energy Information
CCS	Carbon Capture and Storage
CER	Canada Energy Regulator
CI	Confidence Interval
CNA	Canadian Nuclear Association
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
CPI	Consumer Price Index
CUSMA	Canada–US–Mexico Agreement
ESA	European Space Agency
ETS	Error, Trend, Seasonality
EU	European Union
FDI	Foreign Direct Investment
FSRU	Floating Storage Regasification Unit
GDP	Gross Domestic Product
GED	General Economics Division
GHG	Greenhouse Gas
GoB	Government of Bangladesh
IDCOL	Infrastructure Development Company Ltd.

IEA	International Energy Agency
IEEFA	Institute for Energy Economics and Financial Analysis
IESO	Independent Electric System Operator
IISD	International Institute of Sustainable Development
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ITC	Investment Tax Credit
JICA	Japan International Cooperation Agency
kWh	Kilowatt Hour
LCOE	Levelized Cost of Electricity
LNG	Liquefied Natural Gas
MA	Moving Average
MMBtu	Million British Thermal Unit
MRC	Marine Renewable Resources
MW	Mega Watt
NAFTA	North American Free Trade Agreement
NEB	National Energy Board
NETA	National Energy Transition Authority
NRC	Natural Resources Canada
NWE	Northwest Europe
OECD	Organization of Economic Cooperation and Development
PPCA	Powering Past Coal Alliance
PV	Photovoltaic
RMG	Readymade Garments
SEA	Strategic Environmental Assessment
SHS	Solar Home System
SMR	Small Modular Reactor
SREDA	Sustainable and Renewable Energy Development Authority
TCM	Trillion Cubic Meters
TES	Total Energy Supply
TMX	Transmountain Expansion
TPEC	Total Primary Energy Consumption
USAID	United States Agency for International Development
WBA	World Bioenergy Association
WHO	World Health Organization
WCS	Western Canadian Select
WTI	West Texas Intermediate

Appendix A. Production and Consumption Forecast Data with Confidence Interval for All Energy Resources for Canada and Bangladesh

Table A1. Bangladesh: Coal Consumption (Exajoule) Forecasts with 95% CI. [Bangladesh produces negligible amount of coal and as such coal production forecast is not included.]

	ARIMA			ETS			Prophet		
Year	**Forecast**	**Lower**	**Upper**	**Forecast**	**Lower**	**Upper**	**Forecast**	**Lower**	**Upper**
2025	0.3	0.3	0.4	0.3	0.3	0.4	0.3	0.2	0.3
2026	0.4	0.3	0.4	0.4	0.3	0.4	0.3	0.3	0.3
2027	0.4	0.4	0.5	0.4	0.4	0.5	0.3	0.3	0.3
2028	0.4	0.4	0.5	0.5	0.4	0.5	0.3	0.3	0.4
2029	0.5	0.4	0.6	0.5	0.4	0.6	0.3	0.3	0.4

Table A1. *Cont.*

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2030	0.5	0.4	0.6	0.5	0.5	0.6	0.4	0.3	0.4
2031	0.6	0.4	0.7	0.6	0.5	0.7	0.4	0.4	0.4
2032	0.6	0.5	0.7	0.6	0.5	0.8	0.4	0.4	0.4
2033	0.6	0.5	0.8	0.7	0.5	0.8	0.4	0.4	0.4
2034	0.7	0.5	0.9	0.7	0.5	0.9	0.4	0.4	0.5
2035	0.7	0.5	0.9	0.8	0.6	1.0	0.5	0.4	0.5

Table A2. Bangladesh: Gas Production (bcm) Forecasts with 95% CI.

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2025	18.2	17.2	19.2	18.5	15.4	21.6	23.4	21.9	24.9
2026	16.6	14.7	18.5	17.2	13.2	21.1	23.4	22.0	25.0
2027	15.6	12.5	18.6	15.8	10.7	21.0	23.4	21.9	24.9
2028	14.8	10.4	19.3	14.5	7.8	21.2	23.4	21.8	24.9
2029	13.9	8.2	19.7	13.2	4.8	21.6	23.4	21.8	25.0
2030	13.3	6.4	20.3	11.8	1.6	22.1	23.4	21.7	25.0
2031	13.0	4.7	21.3	10.5	−1.7	22.8	23.4	21.6	25.4
2032	12.5	3.0	22.0	9.2	−5.1	23.5	23.4	21.4	25.4
2033	12.1	1.5	22.8	7.9	−8.6	24.3	23.4	21.1	25.6
2034	12.0	0.2	23.8	6.5	−12.2	25.2	23.4	20.9	25.8
2035	11.7	−1.2	24.7	5.2	−15.8	26.2	23.4	20.9	26.0

Table A3. Bangladesh: Gas Consumption (bcm) Forecasts with 95% CI.

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2025	27.1	25.5	28.6	29.2	24.5	33.9	31.4	30.1	32.5
2026	26.9	24.4	29.3	30.1	24.5	35.8	32.0	30.7	33.3
2027	26.7	23.3	30.0	31.0	24.5	37.8	32.7	31.6	33.9
2028	26.5	22.3	30.6	31.9	24.8	39.8	33.4	32.1	34.6
2029	26.3	21.3	31.3	32.8	24.8	41.8	34.0	32.8	35.3
2030	26.1	20.2	32.0	33.7	25.1	43.6	34.7	33.4	36.0
2031	26.0	19.2	32.7	34.5	25.2	45.5	35.4	33.9	36.8
2032	25.8	18.2	33.4	35.4	25.3	47.7	36.0	34.4	37.6
2033	25.7	17.2	34.2	36.3	25.5	49.1	36.7	35.0	38.5
2034	25.6	16.2	34.9	37.2	25.5	51.2	37.3	35.6	39.2
2035	25.4	15.2	35.7	38.0	25.9	52.9	38.0	36.0	40.2

Table A4. Bangladesh: Oil Consumption (kb/d) Forecasts with 95% CI. [Bangladesh does not produce oil and as such the production forecast is not included.]

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2025	321.5	300.0	343.0	279.0	223.0	334.7	272.7	260.1	286.4
2026	296.4	265.5	327.3	295.9	220.2	377.7	284.9	271.2	297.5
2027	293.8	260.9	326.8	313.8	220.3	420.8	297.1	283.5	310.2
2028	349.6	308.5	390.7	332.8	222.3	471.0	309.3	296.9	322.3
2029	351.7	298.3	405.1	352.9	226.1	514.0	321.5	308.3	335.7
2030	331.8	273.2	390.4	374.2	232.6	560.5	333.7	320.4	348.0
2031	370.4	305.6	435.3	396.9	236.9	611.5	345.9	331.0	359.6

Table A4. *Cont.*

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2032	394.6	318.1	471.1	420.9	244.0	675.1	358.1	343.4	372.2
2033	374.7	290.2	459.2	446.3	248.3	735.8	370.3	354.9	385.0
2034	391.5	301.0	482.1	473.3	253.8	785.6	382.5	365.7	397.5
2035	425.6	325.1	526.2	501.9	262.2	864.2	394.7	378.6	412.0

Table A5. Bangladesh: Renewable Energy Forecasts with 95% CI (TWh).

Year	Hydro Forecast	Hydro Lower	Hydro Upper	Solar Forecast	Solar Lower	Solar Upper	Wind Forecast	Wind Lower	Wind Upper
2025	0.9	0.6	1.2	1.6	1.5	1.7	0.1	0.1	0.2
2026	0.9	0.6	1.2	1.9	1.7	2.2	0.1	0.1	0.2
2027	0.9	0.6	1.2	2.2	1.8	2.7	0.1	0.0	0.2
2028	0.9	0.6	1.2	2.6	2.0	3.2	0.1	0.0	0.2
2029	0.9	0.6	1.3	2.9	2.1	3.7	0.1	0.0	0.2
2030	0.9	0.6	1.3	3.2	2.2	4.2	0.1	0.0	0.2
2031	0.9	0.6	1.3	3.6	2.3	4.8	0.1	−0.1	0.2
2032	0.9	0.6	1.3	3.9	2.4	5.4	0.1	−0.1	0.2
2033	1.0	0.6	1.3	4.2	2.5	5.9	0.0	−0.1	0.2
2034	1.0	0.6	1.4	4.5	2.5	6.5	0.0	−0.1	0.2
2035	1.0	0.6	1.4	4.9	2.6	7.2	0.0	−0.1	0.2

Table A6. Canada: Coal Production (Exajoule) Forecasts with 95% CI.

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2025	1.1	0.9	1.3	1.1	0.9	1.3	1.2	1.0	1.3
2026	1.1	0.9	1.4	1.1	0.9	1.4	1.1	1.0	1.2
2027	1.1	0.8	1.5	1.1	0.8	1.5	1.1	1.0	1.2
2028	1.1	0.7	1.5	1.1	0.7	1.5	1.1	1.0	1.2
2029	1.1	0.7	1.6	1.1	0.7	1.6	1.1	1.0	1.2
2030	1.1	0.6	1.6	1.1	0.6	1.6	1.1	0.9	1.2
2031	1.1	0.6	1.7	1.1	0.6	1.7	1.0	0.9	1.2
2032	1.1	0.6	1.7	1.1	0.6	1.7	1.0	0.9	1.2
2033	1.1	0.5	1.7	1.1	0.5	1.8	1.0	0.9	1.1
2034	1.1	0.5	1.8	1.1	0.5	1.8	1.0	0.8	1.1
2035	1.1	0.5	1.8	1.1	0.5	1.8	1.0	0.8	1.1

Table A7. Canada: Coal Consumption (Exajoule) Forecasts with 95% CI.

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2025	0.2	0.1	0.4	0.2	0.2	0.3	0.3	0.2	0.4
2026	0.2	0.0	0.4	0.2	0.1	0.2	0.3	0.2	0.3
2027	0.1	−0.1	0.4	0.1	0.1	0.2	0.2	0.1	0.3
2028	0.1	−0.2	0.4	0.1	0.0	0.1	0.2	0.1	0.3
2029	0.1	−0.3	0.5	0.0	0.0	0.1	0.1	0.0	0.2
2030	0.0	−0.5	0.5	0.0	−0.1	0.0	0.1	0.0	0.2
2031	0.0	−0.6	0.5	−0.1	−0.2	0.0	0.0	−0.1	0.1
2032	−0.1	−0.7	0.5	−0.1	−0.2	0.0	0.0	−0.1	0.1

Table A7. *Cont.*

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2033	−0.1	−0.8	0.5	−0.2	−0.3	−0.1	−0.1	−0.2	0.0
2034	−0.2	−0.9	0.5	−0.2	−0.4	−0.1	−0.1	−0.2	0.0
2035	−0.2	−1.0	0.5	−0.3	−0.4	−0.2	−0.2	−0.3	0.0

Table A8. Canada: Gas Production (bcm) Forecasts with 95% CI.

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2025	198.2	188.8	207.6	197.9	187.8	207.9	203.0	178.1	227.6
2026	200.9	183.7	218.1	200.8	183.4	218.1	205.6	179.5	229.6
2027	203.5	181.0	226.0	203.1	178.3	227.9	208.2	183.1	232.9
2028	206.1	179.4	232.8	204.9	172.6	237.3	210.8	185.2	236.6
2029	208.8	178.4	239.1	206.4	166.7	246.2	213.4	189.0	237.8
2030	211.4	177.8	245.0	207.6	160.7	254.5	216.0	192.4	242.5
2031	214.0	177.5	250.6	208.6	154.7	262.4	218.6	193.7	245.3
2032	216.7	177.4	256.0	209.3	148.8	269.9	221.2	196.2	243.2
2033	219.3	177.4	261.2	209.9	143.0	276.9	223.8	198.2	250.2
2034	221.9	177.7	266.2	210.4	137.3	283.6	226.5	200.3	252.2
2035	224.6	178.0	271.2	210.8	131.8	289.9	229.1	202.0	251.6

Table A9. Canada: Gas Consumption (bcm) Forecasts with 95% CI.

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2025	130.1	124.6	135.6	130.4	120.2	140.6	129.3	126.3	132.2
2026	130.9	123.5	138.2	132.4	118.5	146.3	131.4	128.4	134.7
2027	132.6	124.7	140.6	134.5	117.6	151.4	133.6	130.6	136.9
2028	134.4	125.9	143.0	136.6	117.1	156.1	135.8	132.6	139.0
2029	136.2	127.1	145.3	138.7	116.8	160.5	138.0	134.9	141.5
2030	138.0	128.4	147.6	140.7	116.7	164.8	140.2	136.9	143.6
2031	139.8	129.7	149.8	142.8	116.7	168.9	142.4	138.9	145.9
2032	141.5	131.0	152.1	144.9	116.8	173.0	144.6	140.8	148.4
2033	143.3	132.3	154.3	146.9	116.9	176.9	146.8	143.2	150.7
2034	145.1	133.7	156.5	149.0	117.2	180.9	149.0	145.0	153.3
2035	146.9	135.0	158.7	151.1	117.4	184.7	151.2	146.4	155.7

Table A10. Canada: Oil Production (kb/d) Forecasts with 95% CI.

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2025	6072.8	5829.5	6316.0	6043.4	5421.8	6664.9	6166.3	6029.4	6300.1
2026	6206.6	5761.4	6651.8	6198.7	5240.4	7157.0	6347.6	6216.5	6478.5
2027	6340.4	5744.0	6936.8	6354.1	5080.7	7627.5	6528.9	6380.4	6671.6
2028	6474.2	5744.4	7204.0	6509.4	4921.2	8097.7	6710.3	6554.5	6869.7
2029	6608.0	5753.5	7462.6	6664.8	4754.6	8575.0	6892.1	6721.0	7062.1
2030	6741.8	5767.3	7716.3	6820.2	4577.3	9063.1	7073.4	6889.7	7268.7
2031	6875.6	5783.8	7967.4	6975.5	4387.4	9563.7	7254.7	7026.1	7461.4
2032	7009.4	5801.8	8217.1	7130.9	4183.8	10,078.0	7436.0	7199.4	7679.7

Table A10. *Cont.*

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2033	7143.3	5820.4	8466.2	7286.3	3965.7	10,606.8	7617.8	7344.9	7883.6
2034	7277.1	5839.0	8715.1	7441.6	3732.6	11,150.6	7799.2	7497.7	8112.1
2035	7410.9	5857.3	8964.4	7597.0	3484.2	11,709.8	7980.5	7613.8	8323.2

Table A11. Canada: Oil Consumption (kb/d) Forecasts with 95% CI.

Year	ARIMA Forecast	ARIMA Lower	ARIMA Upper	ETS Forecast	ETS Lower	ETS Upper	Prophet Forecast	Prophet Lower	Prophet Upper
2025	2354.0	2186.0	2521.9	2334.6	2146.7	2522.5	2340.7	2230.7	2453.5
2026	2374.7	2137.2	2612.3	2335.9	2069.9	2601.9	2336.9	2218.3	2452.7
2027	2395.5	2104.6	2686.4	2337.1	2011.0	2663.3	2333.0	2221.1	2454.9
2028	2416.3	2080.3	2752.2	2338.3	1961.3	2715.3	2329.2	2217.8	2446.9
2029	2437.0	2061.4	2812.6	2339.4	1917.4	2761.3	2325.3	2199.6	2441.1
2030	2457.8	2046.3	2869.3	2340.4	1877.7	2803.0	2321.5	2192.5	2449.5
2031	2478.6	2034.1	2923.0	2341.3	1841.1	2841.5	2317.7	2196.7	2442.7
2032	2499.3	2024.2	2974.4	2342.2	1806.9	2877.4	2313.8	2178.5	2445.9
2033	2520.1	2016.2	3024.0	2343.0	1774.8	2911.2	2310.0	2181.4	2451.9
2034	2540.9	2009.7	3072.0	2343.8	1744.3	2943.3	2306.2	2161.6	2447.4
2035	2561.6	2004.5	3118.7	2344.5	1715.2	2973.8	2302.3	2147.5	2447.9

Table A12. Canada: Renewable Energy Forecasts with 95% CI (TWh).

Year	Nuclear Forecast	Nuclear Lower	Nuclear Upper	Hydro Forecast	Hydro Lower	Hydro Upper	Solar Forecast	Solar Lower	Solar Upper	Wind Forecast	Wind Lower	Wind Upper
2025	86.9	75.5	98.4	341.5	316.4	366.6	11.7	11.0	12.5	49.5	44.7	54.3
2026	88.4	72.1	104.6	339.7	302.8	376.7	13.0	11.9	14.2	52.2	44.8	59.6
2027	89.8	69.9	109.7	338.0	290.9	385.1	15.1	13.3	17.0	54.9	45.1	64.7
2028	91.3	68.3	114.3	336.3	279.8	392.7	16.6	14.0	19.2	57.6	45.4	69.7
2029	92.7	67.0	118.4	334.5	269.1	400.0	18.6	15.2	22.0	60.3	45.7	74.8
2030	94.2	66.0	122.3	332.8	258.5	407.1	20.1	15.8	24.4	63.0	46.0	79.9
2031	95.6	65.2	126.0	331.1	248.0	414.2	22.0	16.8	27.3	65.6	46.2	85.1
2032	97.1	64.6	129.6	329.3	237.4	421.2	23.7	17.4	30.0	68.3	46.3	90.4
2033	98.5	64.1	133.0	327.6	226.9	428.3	25.5	18.1	32.9	71.0	46.3	95.7
2034	100.0	63.6	136.3	325.9	216.3	435.5	27.2	18.7	35.7	73.7	46.3	101.1
2035	101.4	63.3	139.5	324.1	205.5	442.8	29.0	19.3	38.7	76.4	46.2	106.6

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