



Comparative analysis of clean energy development in India and Canada

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Abstract

Clean energy has become a critical aspect of climate change and sustainable development worldwide. India and Canada portray a huge contrast in terms of geography, economic foundation and energy demands, but the two countries have made considerable strides towards developing clean energy. In the current paper, I will engage in a comparative analysis of the clean energy landscape in India and Canada through a quartet of key dimensions, including policy frameworks, technological development, financial systems and social outcomes. The development of renewable energy in India has been expeditious, especially regarding solar and wind energy, due to big visions at the national level and the increasing energy needs. Canada, however, has been exploiting its large hydro capacity and institutional capabilities to be a pioneer in the generation of clean power. This study has implemented a thematic and structured strategy to identify core strengths, challenges, and opportunities of clean energy pathways in each country. The results show that in neither of the countries are the available policy options limited or lacking consistency, innovation, and international collaboration, thus impeding clean energy transitions. To conclude the paper, some strategic recommendations on how to take advantage of comparative strengths and how to promote bilateral collaboration are provided.

Keywords: Clean energy, comparative analysis, India and Canada, renewable energy, policy frameworks

Introduction

The energy industry throughout the world is going through a revolution in the generation process in which countries are facing the two threats of climate change and sustainable development. Clean energy which consists of wind, solar, hydro, biomass, and emerging technologies like hydrogen has become a critical supporting pillar in curbing the emissions of greenhouse gases and long-term environmental objectives. Both, the developed and the developing countries are focusing on clean energy transitions, but their approaches differ depending on the economy, policy, technology strength, and natural resource endowments. (Owen, 2024) ^[1] India and Canada are two divergent but educative parallel of clean energy development. Being a fast-developing country with an ever-increasing energy need and a small conventional energy base, India has been actively considering solar and wind energy as a flagship program like the National Solar Mission. (Deo & Chatterjee, 2024) ^[2] On the contrary, Canada, a nation endowed with resources, and where energy demand is rather stable, has traditionally exploited massive hydro generation abilities and is currently growing into wind, solar, and green hydrogen based on its federal and provincial climate plans. This paper aims to perform a comparative analysis of the development of clean energy in India and Canada regarding four main dimensions: policy and regulatory frameworks, technological innovation, financial investments and incentives, and socio-environmental impacts. Based on the exploration of these dimensions, the study will focus on bringing out the successes, struggles as well as teachings that each country can render to the other to fast-track a sustainable energy transition. The importance of such comparative study does not only result in the realization of best practices but also in how various socio-political and economic circumstances influence the outcomes of clean energy. The paper adds to the wider scholarly and policy

debate on energy transitions in the global context and the prospects of international cooperation towards meeting common climate goals, through such analysis. The key aim of the proposed research is to make a comparative study of clean energy formation in India and Canada that would include the analysis of several dimensions, including policy and regulatory systems, technology development, financial processes, and socio-environmental influences. The research endeavours to focus on similarities, differences, difficulties, and best practices that can be used during future policy formation and international cooperation. This study uses a qualitative, thematic, and comparative study. It is based on the secondary data obtained in government policy documents, international agencies like the IEA and IRENA reports, academic journals, and institutional publications with credible sources. Case studies have been used to give contextual information on good projects and regional practices in the two countries. It can be concluded that the comparative model provides a structured examination of each thematic area in the national contexts, which makes it possible to identify the lessons to be transferred and policy suggestions.

Background on the Global Clean Energy Transition

The world energy scenario is undergoing an unprecedented shift due to the actions of the nations that attempt to disengage their economies with fossil fuels and shift to clean and renewable energy sources. The main factors behind this shift are the necessity of slowing down the process of global warming, limiting the emission of greenhouse gases, and achieving the energy security of future generations. In 2015, a major milestone was reached through the signing of the Paris Agreement where an almost universal number of countries agreed to reduce the increase of the global temperature below 2 o C, relative to the pre-industrial levels, with attempts to keep it even at 1.5 o C.

The development of clean energy is not only an environmental need but also a socio-economic requirement because its existence will necessitate rearranging the global energy framework. (Kaiser *et al.*, 2024)^[3] The topic of clean energy, including renewables, namely solar, wind, hydro, geothermal, and biomass, and new technologies, namely hydrogen and energy storage systems, has been gaining traction on the global front. This transition has also gotten faster with the influx of new technology, declining costs of renewable technologies, and rising investment interest. (J & Majid, 2020)^[4] The International Energy Agency (IEA) stated that renewables contributed to almost 30 per cent of the world's electricity production in the year 2022 and that this number would soar in the upcoming decades. (Matterne *et al.*, 2024)^[5] The national policies of governments worldwide are increasingly becoming ambitious in their energy-related aims, with net-zero plans and incentives to be used as encouragement towards utilizing clean energy. Multilateral agreements, international cooperation, and financial investments have also been extremely pivotal in the assistance of energy transitions, especially in developing nations. (McCarney, 2022)^[6] The rate and trend of this transition however is diverse owing to political will plus the economic structures, availability of the natural resources as well as the capacity of the institutions. As clean energy transformation becomes one of the distinctive global trends, the comparison of national experiences is necessary to identify lessons, find effective approaches and carry out collective efforts. In this context, it is worth examining the clean energy trajectories of such countries as India and Canada to get useful information about their heterogeneity and the prospect of learning with each other.

Overview of Clean Energy in India and Canada

Clean energy is the energy gained through sources with minimum or no production of greenhouse gases which are also sustainable in the long run. This involves renewable energy i.e. solar, wind, hydroelectricity, biomass, geothermal, and non-renewable low carbon i.e. nuclear energy. In recent years, hydrogen, and especially green hydrogen derived using renewable electricity via electrolysis, has also made its way into the clean energy discourse as it offers additional means towards decarbonizing hard-to-abate sectors. (Karanasios & Parker, 2018)^[8] The use of a range of clean forms of energy has been adopted in both India and Canada and the aim of each country has been based on the needs of the environment as well as the requirements of energy and availability of resources. India is one of the countries that have paid a lot of concentration on solar and wind energy as it has a lot of sunlight and wind corridors are increasing in India. Bioenergy and small hydro projects are also consumed by the country, and offshore wind and green hydrogen are developed more and more. In comparison, Canada is blessed with huge freshwater reserves together with mountainous topography, and that is why it is finding it very easy to exploit hydropower as the main source of producing clean electricity. (Benson *et al.*, 2022)^[12] More than that, Canada has also been making investments in wind, solar bioenergy and, in particular, nuclear energy, especially in Ontario. Both countries have a huge potential for clean energy realized according to both geographical and meteorological conditions. The solar insolation is high in India and hence it is one of the most prospective areas to develop solar energy

in the country, especially in Rajasthan, Gujarat and Tamil Nadu. It has also a long coastline and inland wind belts with large wind energy potential. Canada, which has a large waterway network and a relatively low population density, has taken advantage of large-scale hydroelectric developments in such provinces as Quebec and British Columbia. Offshore wind along the Atlantic coast also in potential in the country as well as geothermal energy in western provinces. (Eitan, 2024)^[13] Moreover, Canada has available the technological and natural resources to be a world leader in the production of green hydrogen, whereas India intends to be a significant hydrogen consumer and exporter according to its National Hydrogen Mission. Historically, the paths of clean energy development have differed in both countries due to their economic systems and priorities. Clean energy has a long history in Canada because the development of hydroelectricity has a long history in the country, starting in the early 20th century and currently providing more than 60 per cent of the total electricity used in Canada. Interest in diversifying and adopting wind and solar as part of the energy mix started in the 2000s and was driven by a province-based programme and climate policy at the federal level. The clean energy drive in India, though comparatively later, has been fast and dynamic. The renewable energy capacity in India has skyrocketed since the introduction of the National Action Plan on Climate Change (NAPCC) in 2008, followed by the National Solar Mission. (Nergui *et al.*, 2024)^[11] It has been very ambitious, as the country has a target to reach 500 GW of non-fossil capacity by 2030. The above development shows that both countries are pursuing policy innovation, technological adaptation and greater public-private partnerships in adapting clean energy sectors because of the rising importance of clean energy in their developmental capacity as well as environment-based issues.

Policy and Regulatory Frameworks

In India and Canada, clean energy development is guided by elaborate policy and regulation mechanisms that are aimed at promoting sustainable energy production, limiting carbon emissions, and achieving long-term energy security. The policy thrust in India started with the introduction of the National Action Plan on Climate Change (NAPCC) in 2008 and contains eight missions, one of which, the Jawaharlal Nehru National Solar Mission (JNNSM), has been seminal. (Behuria, 2020)^[18] The Solar Mission set the objective to ensure that India becomes a global leader in the use of solar energy by putting in place policy conditions that will diffuse solar energy in India. Moreover, the Energy Conservation Act of 2001, which is an agenda introduced by the Bureau of Energy Efficiency (BEE), allows obtaining some legal backing to carry out provisions of energy efficiency policies across industries. (Sastry, 2025)^[19] The Renewable Energy Act so far is not a law but a proposal which aims to establish a framework of law to govern and encourage the growth and integration of renewable energy development on the grid. Renewable Purchase Obligations (RPOs) and feed-in tariffs, viability gap funding and accelerated depreciation have become policy mechanisms used to encourage investment in renewables by Indian states, although implementation has differed and effectiveness is mixed. (Goel, 2016)^[20] In Canada, a Pan-Canadian Framework on Clean Growth and Climate Change was launched in 2016, acting as the basis for the clean energy transition of the country. It

encompasses carbon price, financing of renewable energy and energy efficiency benchmarks, where it is aided by provincial plans. A decentralised yet progressive approach is reflected by provinces such as Ontario, Quebec and British Columbia, which all have their policies (including cap-and-trade systems, feed-in tariffs and large-scale hydro development plans). (Bansal *et al.*, 2018) ^[21] At the institutional level, the governance of clean energy in India is carried out by the Ministry of New and Renewable Energy (MNRE), which drafts policies and carries out national missions, as well as works with state nodal agencies. Regulatory agencies such as the Central Electricity Regulatory Commission (CERC) and the State Electricity Regulatory Commissions (SERCs) have important roles to play in tariff determination, access to the grid and compliance. In Canada, the governing of clean energy follows a federal executive whereby the activities are put under two heads, the provincial and federal governments. This is because Natural Resources Canada (NRCan) is in charge of federal clean energy policy, although the provinces can take great autonomy in energy planning and regulation, leading to different policy contexts yet strong regional innovation. Regulation, including energy market operations and infrastructure, is controlled by such institutions as the Canada Energy Regulator (CER) and provincial utilities. In comparison, India has managed to make capacity additions quickly with its centralised but very dynamic policy. Nevertheless, it is associated with several issues connected with grid integration, the financial viability of distribution companies (DISCOMs) and inter-state policy coordination. Autonomy of the provinces in Canada enables the adoption of local solutions and long-term investments in infrastructural projects, yet sometimes results in fragmentation of the policies and the rate of the transitions at the national level. Nevertheless, the countries used a combination of regulatory instruments and market-based initiatives to indicate they have an institutional commitment to clean energy. (Government of Canada, 2016) ^[22] The comparison indicates that a top-down, target-orientated system like that of India causes the expansion to be fast but lacks long-term consistency and the trust of the population, whereas the bottom-up and steady policy setting of Canada provides similar experiences that can be used by both nations under the idea of mutual learning and common ground in policymaking globally.

Technological Development and Innovation

India and Canada have tapped various sources of clean energy technology that respond to their individual resource base and development preferences. The major technologies are solar photovoltaic (PV), wind, hydroelectric, biomass power and upcoming hydrogen solutions. Driven by such developments as module manufacturing, integration in the grid, and energy storage, India has experienced quick growth in solar PV and wind capacity. Other sources of concern for rural energy are biomass and small hydro projects. Large-scale hydroelectric energy dominates the technological portfolio of Canada, which is complemented by onshore wind energy, offshore wind energy, solar energy, and nuclear energy. In the recent past, Canada has invested intensively in the R&D of green hydrogen, setting the pace to be a supplier of green fuel in the future. (Baidwan, 2017) ^[26] One of the significant roles played by research and development (R&D) support in the two

countries is to assist in the growth of innovation. The innovation ecosystem in the country consists of state-supported organisations such as the Indian Renewable Energy Development Agency (IREDA) and the Ministry of New and Renewable Energy (MNRE) incubators. Vast amounts of technology in India continue to rely on imports, particularly to obtain solar modules and wind turbines. This dependence is being endeavoured to be decreased through schemes such as Make in India. By comparison, however, Canada has a well-developed innovation system with well-established relationships between universities, government laboratories and the corporate sector as well as in the areas of hydro and hydrogen technologies. (Aldag & Standing Committee on Environment and Sustainable Development, 2019) ^[24] This leads to increased penetration of indigenous technology and export possibilities. In comparison, Canada performs better in innovations because it has a strong investment in R&D and an infrastructure in innovation, whereas India performs better in the scaling of imported technology at rapid rates to the high energy demands. Knowledge transfer and collaboration in innovation could be of interest to both states to further develop technological potential and promote a faster process of integrating clean energy into the world market.

Economic and Financial Aspects

The economic and financial issues play a central role in the development of clean energy in India and Canada. Interestingly, the two governments have launched massive investments accompanied by the involvement of the private sector. The recent decade of India has witnessed a sharp increase in its clean energy investment, which has been enabled through policy incentives, including expedited depreciation rates, viability gap funds, and tax holidays. Concessional financing is offered by the public sector banks and multilateral institutions, whereas the project development is facilitated by the means of private companies and foreign investors. (Bhatnagar & Sharma, 2022) ^[16] Canada is also enjoying the favourable environment of private capital through federal and provincial funding or in the form of grants, tax credits, and government loan guarantees in hydroelectric, wind, and new hydrogen. The subsidies and incentives in the two countries are different in terms of scope and scale. In India, renewable energy certificates, feed-in tariffs in certain states, and direct subsidies are used to reduce upfront costs. Canada is relying more on carbon pricing and clean energy tax credits; the latter indirectly promotes renewables and discourages fossil fuels. Net metering and access to the grid policies are also adopted in the two countries to enable distributed generation. Financing institutions such as the World Bank, Asian Infrastructure Investment Bank (AIIB) and Climate Investment Funds have offered much-needed technical and financial assistance, especially to renewable projects in India. (Alsagr, 2023) ^[15] Canada is also a developed economy that is involved in financing the world but is likely to utilise the private financial markets to a greater extent. On the issue of cost-effectiveness and returns, India enjoys the advantage of cheaper labour and land, and this is why solar and wind projects are very competitive. The cost of capital is higher in Canada compared to other countries, but the infrastructure in place is a well-developed and stable regulatory framework which ensures that investments are not prone to risks and long-term returns are guaranteed. In

combination, these forces in the economy illustrate that there are other pathways to the development of clean energy that are influenced by national factors.

Social and Environmental Impacts

The environmental and societal aspects of clean energy development strategy play the main role in the sustainability of transitions in India and Canada. The role of the community and their perception of a project are substantial for the acceptance and success of the project. Locally, rural renewable projects, such as microgrids with solar energy and biomass plants, are being promoted through increased grassroots participation in India. Nevertheless, land purchasing and evictions are sometimes catalysts of resistance. In Canada, consultations and other benefit-sharing agreements often take place, and local voices determine energy projects, especially when it comes to indigenous populations. One of the social benefits is employment generation. The renewable energy industry in India has provided millions of both direct and indirect employment, starting with production to the installation and maintenance of renewable energy appliances to help in skills enhancement and poverty eradication. Canada also boasts of high Destroying high levels of employment in clean energy sectors, with transition training programs helping workers in the conventional fossil fuel sectors to switch to renewable and newer technologies such as hydrogen. (Anand & Ansari, 2024)^[14] Clean energy projects both present opportunities and create a challenge among the Indigenous people in Canada. Such initiatives as joint projects in which respecting Indigenous rights and encouraging economic involvement are becoming more of a priority are staged as part of a wider reconciliation drive. Climate sustainability is also a joint objective since both of the members aim toward significant carbon emission reduction with clean energy implementation. Renewables are increasing rapidly (need Indian percentage and per cent of low carbon) in addition to preventing or reducing pollution and fossil energy dependence in India, as do hydro and nuclear in Canada. In combination, these social and environmental consequences demonstrate the complex positive side and obligations of clean energy transits.

Case Studies

The Charanka Solar Park, or simply Charanka, is one of the largest solar photovoltaic parks in Asia and one of the flagship projects of the National Solar Mission, located near Charanka in Gujarat. It is a prime example of a large-scale solar installation (more than 600 MW) that gains considerable investment involvement from the private sector; it involves the use of solar panels produced locally. The park presents the driving force behind rapid clean energy growth with the help of governmental financial support in terms of purchasing lands, developing infrastructures and promoting economic gains. In the same way, the wind energy sector of Tamil Nadu is a first mover in India with the contribution of more than 9 GW of installed capacity. (Ghosh *et al.*, 2022)^[17] wind energy favourable weather conditions and the state's favourable policies, such as the use of feed-in tariffs and simplifying the easy approvals, have been able to create a successful wind energy market that has created jobs and got the community involved. Meanwhile, Niagara Falls Hydroelectric Plant is a historic, essential clean power

source within Canada and has been providing dependable renewable electricity since the first hydroelectric plant was begun over one hundred years ago. It has been made successful through regular investment in infrastructure, effective regulatory control and connectedness to the wider grid systems. The wind and solar projects in Alberta can be understood as the attempt of Canada to diversify its hydro sources, and the attention of Canadian policymakers is part of that discussion. Provincial policy is part of that, technological advancement is part of that too, and the private sector can also be seen to be playing its role in the big wind farms in Alberta. These projects have spurred economic growth in the area where they are taking place and made contributions towards emissions cuts. There are lessons the cases can teach us, including the necessity of an efficient policy framework, stakeholders, and an effective mechanism for financing large projects. Replicability is based on modifying these models to suit the availability of resources in a local area, the institutional ability, and the socio-economic context. The two nations have a chance to learn about the successes and difficulties of each other to speed up the clean energy adoption process.

Future Prospects and Strategic Recommendations

Achieving net-zero targets in India and Canada requires coordinated efforts across policy, technology, and finance. India's future pathway involves scaling renewable capacity, enhancing grid flexibility, and investing in green hydrogen and energy storage technologies. Canada must continue diversifying its clean energy mix, expanding hydrogen production, and modernizing ageing infrastructure while maintaining its hydroelectric dominance. Bilateral collaboration offers promising opportunities. Joint research initiatives, technology exchange, and co-financing mechanisms could help both nations overcome technical and financial barriers. India's manufacturing and scale-up capabilities complement Canada's advanced R&D and clean energy technologies, making collaboration mutually beneficial. Strategically, India should focus on strengthening grid infrastructure, streamlining regulatory processes, and fostering domestic manufacturing under "Make in India." Canada can enhance innovation ecosystems, develop supportive policies for emerging technologies, and increase public-private partnerships. Both countries should prioritize inclusive policies that ensure social equity and environmental justice. International cooperation on climate finance and carbon markets can also accelerate clean energy transitions globally.

Conclusion

The above comparative study of clean energy development in Indian and Canadian countries highlights that even though the countries materially occupy diverse socio-economic, geographic, and institutional backgrounds, they both enjoy high and long-term interest in the advancement of sustainable energy transitions. India is moving very fast in this area of clean energy, especially in solar and wind power, due in part to ambitious national policies like the National Solar Mission and largely due to cost-effective deployment models. With a huge pool of renewable resources, government incentives and an increasing investment by the private sector, the country has been among the fastest-growing clean energy markets in the world. Canada, on the other hand, enjoys stable regulatory

frameworks, and it has adequate natural resources, mainly power, which is based on hydropower and forms a major electricity source in the country. A combination of a long history of infrastructure investment and the new interest in wind, solar, and green hydrogen means the country has a reliable and diverse low-carbon energy base. Common problems that the two countries experience are grid integration problems, financial barriers and the necessity to receive social acceptance, especially from the local and indigenous populations. Nonetheless, their robustness in terms of institutions and ecosystems of innovation offers some platforms for beating these challenges. India has used a centralised policy mechanism to quickly add capacity but requires better coordination and infrastructure development, and Canada provides local solutions to policy through decentralised governance, which may create fragmented policy. This paper emphasises the important aspect of cross-national learning. India can learn some lessons in long-term infrastructure planning, sound regulation of its environment, and Indigenous community involvement from Canada. On the other hand, Canada can learn through the scale-up backgrounds of India, cost efficiencies, and the lively contribution of the personal sector. The lessons herein are indicative of the presence of adaptive integrated policies where economic growth goals should be addressed in harmony with environmental sustainability and social fairness. Academically, the study enriches the knowledge in the field of how various governance systems, resource perspective Ness, and market forces impact clean energy changes. The results emphasize that the sharing of knowledge and international collaboration is crucial in the race to attain sustainable and equitable clean energy futures across the globe. Finally, by promoting India-Canada collaboration, a greater level of innovation, financial and policy convergence may be created, so that international reaction to climate change becomes much more effective.

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