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Review

Actualization and Adoption of Renewable Energy Usage in Remote Communities in Canada by 2050: A Review

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Abstract: Remote community initiatives for renewable energy are rapidly emerging across Canada but with varying numbers, success rates, and strategies. To meet low-carbon transition goals, the need to coordinate technology deployment and long-term policy to guide the adoption is critical. Renewable resources such as wind, solar, hydro, and biomass can provide energy at a subsidized cost, create sustainable infrastructure, and provide new economic viability in social value integration. The renewable energy transition is crucial to Canada in sustaining remote and indigenous communities by providing local, clean, and low-carbon-emission energy for heat, power, and possibly transportation. This paper identified 635 renewable resources projects deployed to improve and increase electricity supply. To an extent, balancing demand within the remote and indigenous communities of Canada and highlighting sustainable renewable energy development through ownership participation within the communities is achievable before 2050 and beyond through energy efficiency and the social value of energy. The article identifies clean energy targets as mandated by the different provinces in Canada to reach net-zero GHG emissions.

Keywords: renewable energy transition; socio-technical transition; social value energy; sustainable development

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1. Introduction

Globally, there is growing momentum in developing and commercializing renewable energy. This impetus is driven by well-documented empirical data showing the adverse environmental impact of global dependence on the use of fossil fuels for energy [1,2]. The consumption of fossil-based energy has resulted in well-documented climate change and increasing concentrations of carbon dioxide (CO_2) and greenhouse gases (GHGs) [2]. The essence of sustainable energy innovations is shifting from the centralized global tradition (fossil-fuel-based energy) to bringing in a new energy innovation system through new policies and ensuring the sustainability of low carbon emissions [3]. Studies recently reported that the global energy supply system and demand rely primarily on fossil fuels by over 85%. Replacing fossil fuels with renewable sources for electricity generation will be a prolonged multidecadal process [4,5]. As of 2021, considering the world's energy production from all sources, fossil fuels comprise 80% (24% natural gas, 27% coal, and 29% crude oil), biomass 10%, and electricity 10%. Furthermore, after the coronavirus disease (COVID-19) pandemic in 2020, there was a decline of 4.1% in global energy demand and production; in 2021, global energy production rebounded by 3.4% [6]. The rise of renewable energy sources (28%) is projected to surpass petroleum and other liquids (27%), natural gas (22%), coal (20%), and nuclear (4%) to become the most utilized and consumed energy source for electricity generation by 2050. Energy transition results from reducing technology costs and changes in government policies to an extent, contributing to electric power generation using renewable energy sources to match the electricity demand [7].

Currently, over 95% of energy for electricity, heating, and transportation is derived from the combustion of fossil fuels, constituting the largest source of GHG emissions. In 2021, global GHG emissions were 52.8 global total carbon dioxide equivalent ($GtCO_2e$), with the top GHG-emitting countries (China, USA, Russian Federation, Brazil, and India) accounting for 55% of these emissions globally, while G20 nations accounted for 75% [8]. According to Lamb et al. [9] and Dhakal et al. [10], these global GHG emissions can be further disaggregated into key emitting sectors responsible for most of the growth in GHG emissions since 1990. Such emissions are from agriculture (37%), forestry (18%), industry (28%), transportation (14%), and direct energy utilization in buildings (15%). Developing new energy-efficient and CO_2 emission-reduction technologies and their deployment in the market is key for an industrial energy transition to achieve long-term climate change mitigation strategies [11,12]. Decarbonization in the transport sector also contributes to these mitigation goals, such as electrifying private cars and public service vehicles, that could reduce carbon emissions. Oil products in the transportation demand constitute a global phenomenon and contribute the highest GHG emissions among other sectors [13]. The electrified transport system in Canadian provinces such as British Columbia, New Brunswick, Ontario, Prince Edward Island, Quebec, and Yukon territory is becoming an important discussion; targets for zero-emission vehicles to make up 10% of all new light-duty vehicles sales by 2020, 30% by 2030, and 100% by 2040 have been initiated. Furthermore, similar transport emissions cuts in the European Union, the United States, Mexico, and some Asian countries have been planned, with the aim to deploy fully electric vehicles by 2030 and beyond [13,14]. The International Renewable Energy Agency (IRENA) [15] report highlighted the Paris Agreement and the 26th Conference of the Parties (COP) on the right path to a climate-safe future where countries pledged support to net zero emissions by 2030 and a global temperature rise no more than 2.8 °C under the initial nationally determined contributions (NDCs). Moreover, the report further explores the transformative renewable energy opportunities that could enhance emission reductions and multiple sustainable development goals (SDGs).

In 2020, global fossil fuel CO_2 emissions were 35 billion tonnes, and these data were generated from relevant countries that significantly contribute to energy-related GHGs. Countries such as Brazil, Russia, India, China, South Africa, Mexico, Indonesia, Nigeria, and Turkey had emissions of 15.3 billion tonnes, 47% of the global fossil fuel CO_2 emissions. Coal at 68%, oil at 29% and gas at 26% are the leading CO_2 emissions among the countries mentioned. China showed the highest coal-related CO_2 emissions, followed by India, Indonesia, and Turkey [16]. The International Energy Agency (IEA) [17] Canada report indicated that energy production and use accounts for over 80% of GHG emissions, with fossil fuel combustion in oil and gas extraction, electricity and heat generation, and refining at 26%, transportation at 26%, building at 13%, manufacturing industries at 9%, and fugitive emissions at 7%. Overall, Canada has pledged, under the Paris Agreement 2015, to meet or exceed GHG emissions reduction targets of 30% below 2005 levels by 2030 and possibly net zero emissions by 2050. Consequently, clean fuels for Canada's energy sector represent a low-carbon investment transition to hydrogen, advanced biofuels, renewable natural gas, sustainable aviation fuel, and synthetic fuels [17,18]. Net-zero electricity in Canada has continued to be distinct across ten provinces in meeting their power generation demand in diverse ways, with widely varying mixes of hydro, nuclear, wind, solar, hydrogen, biomass with carbon capture and storage (CCS), and fossil fuel combustion with CCS [18]. The wealth in the bioeconomy ranks Canada as the fourth largest producer of natural gas and crude oil, third largest hydro producer, and tenth largest renewable electricity generator. Furthermore, the cost of renewable energy is decreasing in various markets; thus, making it less expensive compared to gas or coal-fired electricity. To date, Canada has improved in managing a high amount of variable renewable energy without compromising reliability [19–21]. A sustainable energy transition enhances energy sources, conversion, transmission, and consumption, placing emphasis on the leading energy consumption sectors such as heat and power plants and transportation. Most energy transition studies focus on energy sources, technologies, reducing emissions, and community energy as potential pathways for renewable energy deployment [22,23]. The Canadian energy sector aims to have zero traditional coal-fired power by 2030 and maximize the investment in the bioeconomy for sustainable renewable energy transition within remote communities [24]. Studies have reported that renewable energy has attracted significant attention.

Renewable energy sources are naturally occurring sources that are inexhaustible, replenished through natural forces, and play a significant role in the energy transition [25]. Renewable energy sources have been identified as a solution to mitigating GHGs, climate change, and environmental pollution. Moreover, they contribute to socioeconomic and environmental energy sustainability [26]. These renewable sources, such as hydro, wind, geothermal, lignocellulosic biomass, and tidal, are considered future energy sources to replace non-renewable energy from fossil fuels [27]. In addition, renewable energy sources are characterized by achieving sustainable energy in electricity generation to reduce carbon emissions [28,29]. Nwanekezie et al. [30] highlighted that renewable energy sources are a pathway to low-carbon transitions; however, the energy transition has been frustrated by rigid institutions, political challenges, value conflicts, and leadership styles. Hoicka et al. [31] reported that a 63% share of the renewable energy of the total energy system by 2040 must be in place to achieve the 2030 Agenda for Sustainable Development. The Canadian government is ensuring that the renewable energy transition to a low-carbon economy investment remains a people-oriented program and project, focusing on gender equality, indigenous inclusion, and clean energy education and empowerment for all affected communities [17,31].

1.1. Renewable Energy Transition

The global power generation from renewable energy sources remained stable at 28.1% between 2021 and 2022, even at the peak of the COVID-19 pandemic, and 26.3% above 2019. Countries such as Brazil, Canada, Sweden, and Norway showed larger electricity generation, with over two-thirds of hydropower [32]. The energy transition in Canada is consistently moving forward to renewable energy, prioritizing energy efficiency and investing heavily in decarbonized electricity produced in an increasingly decentralized manner from a growing diversity of energy sources. The interprovincial energy trade presents a technically feasible and cost-effective initiative to support increased renewable energy projects and improve grid resilience. Hydropower, solar, wind, bioenergy, nuclear, and geothermal energy would play a leading role in the current transition [21,33,34]. Furthermore, the energy transition requires creativity and enhanced innovation through institutional reform, changing consumer preferences, environmental imperatives, and storage technologies. The target is to achieve more than 90% of electricity from renewable and nuclear sources compared to the current 81% generation. Renewable energy sources' storage technologies improve the flexibility of the grid. To an extent, the costs of utility-scale lithium-ion batteries are decreasing drastically and are projected to decrease in price due to innovations in transportation applications [33,35–37]. Renewable energy transition technologies are categorized into three eras. The first era witnessed hydropower, biomass, and geothermal energy in the nineteenth century. The second generation in the 1980s was tidal-wave power and solar energy. The third or present generation is still developing and is based on advanced biorefinery, gasification, and ocean thermal power [38]. IEA [39] highlighted that renewable sources are increasing rapidly alongside persistent challenges. The challenges include providing strong policies addressing social acceptance of the energy transition, cost, sustainability, and technical limitations.

1.1.1. Hydropower

Hydroelectric power is derived from flowing water; the basic principle is using water to drive turbines. Hydroelectric power is generated by converting kinetic energy from water into electrical energy. Hydropower plants are categorized as dams with reservoirs (storing water over short or long periods) and hydropower without dams and reservoirs (for small-scale operation and designed to operate in a river without any interference). In 2020, hydropower contributed 16% of global electricity generation and will be even more by 2050, surpassing fossil fuels. Norway's electricity comes from 99% hydropower. The world's largest hydropower plant is 22.5 gigawatts (GW), located in the Three Gorges Dam in China, producing approximately 100 terawatt-hours (TWh) per year and serving between 70 and 80 million households [40,41]. Canada has been developing its water resources to produce clean, sustainable, reliable, and affordable electricity, thus, providing 60% of the country's total electricity generation supply. In addition to power generation, reservoirs can control floods, provide the water supply for industrial, agricultural, and domestic use, and power from stored water even during droughts. Hydropower generates tremendous economic opportunities and creates thousands of jobs in communities, partnering with indigenous communities in long-term economic opportunities from coast to coast to reduce the dependence on diesel fuel electricity generation [21,42]. Between 2017 and 2021, over 100 installed hydropower projects across Canada cost approximately $232 billion. Most projects are under review, approved, announced, and under construction [43]. Hydropower is environmentally friendly and releases fewer GHGs than fossil fuels such as coal, natural gas, oil, and diesel. The overall output process is very high, between 90% and 95%, capturing all potential energy of the water. Hydropower challenges could include power loss due to low pressure in the hydraulic circuit, rotational friction, and failures in electrical equipment. Hydropower benefits greatly as low-cost renewable electricity supports power generation and supply between provinces and territories [21,44,45].

1.1.2. Bioenergy

Biomass is organic materials such as agricultural, forestry, and industrial and domestic waste that are converted into bioenergy using various physical-chemical processes. The bioproducts after biomass conversion into biofuels are biodiesel, bioethanol, and methanol for combustion engines [46]. Consequently, a series of drop-in biofuel meetings have been ongoing, establishing technical standards for combustion engine blends with or without fossil-based petroleum. Moreover, in producing biomass feedstocks, environmental and socio-economic impacts are significant in certifying sustainability criteria [47,48]. Various deconstruction, thermochemical, biochemical, and fractionation techniques could be applied to utilize biomass for biofuel conversion. High temperatures (pyrolysis, hydrothermal liquefaction, and gasification) involve the thermal and chemical treatment of biomass without oxygen to produce biochar and bio-oil. Low-temperature destruction (biochemical conversion of enzymes) consists of the breakdown of lignocellulosic internal tissues of recalcitrant structures to open channels for enzymatic reaction processes. The sugars produced are intermediate building blocks that can be fermented into advanced biofuels [49–51]. Globally, biomass is abundant in one form or another, and Canada has massive untapped renewable energy resources; more than 23% of Canada's total renewable energy production is from solid biomass. Thus, biomass is a significant energy source that guarantees energy security with limited environmental impact. In 2021, Canada invested $7 billion to support bioenergy deployments and technologies, and the total energy production is projected to surpass 2.6% in 2020 [37,43,52–54]. The technological pathways have been extended in modifying and exploiting microbes through genetic engineering techniques for biofuel production. The biofuels produced are acceptable due to their renewability, biodegradability, and quality exhaustible gases [55,56].

1.1.3. Wind-Solar Energy and Storage

Wind-solar energy and energy-storage companies have started deploying and installing new capacities to ensure Canada achieves its net-zero target. The focus is to have a strong base of community support, meaningful and sustained community engagement, and strong partnership with rural and indigenous communities in providing wind, solar energy, and energy storage. In addition, clean energy project installations using wind and solar energy are expected to provide $1.5 billion in employment and sustainable income to indigenous communities for the next ten years [33]. Power generation using wind and solar energy is more environmentally friendly than fossil fuels (oil, natural gas, coal, and diesel). In 2021, wind and solar energy produced 10.7% of power generation, surpassing nuclear energy by more than 10% of global power and global power generation by +8.4 points more than in 2010. In decarbonization, low-carbon investments have become significant, driving low technology costs, creating market opportunities for domestic and international markets, and expanding learning by research and development [17,32,40,57,58].

Wind Energy

Wind energy represents a mainstream energy source of new power generation and plays a significant role in the world's energy market. Wind is an inexhaustible and free energy source, available and abundant in most regions of the earth. Wind generation is due to air movement as a result of atmospheric gradients. Wind energy is kinetic energy in flowing air and can be converted into electrical energy by power machine converters or direct use for water pumping, sailing ships, or grinding gain. Applications and the utilization of wind power can be categorized based on wind turbine size classifications such as small ($\leq$100 kilowatts (kW)), mid-size (101 kW—1 megawatt (MW)), and large-scale (>1 MW). In 2021, global offshore wind capacity installations tripled (+21 GW), and China topped the list [32,59]. Wind energy is Canada's lowest-cost source of new generating capacity. Globally, wind energy (698 GW) was the second largest renewable energy source installed in 2020, and most of the production was from onshore, while the remaining 34 GW was from offshore. Canada has no offshore wind farms but has proposed to install some that are 3.6 GW in capacity, having realized the technological advancement that turbines could be built more than 60 km from shores and in deep water (2000 m). Wind power is cheaper than coal electricity; thus, offshore wind is more expensive than other renewable energy sources. The Canadian energy regulator is working on achieving 40 GW of installed wind capacity by 2050 [60–62].

Solar Energy

Solar radiation is radiant energy direct from the sun as electromagnetic waves. Technologies and processes have been developed and applied to collect and utilize solar energy. A solar cell system converts light energy into electrical energy using a semi-conductive material (silicon), and an inverter converts the power before distribution [63]. The amount of energy produced per day depends on the solar panel area, shading, orientation, and watt class. Solar energy cost has been reduced to 90% in the last decade and continues to decline; also, there is a geopolitical shift in the global energy market for the solar photovoltaic industry. However, the main challenge of solar energy is the variability and intermittence in supply and low electricity conversion efficiency. In 2021, global solar power increased steadily by 23%, and installations remained dynamic at 133 GW. At the end of 2022, Canada installed approximately 4 GW of solar energy and projected 20 GW in 2050. Globally, the annual market will grow by 17% per year, with almost 160 GW in capacity for 2021 and projections of 200 GW by 2026 [17,32,57,58,62].

1.1.4. Nuclear Power

Canadian nuclear power plants are among the 30 uranium plants globally generating electricity. As of 2019, approximately 25% of the low-carbon electricity was produced from nuclear, making it the second largest alternative energy source after hydropower. Canada is the largest uranium producer in the world, with 13% production in 2019 and 22% in 2017, of which 85% is exported worldwide, and the remaining 15% is used to fuel reactors in Ontario and New Brunswick. Canada has 19 operable nuclear reactors, generating 15.3% (98.2 TWh) with 14 GW of electricity capacity installed in 2021. Currently, Saskatchewan is Canada's only province producing uranium [19,37,64]. Uranium hopes to reduce emissions and related environmental impacts; between 2017 and 2021, Canada invested approximately $139 billion in nuclear power projects [43,65]. Canada is initiating a nuclear innovation for a low-carbon future through small modular reactors for use in heavy industry and remote communities. The nuclear energy invention is a world-class technology that provides non-emitting energy for a wide range of applications, generating huge revenues estimated at $150 billion yearly from the global market by 2040 [66]. Small modular reactors are sustainable, cheaper, faster to deploy, generate less waste, and have less risk of explosion [67].

1.1.5. Geothermal Energy

The use of geothermal heat from the earth's molten core to generate electricity is another option. Furthermore, a ground source for heating and cooling is known as a ground-source heat pump. The steam, heat, or hot water from geothermal reservoirs provide the force that spins the turbine generators and produces electricity. There are varieties of geothermal power plants, namely the (a) dry steam reservoir, (b) hot water reservoir, and (c) low-temperature reservoir (90–150 °C). These technologies produce electricity at lower GHG emission levels and play important roles in achieving targets for energy security, economic development, and the mitigation of climate change. Apart from electricity generation, other uses include health spas, greenhouses, aquaculture, and milk pasteurization. Geothermal energy contributes >1% of global electricity generation, and Canada contributes the same but with a capacity projection of 10 megawatts of electricity (MWe) by 2050. Only the Northwest Territories in Canada have explored and developed geothermal wells. The government's investment in geothermal technologies is $200 million shared with tidal energy to expand the range of decarbonization options as forecasted [19,37,53,68,69]. According to Hutter [69], the global geothermal power installation capacity increased by 3.65 GW (27%) between 2015 and 2020. Thus, between 2017 and 2021, the total investments in geothermal projects were valued at $1.3 billion. The challenges that accompany adopting and accepting geothermal plants are the huge development costs, high upfront risk, huge conventional technology costs, and low electricity conversion efficiency [43,70]. Utilizing these renewable energy projects is believed to boost low-carbon economic investment and provide a channel for achieving the net-zero target by 2050.

Canada's economy has significantly benefited from the energy sector, contributing 11% of the gross domestic product with over 250,000 jobs created. The Canadian government is gradually phasing out its coal-based electricity and targeting the increase in electricity generation from renewable energy sources. Furthermore, remote communities are abundantly endowed with energy supply, such as large hydroelectric reservoirs in British Columbia, Ontario, Quebec, and Manitoba; hydrocarbon resources in western Canada and offshore East Coast; northern Saskatchewan uranium deposits; and numerous locations for wind and solar projects across the country [19–21]. Remote communities are primarily First Nations, which control and own 15 million hectares, whereas the Inuit have over 45 million hectares of land. To an extent, over 90% of renewable energy projects are on indigenous land [19]. This paper focuses on reviewing the transition to deploying and installing renewable energy resources to increase electricity demand using a case study of remote communities in Canada within the last decade. The specifics identify the number of renewable energy sources as viable electricity generation alternatives in the indigenous and remote communities between 2010 and 2021, ownership patterns for sustainable benefits, and economic development in achieving net-zero GHG emissions by 2050. The review study materials were collected from the following databases: Canadian renewable energy-climate-action-statistics 2021, Canadian renewable energy association 2021, and Canadian renewable energy project map 2022.

2. Energy Transition within Canadian Remote Communities

In 2020, Canada was regarded as having the seventh-largest renewable energy production capacity globally [71]. Canada has clean electricity systems; 80% of the electricity is from hydropower, wind, solar, and nuclear. The mandatory renewable energy target (RET) policy has been legislated in many countries, and the focus is to promote alternative energy and reduce fossil fuel dependency [72]. The European Union is reported to have achieved RET's first phase of 20% by 2020 and followed up with an ambitious target of 35% by 2030. North American countries such as the USA, Canada, and Mexico have a target of 50% RET by 2025, Latin America has 70% RET by 2030, and West African countries are aiming for 38% RET by 2030 via the creation of 20 GW solar energy generation [73]. Moreover, the clean energy target [14] and IEA [71] Net-Zero by 2050 reported that Canada's target is to generate 90% of electricity from non-emitting sources and possibly net-zero greenhouse gases (GHG) by 2035. Natural Resources Canada reported that between 2010 and 2018, renewable electricity generation across the country increased by 16%, coming from wind and solar, whereas 67% of electricity needs are from biofuels, hydro, solar, and wind [53]. The energy transition is not limited to engineering, technologies, and bioeconomy but rather includes physical and social geographies, social meaning, and the political organization of energy production, distribution, and consumption [74,75]. Overall, the goal and interest are to continue advocating for a global transition to a cleaner and green economy and possibly decrease market demands in the oil and gas industry. Furthermore, through the Energy Sector Management Assistance Program, Canada and the World Bank provided $25 million to develop and implement renewable energy in low- and middle-income populations within communities [24,76]. The framework supports social energy designs with flexible regulations and policies [77]. Canada has ten provinces and three territories and is the second-largest country in the world by total land area. With a massive land area, Canada ranks fourth as the world's largest area of freshwater lakes. The 2021 Canadian census recorded an increase of 5.2% in population growth over 2016 data. Thus, the Canadian population had the lowest growth rate of 0.5% between 2011 and 2021 [78]. Most renewable energy projects are domiciled in 152 out of 188 First Nations communities across Ontario, British Columbia, Quebec, and Nova Scotia. British Columbia and Ontario are tipped to have high numbers of indigenous communities and more supportive policies for renewable energy transition than other provinces [31]. In 2021, the Canadian government released $40.1 billion in gross domestic expenditure for research and development (GERD) to support natural sciences, engineering, social sciences, humanities, and art projects. The 2021 funding was initiated from the research and development expenditures in 2019 and 2020, which comes from the following sectors: The federal government, provincial governments, business enterprises, higher education, private non-profit organizations, local research organizations, and foreign patterns [76].

Remote communities in most parts of Canada are shifting to renewable energy because of the high grid electricity cost, affecting their socioeconomic energy value and prompting a dive into carbon-intensive diesel-powered electricity [77]. These communities use diesel to meet both their electricity and heating needs. This emphasis is important because it points to two technological pathways for the use of biomass: (a) strictly for heating and (b) combined heat and power. Generally, electricity generation by diesel in the 144 Canadian indigenous communities has shown environmental degradation, poor quality services, and potentially restricted community development. To an extent, non-technical barriers and technological constraints in these communities have limited the renewable energy transition [79]. Stefanelli et al. [77] highlighted that renewable energy development in electricity generation is increasing across the country. As of 2017, only six Canadian provinces (Alberta, British Columbia, Nova Scotia, Ontario, Quebec, and Saskatchewan) generated more than 94% of energy demand from renewable sources [53]. Hoicka et al. [31] reported that 292 communities were off-grid in a 2011 report, wherein 170 are indigenous and over 50% depend on diesel fuel, which is expensive to transport. In addition to the Copenhagen Accord 2009, Cancun 2010, and Paris Climate Conference 2015 agreements, provincial governments initiated renewable energy targets and policies to assist in accomplishing action plans and frameworks to reduce emissions by 2030 [14]. Consequently, the 2015 United Nations mandate of 17 SDGs (Goal number 7) supports renewable energy transition through affordable, reliable, sustainable, and modern energy for all [80,81]. The Canadian Pact for a Green New Deal, launched in 2019, advocates for a 100% renewable energy transition and indigenous communities' reconciliation, recognizing every potential renewable energy project in Canada that resides on indigenous traditional lands. The benefits of the technological niche are distributed locally, believing that community energy is a potential pathway for renewable energy deployment and bioeconomic advancement [31,82].

Several studies have tracked renewable energy transition deployment via electricity generation within Canadian communities. Many publications on the renewable energy transition, including energy policies, have shown efficiency in research and development to improve energy access for remote communities seeking electricity generation diversification across Canada. Figure 1 displays 65 published research papers between 2010 and 2021 that support the growing interest and development in the renewable energy transition within remote communities of Canada. The profile in Figure 1 suggests that the research and development of the energy transition for green electricity generation have been active in the last decade in Canada. Several strategic studies on renewable energy actualization and adoption have revealed various frameworks for the renewable energy transition.

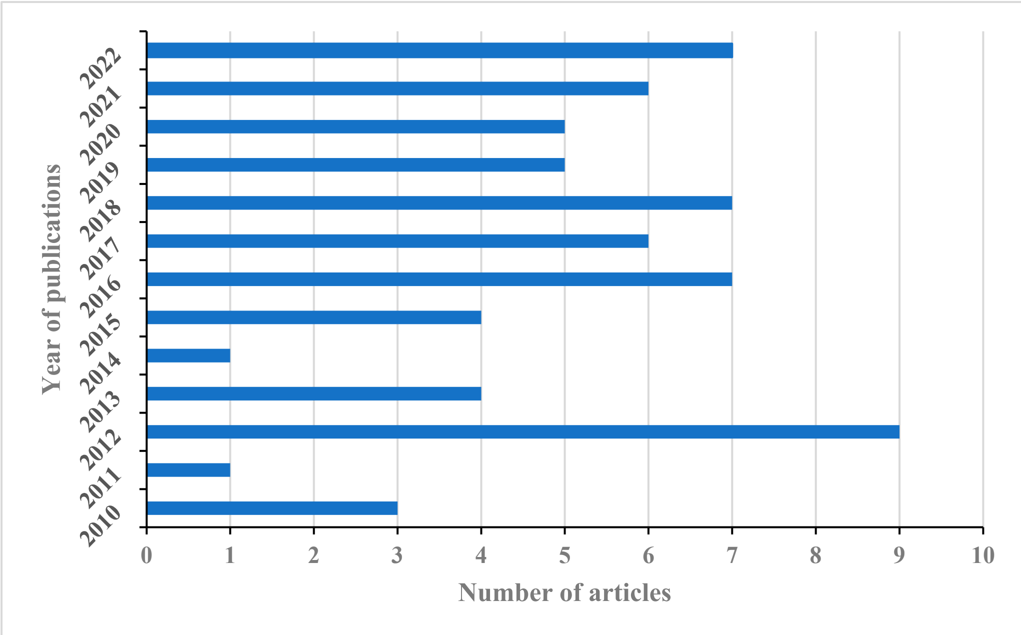


Figure 1. Number of papers published tracking renewable energy transition within Canadian communities (by April 2023).

Nwanekezie et al. [30] studied the strategic assessment of the renewable energy transition and development in Saskatchewan, Canada. The results indicated opportunities and risks in the energy transition and its economic impact. They also highlighted the actualization and implementation strategies to ensure an effective renewable energy transition and target realization for future electricity generation within remote communities. In addition, Stefanelli et al. [77] suggested that indigenous communities should be part of the decision-making process and ownership of renewable energy and energy autonomy. Since technology deployment is within the provinces, indigenous involvement would involve leadership, motivations, partnering, or/and participation in the renewable energy sector to establish more reliable energy systems, autonomy, and long-term financial benefits due to clean energy. Barrington-Leigh and Ouliaris [83] examined the renewable energy landscape in Canada. The study used the population density nationwide to analyze renewable energy sourcing, development, and expansion. The study suggested that renewable energy technologies can be deployed, but two-thirds of the energy comes from onshore and offshore wind, while the remaining comes from hydro. Canada's total electricity demand from renewable sources is 82% compared with the top four electricity-generating nations, such as Russia, the US, China, and India. Notably, from 2000 to 2018, Canada's greenhouse emissions from electricity production decreased by 50% due to the renewable energy transition [39]. Hoicka et al. [84] reported a similar study on renewable energy transition implementation, using European policy advice for renewable energy communities. The study used renewable energy directives to highlight the benefits and challenges of the community energy transition and provides technology solutions and policy advice for effectively implementing the renewable energy transition within the communities. Karanasios and Parker [79] studied the transition by tracking renewable electricity in remote indigenous communities in Canada. The findings indicated that from 1980 to 2016, seventy-one renewable energy resource projects were deployed in remote communities (Yukon, Northwest Territories, British Columbia, and Ontario). The indigenous communities' transfer of ownership and active participation sustained the energy transition, economic development, and self-governance benefits. Mercer et al. [85] investigated barriers to the renewable energy transition in a case study of wind energy development in Newfoundland and Labrador. The study reported no single barrier to developing renewable energy sources but provided policy solutions to sustain the wind energy development plan. Hoicka et al. [31] conducted a survey and the involvement of indigenous communities in Canada's energy transition, which is a potential pathway to reconciliation. The study revealed 41 renewable energy projects controlled by indigenous communities and suggests that supporting equity ownership and comprehensive policy would increase attention and reconciliation for community development. The literature studies highlighted that research and development is a driving factor in promoting new renewable energy technologies for energy policymakers and scaling up.

2.1. Renewable Resources Deployment within Remote Communities (2010–2023)

In the last decade, Canada has been a global leader in renewable energy deployment and second in substantial diversified renewable resources such as hydro, wind, solar, biomass, geothermal, and coastal tides (within remote communities) to produce energy. Canada was the third-largest exporter of electricity in 2018; however, in 2017, over 94% of electricity demand came from renewable sources [53]. The energy transition pathway identifying renewable energy project deployments within remote communities covers 2010 to 2020 sourced from hydroelectric, wind, solar, and biomass.

2.1.1. Actualized and In-Operation Renewable Energy Projects

Table 1 shows the number of renewable energy projects deployed and operational in different remote communities within the twelve provinces. Figure 2 shows the growth of Canada's installed biomass, hydro, wind, and solar energy projects between 2010 and 2021. According to Pneumatikos [86], the Canadian government in the late 1970s initiated support for renewable energy transition development within remote communities to reduce the over-dependence on fossil fuels. Notably, the increase in electricity consumption due to population, residential, and community building growth resulted in renewable development due to the increased demand for diesel-generated electricity [20,31]. The data show that 635 renewable energy projects deployed between 2010 and 2021 are associated with the communities participating in renewable energy in Canada. Most deployed and in-operation projects (>50) are in Ontario, British Columbia, Nova Scotia, and Quebec. Between 2010 and 2021, the actualized renewable energy installations for electricity generation increased by 30%, with wind and solar energy installations in operation having the highest growth. Water resources have been sustained to produce clean, reliable, and affordable electricity for nearly 140 years [87].

Table 1. Number of deployed renewable energy technology projects in remote communities of Canada [31,33,88].

Province	Biomass	Hydro	Wind	Solar	Total In-Operation
Alberta	6	0	17	19	42
British Columbia	23	50	13	3	89
Manitoba	0	1	2	1	4
New Brunswick	3	0	7	0	10
Newfoundland and Labrador	1	0	1	0	2
Northwest Territories	0	2	1	2	5
Nova Scotia	2	0	72	2	76
Nunavut	0	0	0	2	2
Ontario	22	26	93	174	315
Prince Edward Island	0	0	2	1	3
Quebec	8	14	42	4	68
Saskatchewan	2	0	7	6	15
Yukon	0	2	0	2	4

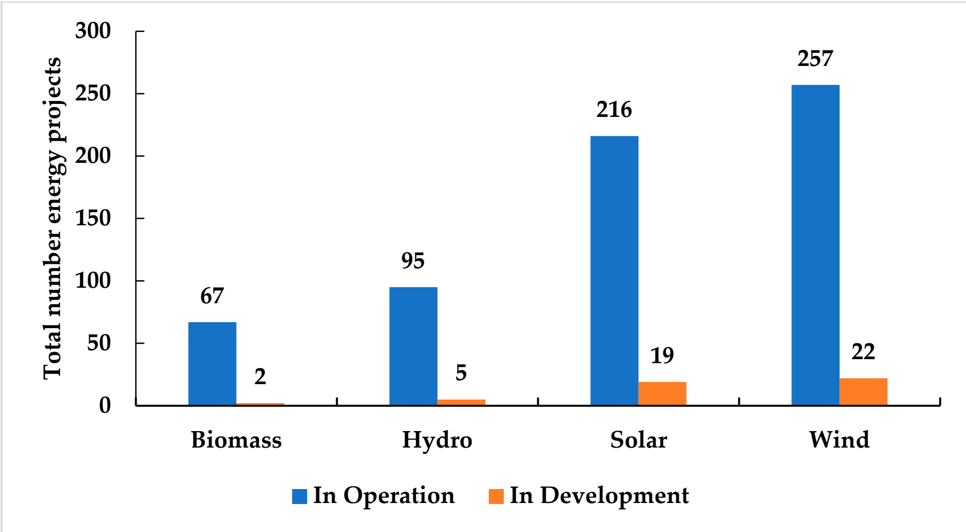


Figure 2. Number of biomass, hydro, solar, and wind projects in operation and development in Canada (2010–2021) [31,33,88].

Figure 2 shows that 15% of hydro projects have been installed and become operational within the last decade. British Columbia has the highest number of hydro projects, followed by Ontario and Quebec (Table 1). Wind and solar constitute 40% and 34% of installed and fully functional projects across the communities of Canada. Wind and solar deployed projects have increased by 10% as new renewable generation capacity additions between 2018 and 2021 for electricity generation. The data show that Ontario has the highest number of solar and wind projects, followed by Nova Scotia and Alberta. Wind energy deployments have been installed most in each indigenous community of Canada compared to solar, hydro, and biomass. Over 299 communities in the reported provinces and territories (2019 and beyond) and over 35 indigenous communities have benefited from wind energy installations. Table 1 also shows that remote and indigenous communities in eight provinces are home to 67 operational biomass-to-energy generation units, and 45 are installed in British Columbia and Ontario. Thus, British Columbia's electricity generation is 99% from renewable sources, leading to supporting energy efficiency for clean energy. Generally, renewable source projects in development and operation are projected to grow significantly [53].

The Canadian government has supported clean energy projects for the past two decades through the Clean Energy for Rural and Remote Communities Program.

An additional $300 million has been provided for clean energy projects in indigenous, rural, and remote communities until 2027 [89]. Figure 3 shows the number of biomass, hydro, wind, and solar energy projects installed annually across Canada's remote and indigenous communities between 2010 and 2021 [31,33,88]. The data offer descriptive results for different renewable energy installations per year in the last decade for the participating communities. The results show that wind and solar energy projects are the most frequently installed within the study period. Between 2013 and 2015, 325 projects were established, and wind and solar projects comprised approximately half of the deployed projects between 2010 and 2020. By 2019 and beyond, wind and solar energy dominated renewable energy source deployment across the communities of Canada. The period showcases new phase deployments of renewables (solar, wind, hydro, and biomass).

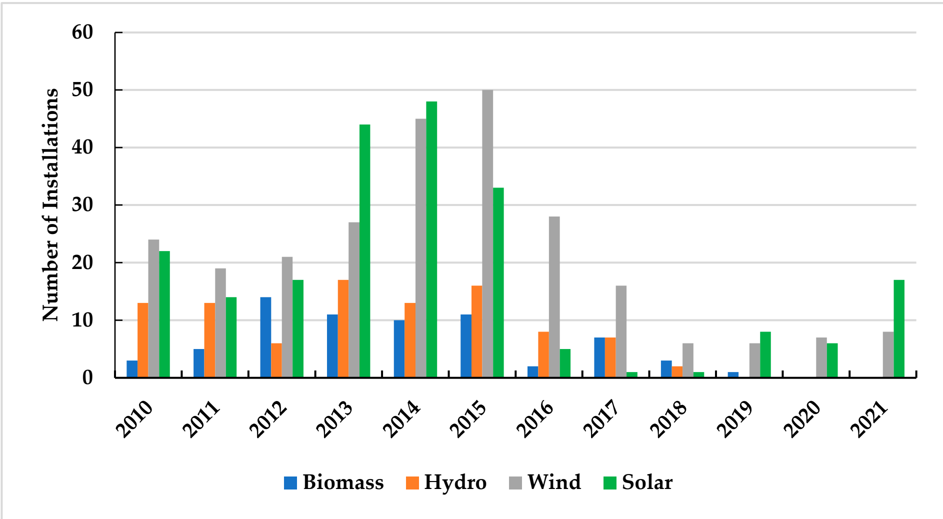


Figure 3. Installed and in-operation renewable energy projects between 2010 and 2021 [31,33,88].

The Canadian Renewable Energy Association's 2050 vision [90] report highlighted that wind and solar energy are the lowest-cost forms of new electricity generation per megawatt-hour compared to hydropower, nuclear, or fossil fuel. Moreover, Miller et al. [91] reported 26 community energy projects in western Canada. The report highlighted rural and remote communities' interest in renewable energy technologies, ownership structures, and strategic plans for economic sustainability. The deployment of energy projects within communities is evidence of renewable energy target accomplishment and a roadmap for achieving zero carbon emissions in Canada by 2050.

2.1.2. In-Development Renewable Energy Projects

Figure 2 and Table 2 show forty-eight in-development renewable energy projects within indigenous and remote communities of eight provinces.

Furthermore, more than 50 in-development projects (wind, solar, hydro, and biomass) are without installation years; thus, the quest is to meet the electricity demand within the off-grid communities by 2030 and a powerful boost of Net-Zero emissions by 2050. Beyond 2023, Alberta and Ontario are projected to be Canada's leading provinces in wind and solar deployment [33,92,93]. Moreover, the data reveal that in-development projects within indigenous communities increased in 2019 and dropped significantly after 2020 (Table 2). The decrease could be due to the global COVID-19 pandemic, which was associated with supply-chain challenges with the lockdown period for approximately two years.

Table 2. In-development renewable energy projects between 2018 and 2023 [88].

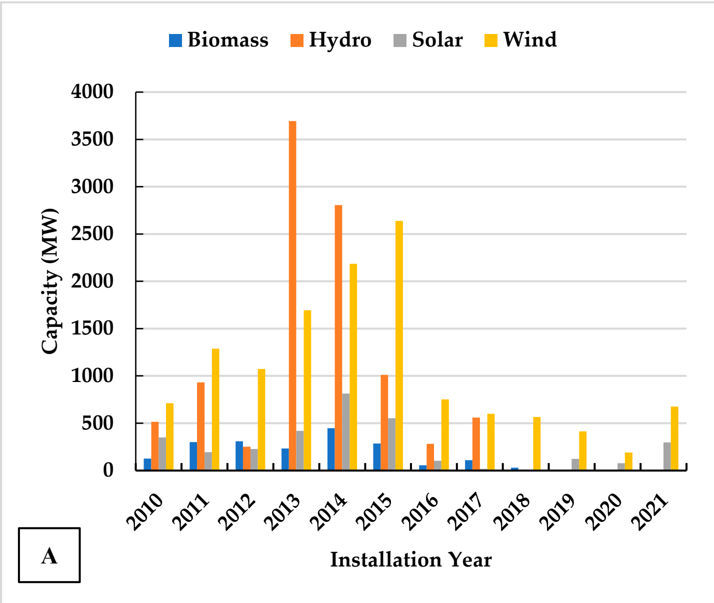
Province	Project	2018	2019	2020	2021	2022	2023
Alberta	Solar	5	7	1			
	Wind	1	11	4	1		
British Columbia	Hydro	1					
Manitoba						1	
Newfoundland			1				
Northwest Territories							1
Quebec				1			
Ontario	Biomass	1				1	
	Solar	2	3				
	Wind		5				
Saskatchewan	Solar		1				

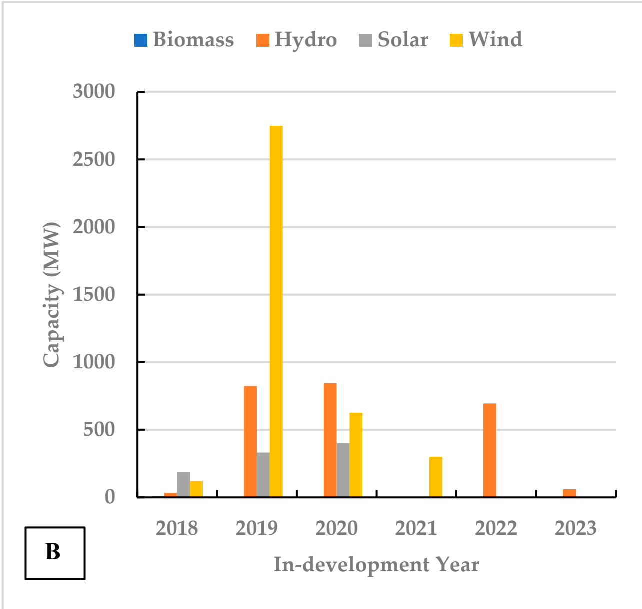
2.1.3. Installed and In-Development Projects Capacities

Canada is among member countries advocating against climate change for a cleaner and greener economy; it has 100% fund support from the World Bank-led Energy Sector Management Assistance Program to actualize and adopt the renewable energy transition [24]. Figure 4 shows the growth of installed and in-development biomass, hydro, solar, and wind energy capacities within remote and indigenous communities in various provinces.

In addition, the results in Figure 4a–c describe each project's size installation capacity, indicating Ontario has the highest installed capacities in wind energy projects followed by Quebec. British Columbia has the highest installed capacities in hydropower, followed by Quebec. Ontario has the highest installed solar electricity capacity, followed by Alberta.

The solar electricity market has grown since achieving a total capacity of 2000 MW in 2014, between 2015 and 2021, adding 33% capacity growth of approximately 1120 MW. According to the report by Solar Power Statistics Canada [94], approximately 98% of solar power generation capacity is in Ontario, making it ranked one of the top 20 solar electricity markets with high installation capacity globally. According to Miller et al. [91], renewable energy project size capacity is deployed based on a community's scale. The reported study for deployed and functional projects' capacity between 2010 and 2021 shows that 1.5% of the projects are in the range of <99 MW, 7.2% are between 100 and 499 MW, 10.9% are between 500 and 999 MW, and 80.8% fall within 1000 and 10, 000 MW. The total deployed capacity yearly shows that 2013 and 2014 had ≈22% installed capacity, with hydropower being the highest, followed by wind energy projects, which dominated in subsequent years. By 2021, Ontario, British Columbia, and Quebec had installed ≈24,300 MW, representing 87% of the total installed capacity from renewable sources. Before the end of 2021, the 12 provinces participating in renewable energy projects had installed a total generation capacity of approximately 28,000 MW of wind, solar, hydro, and biomass across their communities. The in-development projects in eight provinces and territories have proposed an installation capacity of ≈7190 MW. Consequently, in 2019, Canada produced 635 terawatt-hours (TWh) of electricity generation. Over half of the electricity is generated from renewable sources (66.6%), such as hydro, wind, solar, and biomass. The remainder is produced from nuclear (15%), natural gas (10.2%), coal (7.1%), petroleum (1%), and others (0.1%). Moreover, in 2050, total electricity generation is projected to increase by approximately 819 TWh [43].





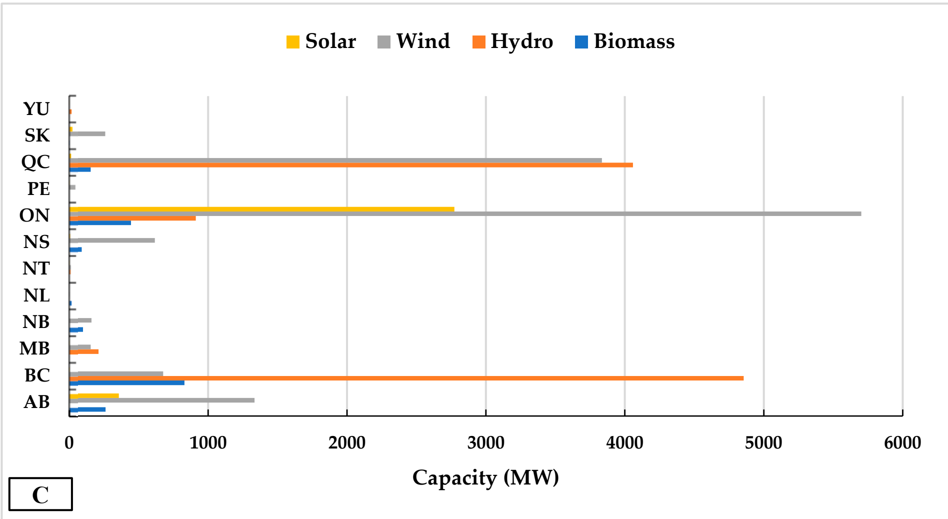


Figure 4. Total renewable energy growth capacities: (**A**) In operation, (**B**) In development, and (**C**) Province capacity [31,33,88]. AB: Alberta; BC: British Columbia; MB: Manitoba; NB: New Brunswick; NL: Newfoundland and Labrador; NT: Northwest Territories; NS: Nova Scotia; ON: Ontario; PE: Prince Edward Island; QC: Quebec; SK: Saskatchewan; YU: Yukon.

Figure 5 shows electricity generation across remote and indigenous communities in Canada. Between 2010 and 2021, wind generation across the remote and indigenous communities grew by 46% representing ≈12,800 MW spread across 257 wind energy projects, 36% for hydropower generation ≈ 10,060 MW capacity across 95 installations, 11% for solar power ≈ 3172 MW capacity in 216 project installations, and 7% for biomass ≈ 1896 MW across 67 bioenergy plants. In addition, in-development renewable installation capacities are projected to increase the green electricity generation capacity in remote and indigenous communities. Between 2018 and 2023, the in-development generation capacities of wind (53%), hydro (34%), solar (13%), and biomass (0.2%) will be included in the existing clean and green electricity generation across Canada. Overall, rural and remote communities across the country are looking ahead to future clean energy opportunities [92].

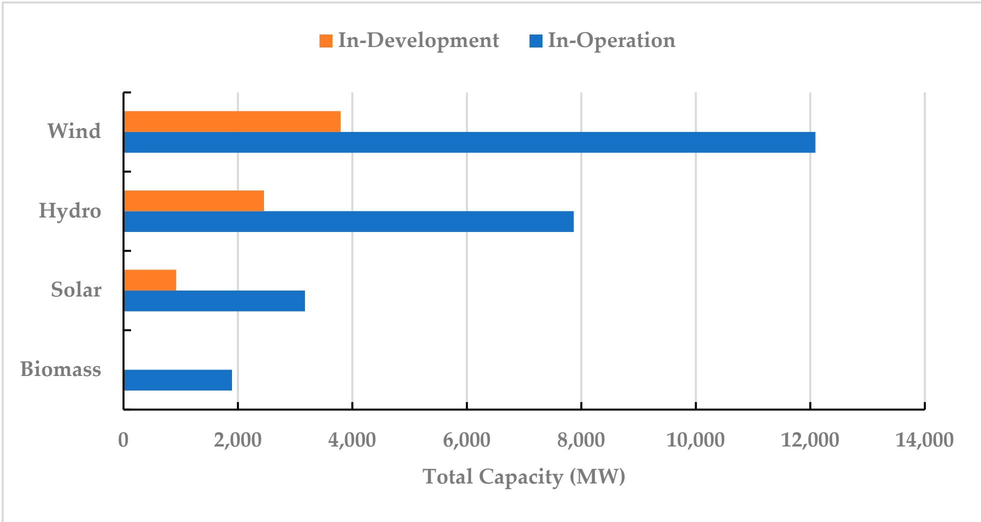


Figure 5. Total capacity electricity generation from renewable energy sources within remote and indigenous communities [31,33,88].

2.2. Ownership Pattern for Sustainable Benefits and Economic Development

Remote and rural communities are part of the regions in which small cities and towns are located that make up the Canadian landscape; they are in close proximity to the primary economic sectors such as agriculture, energy, waterways, and forestry [91]. According to the 2021 Canadian census population, indigenous people recorded 1.8 million in population growth, and between 2016 and 2021, their population increased by 9.4%. Moreover, the First Nations population increased by 9.7% and the Inuit population by 8.5% from 2016 to 2021. The population growth increase, to an extent, could be challenged by employment opportunities, rural livelihoods, and local amenities [91,95]. Through community energy deployments and actualization, the outcomes and system processes bring economic stability, social benefits, project influences, and foreign and local patterns [23,96]. Renewable energy transition sustainability is achieved by engaging participants to manage the projects after installation [91]. Table 3 shows the categories granted authority to supervise and manage the project outcomes and processes (community, joint, municipal, and private/public) across Canada's remote and indigenous communities. Furthermore, supplementary data (Table S1) are attached, indicating the breakdown of ownership categories within the participating provinces between 2010 and 2022.

Table 3. Categories of in-operation renewable energy projects between 2010 and 2021 [31,33,88].

Renewable Energy Source	Community	Joint	Municipal	Private	Provincial	Total
Biomass	2	5	6	52	2	67
Hydro	5	16	5	58	11	95
Solar	5	5	3	203	0	216
Wind	6	27	4	219	1	257
Total	18	53	18	532	14	635

The data in Table 3 highlight specific instances of the community's engagement with ownership of renewable energy infrastructures. The ownership description covered the communities in the thirteen provinces, thus indicating the project name, deployment location, installation status, year, and capacity deployed [31,33,88]. The report reveals that 635 owners of in-operation renewable projects and indigenous communities are fully represented in managing the renewable energy project as 100% community owned or in collaboration with the private sector and government. Community-controlled energy infrastructure has many opportunities to design their energy project with support from the municipality and province; in other words, the support for the renewable energy transition represents community empowerment through revenue generation, energy security, and independence [97]. As biomass, hydro, wind, and solar energy projects are deployed throughout Canada, as shown in Table 3, community support and customer satisfaction have been the characteristic reaction. The report shows that private ownership controls 84% of the renewable energy infrastructure, followed by 8% joint ownership, which involves shared, cooperative, majority, or minority ownership. Community and municipal control have 3% ownership each, while provincial control is 2%. Moreover, the report highlighted that some renewable energy installations are deployed in areas of high renewable energy potential or communities that experience an unreliable power supply [89]. Ontario, British Columbia, and Quebec have the highest representation in almost all categories, especially in private ownership. In addition, government participation (municipal or provincial) in managing the renewable energy infrastructure occurs more in Quebec, followed by Ontario, British Columbia, Saskatchewan, Alberta, and Northwest Territories (Table S1). On the other hand, government and community initiatives have the potential to control and manage renewable energy projects, influencing development, success, and sustainability [97]. Saskatchewan communities that share borders with Alberta and the province of British Columbia could share some of their high-potential wind resources. In the same vein, Quebec could benefit from the wind resource advantages of Newfoundland and Labrador, thus encouraging the transport of a large amount of green electricity within provinces [83]. Renewable energy project ownership is not only for government and foreign partners; indigenous companies' collaborations with other energy companies have been encouraged. The goal is to support and sustain the local economy for community resource development.

3. Sustainable Energy Transitions

Sustainable renewable energy transitions involve extensive clean and green energy development, such as wind, solar, hydro, biomass, and other renewable energy sources [98,99]. Studies reported that the global techno-institutional complex favours fossil fuels and discriminates against and sets back renewable energy transitions [20,100,101]. To an extent, energy policies are a possible framework that can assist in overcoming the challenges and improving the competitiveness of clean energy [98]. This review aims to contribute uniquely to how sustainably the deployed renewable projects contribute to environmental quality and economic equity. Moreover, sustainable energy transition strategies depend on a technological niche: The demand for energy saving, production efficiency, and fossil fuel alternatives using renewable energy sources and low-carbon nuclear [102]. IRENA [103] highlighted that the sustainable energy transition could remain technical, economically feasible, and beneficial by developing policy initiatives that challenge the global electricity transition for sustainable energy and electricity systems.

According to Mahbaz et al. [101], sustainability describes knowledge and technology transfer in developing human capabilities in managing natural resources as a long-term investment in consumable utilities. In other words, the renewable energy revenue transition functions as part of a sustainable society by providing infrastructure maintenance and improvement, quality healthcare, and educational and knowledge skills. Within this period (2010 and 2021), the deployed and operational renewable energy infrastructure can be sustained in two phases: (a) Energy policy and subsidy strategies and (b) research and development programs. Urgent attention is required to power Canada's journey to net-zero and immediate action is necessary to speed up the execution of renewable energy projects, especially wind and solar [33]. As reported by previous research studies, unplanned energy policies and subsidies are barriers causing an impediment to renewable energy actualization and adoption [24,29,75,79,85].

The existing United Nations Climate Conference (COP21), which formed a national policy framework in Canada, supports the transition to a global low-carbon economy. The policy provides the foundation for developing consultation strategies on the regulatory design with support from the central government in a joint venture with provinces, territories, and indigenous people in developing a pan-Canadian Framework on Clean Growth and Climate Change compared with other countries [103]. Similarly, in supporting the establishment of sustainable development goals (SDG 13: climate action) and promoting renewable energy development and adoption, the policy strategy plan will continue to support public–private partnerships through human resource development, economic expansion, and achieving green energy goals by 2030 [24,104].

The government is obliged to formalize indigenous power proponent policies through a partnership with indigenous governments and organizations in energy policy design and opportunities to develop indigenous power proponents where electricity generation is highly subsidized [92,105]. Furthermore, the renewable energy transition can be successful once there is genuine restructuring and transformation of contemporary understanding between the government and indigenous communities [31]. Energy policies are politically motivated, and, to an extent, developing sustainable energy could provide relevant and suitable policy recommendations for the intended user [106]. Energy policies are also political drivers that the government uses to influence sustainability in society by establishing energy supply security, energy affordability, and environmental impact [107].

3.1. Environmental Quality in Sustainable Energy Transitions

Environmental quality is a framework for improving the sustainability of renewable energy development [108]. To check and regulate any environmental impact, an initiative towards increasing sustainability would be enabled in terms of clean energy targets and sustainable energy indicators; the reporting period is from 2010 to 2021. According to the low-carbon power [109] report, the sustainable energy indicator is based on low-carbon energy; clean energy targets are categorized as renewable energy targets, GHG reductions, and other clean energy targets. However, in sustaining the environmental quality and generating clean energy, Canada is only ranked 24th regarding global low-carbon power, showing 82.1% of the electricity generated from low-carbon sources. Fragkos et al. [58] studied energy system transitions and low-carbon pathways and strategies until 2050 within Australia, Brazil, Canada, China, EU-28, India, Indonesia, Japan, the Republic of Korea, Russia, and the United States. The study highlighted their low-carbon economies and showcased consistency with limiting a global temperature increase ≈below 2 °C. Emission reductions are actualized through the deployment of renewable energy projects, energy efficiency improvements, and the electrification of energy services using low-carbon technologies, achieving the country's renewable energy policy plans, and implementing socioeconomic considerations. Kabeyi and Olanrewaju [102] reported on the sustainable energy transition for renewable and low-carbon grid electricity generation and supply. The study indicated that sustainable energy development could be determined by deploying social, environmental, economic, technical, institutional, and political sustainability. China's pathway to a low-carbon economy includes low-carbon cities, a circular economy and low-carbon technology, afforestation and carbon sink, emission trading, and emission reduction targets [110]. The report findings showcased achievements in low-carbon policy implementations, such as drastically reducing carbon emissions in optimizing the energy and industrial structure and establishing a national carbon trading market for the electricity industry. Similarly, Peng et al. [111] investigated the drivers toward a low-carbon electricity system in China's provinces, indicating that energy efficiency improvements and decreasing fossil fuel applications were used to achieve low-carbon transitions within the twenty-one provinces between 2005 and 2015. The results showed that energy efficiency was the dominant driver for decarbonizing 16 provincial power sectors, whereas installing low-carbon electricity generation and natural gas substitution for coal and crude oil drastically reduced carbon emissions.

Figure 6 describes low-carbon power generation in selected major economies between 2010 and 2022 for investment in power generation plants, power grids, electric vehicles, and energy efficiency in buildings, industries, and transportation. Low-carbon energy is based on the total primary energy demand and electricity generation from biofuels, solar, wind, hydropower, gas, coal, geothermal, nuclear, and unspecified/other fossil fuels. The data show that hydropower is generally the primary low-carbon source worldwide. Germany and South Africa's primary low-carbon source is wind, whereas France and the United States use nuclear [106]. Low-carbon power investment appears to be manageable if there is a massive decline in fossil fuels globally: related scenarios are considered in selected countries compared with the world data. France, Brazil, and Canada show strong low-carbon power investments, followed by Germany, the United States, China, and Australia, and the lowest are seen in India and South Africa. The world's low-carbon power has continued to increase and was recorded as ≈1.8% in 2010, compared to selected countries whose low-carbon power growth has been random between 2010 and 2022. In addition, within the reported period, the average emissions intensity from electricity generation has continued to vary depending on the country's low-carbon power investment. For example, China's carbon emission intensity was reduced substantially from 1971 to 2015 by 74% compared to a 65% carbon intensity reduction in the United States [110]. The data show global awareness of carbon emission reduction, and each country has set a target to achieve zero carbon emissions beyond 2030. The environmental quality review is compared with other regions to understand and improve GHG emissions reductions, particularly in countries with large fossil fuel reserves.

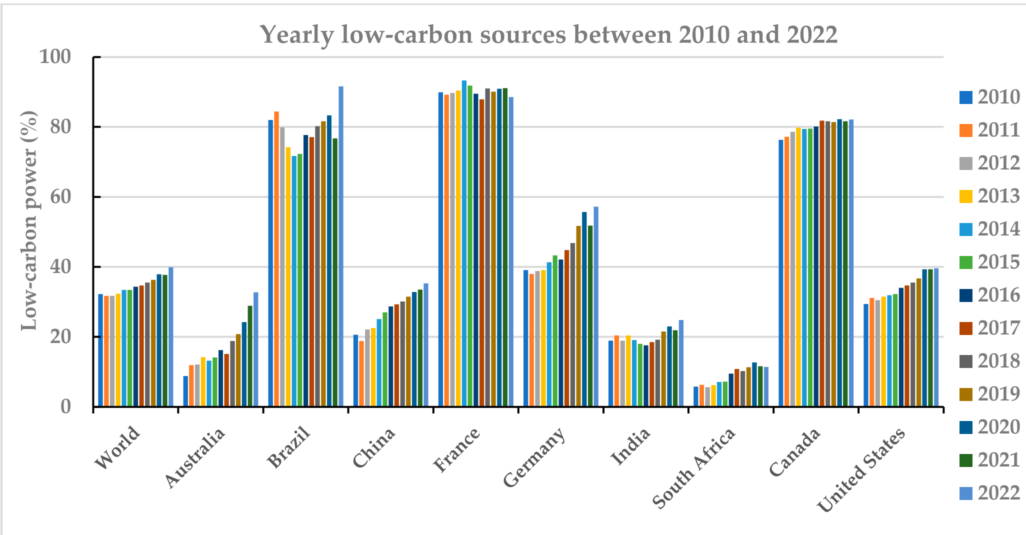


Figure 6. Percentage of electricity generated domestically from low-carbon sources [109].

3.1.1. Sustainable Energy Indicators Canada's Perspective

Our study data were collected from the Canadian Energy Regulator (CER), Environment and Climate Change Canada (ECCC), and Low-Carbon Power (LCP). The focus is on low-carbon electricity generation from biomass, hydro, wind, solar, and others (geothermal, landfill gas, nuclear, wave, and tidal), as observed and recorded between 2010 and 2022 (Figure 7). With the increase in renewable energy installations every year, there are possibilities that low-carbon electricity generation will continue to increase and sustain the Canadian Renewable Energy Association's (CanREA) 2050 vision for net-zero emissions. In 2019 and 2020, Canada recorded an approximately 1% increase in primary energy demand from low-carbon resources, indicating community initiatives and engagement in accepting the renewable energy transition even after the devastating COVID-19 pandemic challenges. Electricity generation from low-carbon renewable resources has come to stay, as observed from the data in Figure 7. Between 2018 and 2020, electricity generation from low-carbon resources increased by 3%, with the highest value of 83.01% in 2020. The Canadian government's action plan outlines the progress and ongoing efforts being made to improve the low-carbon power investments roadmap and turn it into reality.

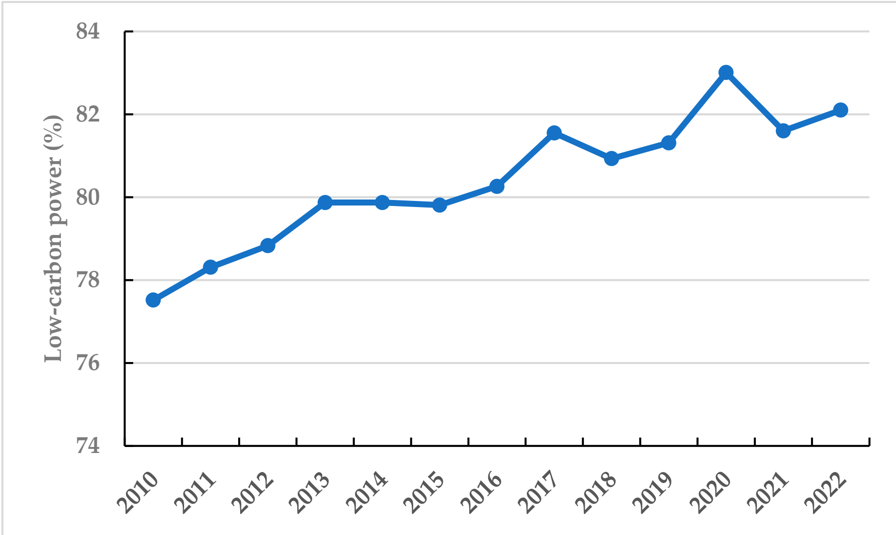


Figure 7. Low-carbon energy from renewable energy resources in operation in Canada between 2010 and 2022 [18,109,112].

3.1.2. Clean Energy Targets Roadmap in Canada

Canada continuously invests in renewable energy, initiating and encouraging small modular reactor (SMR) programs for zero emissions and providing business opportunities for indigenous, private, and foreign companies. SMRs are nuclear fission reactors and are a promising market for people in remote and indigenous communities, with a potential value of $5.3B between 2025 and 2040 [66]. Canada has mapped out three areas for SMR application: (a) on-grid power generation in provinces phasing out coal operation, (b) on- and off-grid combined heat and power for heavy or medium industries, and (c) off-grid power, district, and desalination in remote communities [113]. In addition to that, the future renewable energy capacity is expected to grow with wind installation and power projects doubling and solar energy deployment tripling by 2040 [109]. The International Renewable Energy Agency [15] reported that 144 of 193 countries were involved in the Paris Agreement on renewable energy targets. However, by November 2021, the report was updated with additional information on renewable energy targets, such as clean goals, emission reductions, and transformative opportunities through SDGs.

Table S2 lists clean energy targets carried out in provinces and territories across Canada. The data show that twelve provinces and territories have GHG reduction targets, and nine have initiated other clean energy targets such as zero-emissions vehicle sales, building efficiency, low-carbon fuel, and energy efficiency targets. The Alberta government hopes to phase out coal usage for electricity by 2030 to accommodate the full implementation of green energy. Moreover, Nunavut is the only territory that is yet to create renewable energy and GHG reduction targets. Seven provinces and territories (Alberta, New Brunswick, Northwest Territories, Nova Scotia, Quebec, Saskatchewan, and Yukon) have renewable energy targets to generate over 90% of electricity from non-emitting sources by 2030. Government, foreign, and private organizations, including indigenous groups in the energy sector and civil society, are invited to join the energy action plan and develop strategies to achieve renewable energy targets.

3.2. Economic Equity in Sustainable Energy Transitions

In Canada, the current economic investment in the renewable energy sector is advancing in the SMR program for zero emissions by deploying clean technologies, achieving carbon neutrality by 2050, and providing business opportunities for indigenous and foreign companies [92,114]. In addition, the low-carbon economy transition remains a people-orientated program through social value creation, gender equality, indigenous people's inclusion, and an opportunity to address seven affordable, reliable, sustainable, and modern clean energy

SDGs of the United Nations. The target goals by 2030 are as follows: (a) Promote clean energy research and technology development; (b) sustainable renewable energy; energy efficiency and advanced and cleaner fossil fuel technologies; and (c) promote investment in renewable and clean energy infrastructure and technology [17,81,104]. To an extent, the socio-technical design of energy projects is evaluated and determined by what type of renewable energy services are provided using appropriate strategies that can potentially improve the social value [74]. Consequently, the energy transition requires the active participation of private, public, and local institutional investors to facilitate and motivate the appropriate incentives to support socioeconomic structures and investment transformation [102].

Similarly, the ECCC [112] report highlighted the 2030 emissions reduction plan, which supports clean air and a strong economy. The report revealed that the Canadian government has a plan to invest $900 million in agricultural climate solutions and clean technology, transformative science in fundamental and applied research, knowledge transfer, and developing metrics for sustainable farming practices, including the development of energy-efficient equipment in support of a net-zero transition economy by 2050. In addition, Canada is empowering remote communities by supporting regional growth opportunities and energy systems transformation, an initiative to improve the economic prosperity and development of sustainable jobs in a net-zero economy. In addition, the government provides tax incentives to business investments in low-carbon generation equipment involving wind, solar, biomass, or geothermal energy [18,37]. Fragkos et al. [58] highlighted that low-carbon investment in carbon emission reductions could be significantly higher, creating market opportunities for countries and businesses. However, the market opportunities are power generation (wind: Onshore/offshore, solar PV, and carbon capture and storage), energy efficiency, decarbonized fuel production (advanced bioethanol, hydrogen, and synthetic e-fuels), electric vehicles, and research and development. The journey to the net-zero bioeconomy 2050 Vision is a wake-up and urgent call to stakeholders in renewable energy sectors to move Canada onto the roadmap to meeting its commitment to achieving net-zero gas emissions for electricity generation beyond 2050.

4. Summary and Conclusions

This review details and identifies all installations of renewable energy projects in operation and in development across Canada's rural and remote communities. Six hundred and thirty-five installations with a total generating capacity of approximately ≈28,000 MW of electricity are in operation, involving a mixture of renewable sources of wind, solar, hydro, and biomass. The generated capacities are believed to support remote off-grid communities to enhance the resilience of grid-stabilizing utility-scale projects. Wind and solar energy deployment are projected to grow significantly to meet the electricity demand by 2030.

Consequently, reports showed adequate information on the ownership structure of each province's renewable energy projects, thus indicating future projections. Moreover, data showed that communities are engaged in ownership with 100% community-owned or -partnered renewable energy infrastructure. Over half of the projects are controlled by private ownership, of which ≈30% bear community names [88]. Government participation (municipal or provincial) in the ownership of renewable energy projects was fully represented. This study recommends the continuous research and development of a sustainable renewable energy policy and full implementation of the clean energy targets in support of CanREA's 2050 vision for net-zero emissions.

The low-carbon economies of Canada, Australia, the European Union, China, and the United States are projected to attain zero carbon by 2050, and their mitigation is in line with pathways toward a 1.5 °C temperature reduction. Energy system decarbonization requires an emission reduction driven by electricity generation, advanced biofuels, and improved clean synthetic fuels [106]. Renewable energy sources will hopefully increase global electricity generation and supply beyond 2030. Solar PV will rise by 145 TWh, approaching 1000 TWh in 2021, and wind will rise by 275 TWh or close to 17% from 2020.

Solar and wind are expected to contribute to the growth of two-thirds of renewable energy sources in 2021 and beyond [115]. However, the COVID-19 pandemic created significant challenges for energy transitions, with an overwhelming emphasis on economic recovery at the cost of global bioeconomy investments.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/en16083601/s1, Table S1: Renewable energy ownership categories across Canada between 2010 and 2021; Table S2: Provincial clean energy target in Canada.

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Data Availability Statement: The data supporting reported results can be found using the following links: https://www.renewablesassociation.ca/by-the-numbers; www.futureenergysystems.ca/resources/renewable-energy-projects-canada; https://lowcarbonpower.org/region/Canada; https://www.canada.ca/en/environment-climate-change/news/2022/03/2030-emissions-reduction-plan--canadas-next-steps-for-clean-air-and-a-strong-economy.html; https://doi.org/10.1016/j.erss.2020.101897; www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021/canada-energy-futures-2021.pdf (accessed on 27 March 2023).

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

Canadian Energy Regulator: CER; Canadian renewable energy association: CanREA; Carbon capture and storage: CCS; Carbon dioxide: CO_2; Conference of the Parties: COP; Coronavirus disease 2019: (COVID-19); Environment and Climate Change Canada: ECCC; Gigawatts: GW; Global total carbon dioxide-equivalent: $GtCO_2e$; Greenhouse gases: GHGs; Gross domestic expenditures for research and development: GERD; International Energy Agency: IEA; International Renewable Energy Agency: IRENA; Kilowatts: kW; Low-Carbon Power: LCP; Megawatt: MW; Megawatts electric: (MWe); Nationally determined contributions: NDCs; Renewable energy target: RET; Small modular reactors: SMRs; Sustainable development goals: SDGs; Terawatt-hours: TWh.

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