Karakorum Center
For Sustainable Development

“Reference Study on Renewable Energy in Mongolia since 1990”

Enumerative bibliography / Desk Study

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KONRAD ADENAUER STIFTUNG

We wish to express our sincere appreciation to the Konrad Adenauer Foundation Mongolia for their support of the research project on the renewable energy sector of the country. Their generous financial assistance has been pivotal in enabling us to conduct a thorough investigation into the complexities of Mongolia's renewable energy landscape. We are deeply grateful for the Foundation's commitment to fostering knowledge and understanding in this critical field. Their interest in the energy sector of Mongolia not only propels our research forward but also contributes to the broader dialogue surrounding sustainable energy development.

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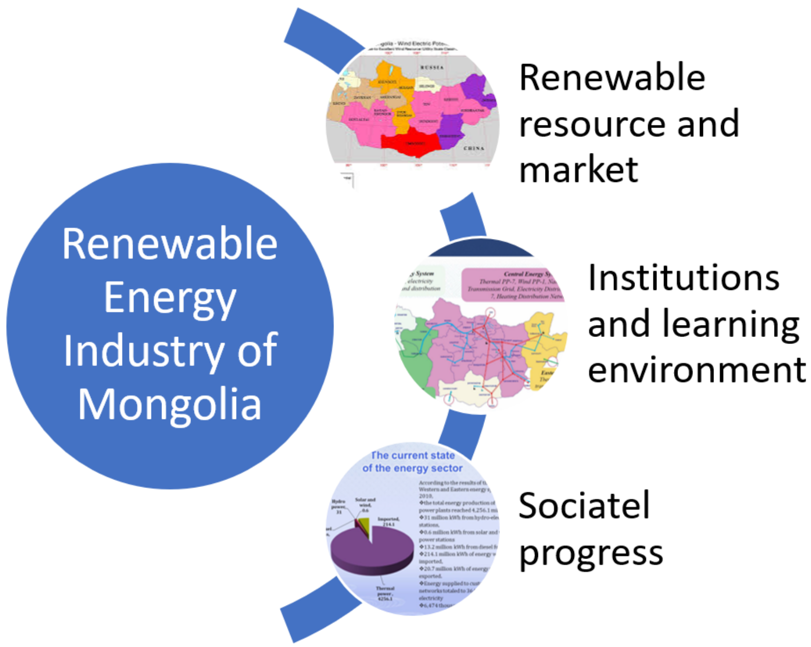
Abstract.

This study reviews the literature on renewable energy in Mongolia since 1990, showcasing its evolution and significant role in economic processes and local development policies to meet societal needs. It supports legal regulations and the learning environment of Mongolia's renewable energy industry, emphasizing the efficient use of renewable energy. Additionally, the review highlights a growing demand for access to renewable energy, envisioning future conditions to be better than present. Moreover, it delves into barriers within the renewable energy sector, government opportunities, and challenges over the past three decades. This analysis aims to navigate the development trajectory of Mongolia's renewable energy industry, providing valuable insights for future progress.

Graphical Abstract.



Keywords: renewable energy industry, Mongolia, contribution to the economic process, systemic changes

1. Introduction

Development Trajectory and Perspectives of Renewable Energy in Mongolia

This review introduces Mongolia's renewable energy resource capacity, explores the utilization and functions of the renewable energy industry, enumerates various literature reviews in detail, and explains the development concerns and perspectives of renewable energy in Mongolia since the 1990s.

As renewable energy users gradually increase and a diverse range of applicable information becomes available in this industry, the consumption and utilization of renewable energy have become apparent. This growing demand forms a development trajectory for renewable energy, complementing traditional coal-driven energy sources. The review is a cornerstone, consolidating information gathered over three decades in Mongolia's renewable energy industry.

Furthermore, the review sheds light on various propositions within the renewable energy industry over the same time horizon as the market system development in Mongolia. Regarding the market system, the renewable energy industry focuses on capacity and resource utilization, the link between demand and supply, coherence of development policies and regulations, and societal progress. Simultaneously, it examines international trade relations.

These insights contribute to a comprehensive understanding of the multifaceted dynamics shaping the development trajectory and perspectives of renewable energy in Mongolia.

Renewable Energy Resources and Exploitation

Cost-benefit effectiveness is paramount in every industry, especially emerging ones like renewable energy. The costs associated with renewable energy encompass capital costs, operational and maintenance costs, and the cost-effectiveness of mitigation. On the other hand, the benefits extend across economic factors (improved energy supply, balance of payments), societal factors (defining and measuring improvements in people's living conditions), environmental factors (reduced air pollution, GHG emission reduction by 2030), and institutional factors (long-term development policy planning, transition, and the transformation of science and government action plans).

For Mongolia, the initial motivations to harness renewable energy emerged in the 1970s, driven by the global energy crisis and the underdevelopment of rural areas due to a lack of electricity (Г.Пүрэвдорж, Сэргээгдэх эрчим хүчний түүхэн замнал, хөгжлийн ирээдүй, 2019).

The National Renewable Energy Laboratory (NREL) of the United States Department of Energy estimates Mongolia's total renewable energy potential, including wind, solar, geothermal, and hydro resources, to be as high as 2,600 GW. Notably, the Gobi Area stands out with tremendous renewable energy potential, benefiting from favorable climatic and weather conditions to effectively utilize these resources (Oyunchimeg Ch, 2020).

Wind

Mongolia boasts immense potential for wind energy, covering more than 160,000 square kilometers or 10% of the total land area, with a power density ranging from 400-600 W/m2. This vast wind resource could support over 1,100 GW of installed capacity, delivering more than 2.5 trillion kWh annually. To put this into perspective, it is equivalent to 14% of global electricity consumption in 2017 (UNDP, 2012).

Every aimag in Mongolia demonstrates significant wind potential, with no less than 6,000 MW each, three aimags boasting at least 20,000 MW, and nine aimags exceeding 50,000 MW of wind power potential (UNDP, 2012). The country's wind energy potential indicates the capability to generate 2550.1 TWh of electricity annually solely from wind, with 1975.5 TWh produced from low wind speed areas, constituting 83% of the total potential wind energy area (Oyunchimeg Ch, 2020).

Private companies have actively invested in wind power plants. Notably, Newcom's 52 MW wind plant in the Salkhit valley of Tuv aimag has been operational since 2013, and another wind power plant in Sainshand, established in 2018, aims to generate 52 MW of electricity. These ventures are integral to the Government's commitment to achieving Mongolia's targets of increasing renewable power-generation capacity to 20% by 2023 and 30% by 2030 (Yong Chen, 2016).

Mongolia has emerged as a potential major wind power producer, with a wind resource potential exceeding 1.1 TW of installed generating capacity at 30 meters high. This resource is primarily concentrated in the southern and eastern regions of the country, with the potential to generate at least 2,550 TWh of electricity annually, approximately half of China's total electricity consumption in 2014 (Yong Chen, 2016).

Solar Photovoltaics and Thermal Energy

Mongolia also possesses significant potential for solar power and solar heating. According to calculations by the National Renewable Energy Laboratory (NREL), Mongolia experiences an average of 270-300 sunny days annually, providing an estimated 2250-3300 hours of daylight each year (UNDP, 2012). The availability of solar radiation in Mongolia is deemed reliable, with less than 2,600 recorded hours annually (Yong Chen, 2016).

With an average daily solar energy range of 3.4-5.4 kWh/m2 across a total area of 23,461 km2, Mongolia can yield 4774 TWh of solar electricity annually. NREL calculations highlight the Gobi Desert as the world's third-highest desert with significant solar electricity generation potential. The sub-region of the Gobi Desert bordering China is particularly noteworthy, ranking as an excellent site for solar energy resources and making it a priority for renewable electricity exportation.

Mongolia has an estimated total installed solar PV power generating capacity of 6,000 kW. This includes seven off-grid village-scale solar PV power systems with a combined installed capacity of 1,000 kW and two grid-connected systems with a capacity of 500 kW. Since 2002, under the Renewable Energy and Rural Electricity Access Project, supported by the World Bank and other donors, over 100,000 solar ger (home) systems have been provided, benefiting approximately half a million people—equivalent to 70% of the nomadic population. The aggregated generating capacity of these systems is approximately 5,000 kW (Yong Chen, 2016).

Hydropower

Another significant potential resource in Mongolia is hydropower generation. The country boasts approximately 3,800 small rivers, totaling 65,000 km in length, with a gross theoretical potential of about 6.2 GW. More than 1 GW of this potential has been identified, and the industry operates 13 hydropower stations, predominantly consisting of small or medium-sized plants. Only four plants are connected to local grids, while the remainder serves isolated grids in nearby soums. Notably, three plants have an installed capacity exceeding 1 MW: Durgun (12 MW), Taishir (11 MW), and Bogdiin gol (2 MW).

In 1994, the Institute of Water Policy of Mongolia estimated the gross theoretical hydropower production capacity for all rivers with a runoff of more than one cubic meter per second (m^3/s) at 6,400 MW. At total capacity, this would deliver a potential of 56.2 million MWh of electricity annually. However, the actual hydropower potential is estimated to be between 20% and 60% of this figure, translating from 1,280 MW to 3,840 MW (Oyunchimeg Ch, 2020).

Geothermal

Mongolia is home to 43 geothermal areas, many of which are utilized for various purposes such as heating, bathing, and medicinal use. National Sanatoriums make use of thermal waters from shallow (typically deep) wells in locations like Tsenkher, Hujirt, Shargaljuut, Zart, Shivert, Khalzan uul, Eruu, and Tsagaan tal (Oyunchimeg Ch, 2020).

Geothermal energy, often harnessed through heat pump technology, has the potential to contribute to district heating. In Mongolia, some hot springs in the Khangai area are modestly employed for house heating, greenhouse heating, and space heating. Notably, the village of Shargaljuut in Bayankhongor aimag has been utilizing geothermal hot springs (with a temperature of 92°C and a flow rate of 25 l/s) for house heating since 1960. This is an exemplary case of geothermal energy utilization for heating in Mongolia (Yong Chen, 2016).

Bioenergy

Mongolia relies significantly on renewable energy resources derived from biomass fuel, primarily from livestock, including dried cow dung, pellets, horse dung, hardened dung, and urine from sheep and goats (Radii, 2008). This practice, deeply rooted in Mongolian tradition, stems from the historical herding of livestock. Even today, dried cow dung remains a cost-effective and easily collectible fuel throughout all aimags of Mongolia, especially in regions with limited or no forest reserves.
As of 2022, Mongolia boasts approximately 71 million livestock (NSO, 2022), generating substantial biomass annually. This abundance holds the potential for biogas production and power plants utilizing biomass. Although attempts to establish biogas plants face challenges due to the scattered locations of herders, recent signs of recovery in the nomadic livestock industry suggest a potential increase in biogas plant prevalence. For instance, large dairy farms or collab-

orative efforts between several farms could make biogas production more economically viable, given their significant daily output of animal dung (Yong Chen, 2016).

Mongolia supports two major forest biomes: boreal forests in the north covering 14.2 million hectares (87%), predominantly featuring larch and birch, and saxaul forests in the southern arid regions, accounting for 2.0 million hectares (13%). Despite their dryland woodland ecosystem, Saxaul forests are officially classified as 'forests' under national definitions (CCPIU, 2017).

Renewable Energy Demand

Mongolia's key institutional renewable energy users include the Mongolian Telecom and the Civil Aviation Authority. Mongolian Telecom operates small stand-alone PV systems in most Soum Centers' communication centers. These systems, typically around 900 Wp, consist of locally manufactured 50 Wp modules and varying battery sizes, ranging from approximately 100 Ah to considerably larger battery banks. Although these PV systems are generally not connected to local mini-grids, they may use the grid to top up their batteries, supplying telecommunications equipment for voice telephony. Similarly, the Civil Aviation Authority employs PV systems for air traffic control (Benjamin et al., 2011).

Herder households have become renewable energy users through initiatives like the 100,000 Solar Ger program. Additionally, many households across rural and urban areas have adopted renewable energy for their electricity consumption. The growing awareness of sustainable and green energy aligns with this trend, presenting an opportunity to use renewable energy resources efficiently.

However, a notable challenge lies in the comparatively higher cost of electricity produced from renewable sources. The price per kWh is higher than electricity from conventional power plants or imported sources, and the current currency exchange rate exacerbates this price difference. Although a recent introduction of a "RE support tariff" at 4 MNT per 1 kWh attempts to address this difference, the issue persists. As part of their renewable energy development policies, many countries have implemented support tariffs or green tariff structures to mitigate such challenges (Maidowski, 2012).

The Renewable Energy Law of Mongolia (Parliament, 2007), specifically Article 11 on Renewable Energy Tariffs and Prices, outlines guidelines for Feed-in-Tariffs (FiT) applicable to renewable energy generators. According to the law, the Energy Regulatory Authority establishes tariffs and prices for energy generated by renewable energy sources connected to the transmission network. These tariffs are guaranteed to investors for ten years from the law's enactment, i.e., until January 2016. The legal framework in Mongolia establishes specific prices for electricity supplied by different renewable energy sources connected to the transmission network. According to the law enacted in 2015:

- Wind power source: $0.08–0.095 per kWh
- Hydropower station with a capacity of up to 5 MW: $0.045–0.06 per kWh
- Solar power source: $0.15–0.18 per kWh

Any price difference for electricity generated by these renewable sources must be absorbed within the selling prices of other generators connected to the transmission network. Additionally, local regulatory boards can set tariffs for stand-alone power sources within certain limits:

- Wind power source: $0.10–0.15 per kWh
- Hydropower plant with a capacity of less than 500 kW: $0.08–0.10 per kWh
- Hydropower plant with a capacity of 501–2,000 kW: $0.05–0.06 per kWh
- Hydropower plant with a capacity of 2,001–5,000 kW: $0.045–0.05 per kWh
- Solar power source: $0.2–0.3 per kWh (Mongolia, 2015).

Mongolia is considering implementing a quota system to foster renewable power generation and meet government-set targets. This system, the Renewable Portfolio Standard or tradable green certificates, would assign quota obligations to power grid enterprises, large-scale power-invested enterprises, and local governments. These entities would be required to generate a certain percentage of their electricity from renewables directly or by purchasing renewable electricity credits. The quota system's careful design, management, and adaptation aim to create a cost-effective policy scheme. The benefits include market-friendly price discovery, technology neutrality for least-cost choices by investors, and the potential for regional approaches across borders. This system also prepares the country for a regional renewable electricity market, particularly with neighboring China, where a similar scheme is in progress. If implemented successfully, a regional market for tradable renewable electricity certificates could provide an additional revenue stream for Mongolia (Oyunchimeg Ch, 2020).

Renewable Energy Supply

Mongolia's renewable energy supply, as outlined in the Technology Needs Assessment (Ministry of Environment and Green Development, 2013a), encompasses various technologies, including large-scale dam-based hydro for electricity supply (over 100MW), medium-sized dam-based hydro (10-100MW), pumped storage hydroelectricity, on-shore wind turbines, large-scale solar PV (off-grid, grid-connected, solar home systems), solar thermal (CSP, central receiver tower, parabolic through collector, and dish), and carbon capture and storage.

National consultants prepared Technological Fact Sheets (TFSs) for each shortlisted technology, evaluating their potential for reducing greenhouse gas emissions, impact on Mongolia's development priorities (economic, social, environmental, and market), and associated costs. After scoring based on projected costs and benefits, the top three selected technologies were identified as large-scale hydropower, wind turbines, and pulverized coal (PC) combustion technologies (Lee, 2019).

Despite establishing 13 hydropower stations since 1994, only nine are currently operational, indicating underutilization of the potential within the market. Notably, the planned 220 MW Egiin Hydroelectric Power Generation project on the Eg River has been scaled up to 315 MW, with an annual generation of 606 GWh. This project, situated close to the Central Energy System, has passed preliminary feasibility and environmental impact assessments. The Mongolian Government initiated the construction of roads, bridges, and a high-voltage transmission line in 2016 to proceed with the Egiin project. Similarly, the Shuren hydropower schemes, including a 240 MW facility on the Selenge, face challenges that need addressing before progressing. The feasibility study for a proposed hydropower project on the Hovd River in the western area has been completed and is under government review (Oyunchimeg Ch, 2020).

Market Potential

The feasibility of large-scale electricity export to Russia faces constraints due to the energy-rich nature of Russia's Central Siberian Plateau region, which boasts abundant coal, natural gas, and hydropower resources. However, current proposals for export-oriented projects focus on developing a 3,600MW (6 x 600MW) mine-mouth coal power plant complex designed for electricity export to China. The anticipated total installed capacity of the complex is expected to reach 10,800MW. A 500kV DC transmission line to China, spanning 1,300km, will be constructed to facilitate this export. A 200kV DC connection to the Central Energy System (CES) is also planned. Proposed projects include a 220 kV network connecting Russia, Mongolia, and China, fostering power exchange among these countries. This interconnected plan enhances the Mongolian grid's reliability and security.

Looking ahead, the China-North Grid, which includes Inner Mongolia, is expected to become strongly interconnected with Beijing/Tianjin, China Central Grid, and China Northeast Grid through a combination of 500 kV, 765 kV, and ultra-high voltage (UHV) 1000 kV lines, incorporating both AC and DC connections. This interconnection can reshape the electricity market situation and create long-term prospects for power exchange with Korean and Japanese markets (PwC, 2016).

While the market potential for renewable energy varies across sources and regions, a comprehensive analysis is needed to assess their market power across different geographical boundaries.

Renewable Energy Policies and Regulatory Frameworks

The Mongolian Government is committed to increasing renewable energy generation, setting a target of 30% of electricity capacity from renewables by 2030. To support this goal, a Feed-in Premium (FiP) was introduced in 2015 to ensure renewable generators receive the difference between the market price and the set FiP remuneration. As the Mongolian electricity market is not fully liberalized, the Mongolian Energy Regulatory Commission (ERC) regulates the market price, also known as the electricity rate (Institute, 2015).

Recognizing the importance of green growth in long-term economic strategies, the Mongolian Government outlined renewable energy targets for 2023 and 2030 in the State Energy Sector Policy. This policy aims to transform Mongolia into an energy exporter using advanced and environmentally friendly technologies. The strategic vision involves a two-stage implementation plan from 2015-2023 and 2024-2030, with a two-fold increase in installed capacity during the first stage. The Government seeks to modify the electricity tariff structure to attract private investors and ensure economic viability for existing energy companies. The goal is 100% energy access, involving stand-alone household renewable-based electricity generation systems for nomadic herders and developing high-capacity transmission infrastructure in cooperation with other countries (Yong Chen, 2016).

The electricity price regime incorporates tariff differences between renewable and conventional sources, encouraging renewable-based power generation through a cross-subsidy mechanism. The Renewable Energy Law mandates the establishment of a Renewable Energy Fund, financed by state and local entities and institutions, and collected through selling certified emission reduction units. Feed-in Tariffs (FiTs) were introduced to create an enabling environment for private sector engagement and attract investments in renewable energy projects.

However, challenges persist, including distorted electricity prices due to coal power subsidies, a lack of legal frameworks to prioritize dispatching renewables, and weak institutional capacity for on-grid variable renewables. Despite these challenges, the Renewable Energy Law sets specific FiT ranges for energy generated from renewable sources, with the ERC having regulations for geothermal and biomass electricity generation. To address currency exchange risks for foreign investors, the law stipulates that USD shall be used to pay FiTs.

The regulatory landscape is governed by the National Policy established in 2005 and the Renewable Energy Law enacted in 2007. The sector operates under the Ministry of Mineral Resources and Energy, which includes the Energy Authority established in 2009 and the Renewable Energy Department. The National Renewable Energy Centre, formed in 2008, is a focal point for renewable energy dissemination in rural areas (YONEDA, 2010).

2. Materials and Methods

The implementation of renewable energy projects in Mongolia has evolved over the years, marking significant milestones in international cooperation and the establishment of various plants. Here is a chronological overview of key developments:

1. 1970-1990. The first experiments and research on renewable energy sources have started at the Academy of Sciences and MUST. The Institute of Physics and Technology of MAS and NUM researchers jointly measured the Volt-Ampere parameters and tested the possibility of extracting electricity from the sun's intensity. Since then, much research has been conducted to convert renewable energy sources such as sun, wind, and water into electricity and thermal energy and develop solar thermal energy techniques and technologies. The first doctoral and master's works have begun. With the support of UNDP, in 1975, the Institute of Physics and Technology of MAS established its first research laboratory. It tested solar power generators in a few urban and rural households. In this way, a professional organization - the Renewable Energy Science and Industry Cooperation (RESIC, 1989)- was established, and it was the foundation for strengthening researchers and research laboratories.

2. **From 1991 to 2005**, RESIC carried out the work of spreading renewable energy sources in urban and rural areas, supported by the international grant projects of NEDO, JICA, UN, USAID, DANIDO, EU TASIS, GTZ, and the Government of Mongolia. The "100,000 Solar Ger" national program started in 1999 and aimed to provide electricity to rural areas using energy implemented, and rural consumers began to receive solar devices like conventional energy sources.

3. **2005-2020.** The National Renewable Energy Program (2005-2020) and the Law on Renewable Energy (2007) were approved, and the renewable energy sector developed under government policy and legal regulations. We have started cooperating with regional countries to implement the Gobi Tek-Asia integrated network initiative to export electricity from the large-scale renewable energy complex based on the solar and wind resources of the Gobi region of Mongolia to Northeast Asian countries. The plan of action included a detailed determination of Mongolia's renewable energy resources, the creation of a database, and raising the level of research and analysis of new technologies. Work has begun to create a favorable legal and tax environment for increasing investments in renewable energy and a financing system to support renewable energy production. They are using solar, wind, biomass, liquid, and gas fuels, geothermal heat, fuel cells, and other new sources for energy supply to households, enterprises, remote settlements, teams, and independent consumers, and supporting the supply of excess energy to the grid and regulating commercial activities.

4. **2024-2030.** This is the period of sustainable development of electricity export and renewable energy. The goal is to increase Mongolia's safe energy resources to at least 20 percent and increase the share of renewable energy to 30 percent of the total installed capacity. It is working to become one of the active participants in energy trade in Northeast Asia.

These milestones underscore Mongolia's journey in embracing renewable energy technologies and reflect its commitment to sustainable and eco-friendly energy solutions.

Table 1. Materials

		1990-1999	2000-2009	2010 to present
1	**Books**	1	5	1
		1990	2001, 2002, 2003-1, 2006-1, 2007	2019
2	**Bibliography**		2	1
			2008, 2009	2019
3	**Theses, dissertation**	6	8	2
		1992-1, 1995-2, 1998-PhD 1, 1998- BA-2	2000 – MA1, 2001-3, 2004-1, 2005-2, 2006-1	2012, 2019
4	**Articles and periodicals**	24	30	
		1991-3, 1992-1, 1993-2, 1994-1, 1995-9, 1997-1, 1998-2, 1999-5	2000-6, 2001-4, 2002-1, 2003-5, 2004-12, 2005-2	
5	**Conference Proceedings**	27	79	46
		1990-1, 1991-2, 1993-3, 1994-2, 1995-2, 1996-7, 1997-4, 1998-4, 1999-2	2000-4, 2001-4, 2002-4, 2003-10, 2004-5, 2005-6, 2006-4, 2007-5, 2008-19, 2009-18	2018-19, 2021-27
6	**Policy documents, development programs, and projects**	10	50	
		1995, 1996-2, 1998-1, 1999-6	2000-5, 2001-8, 2002-1, 2003-9, 2004- 18, 2005-8, 2007-1	
7	**Laws, amendments, rules, and regulations**		3	1
			2001-2, 2007-1	2015
8	**Patents**	5	3	
		1992-3, 1997-1, 1999-1	2002, 2004, 2006	
9	**Domestic and international project reports and evaluations**	9	37	
		1990-1, 1992-3, 1993-2, 1994-1, 1996-2	2004-18, 2006-19	
10	**International Conference, forums, expert and consultation meetings, workshops, seminars, trainings**	4	34	
		1993-2, 1995-1, 1999-1	2000-5, 2001-7, 2002-2, 2003-5, 2004-2, 2005-3, 2006-4, 2007-5, 2009-1	
11	**Documents from the site**		9	16

Author’s elaboration.

The bibliography by Ж.Доржпүрэв (2009) encompasses 21 units, delving into various documents such as the ADB project preparatory document on renewable energy development in small towns and rural areas in Mongolia (2002), the clean energy report on the hydrothermal heat supply of the province center (2005), and the World Bank project preparatory document on Mongolia - Renewable Energy and Rural Electricity Access Project (2006).

A particularly noteworthy inclusion is Mongolia’s wind energy resource atlas (Elliott et al. D., 2001), which is considered the most authoritative estimate of wind energy potential. This atlas serves as a crucial reference for selecting potential wind farm sites.

Between 2000 and 2009, academia engaged in discussions on the process of renewable energy transitions, exploring theories related to socio-technical change, technology diffusion, pricing, tariffs, and broader energy transitions. These theories delineate the actors involved in transitions and the dynamics governing their actions, attributing agencies to various stakeholders, ranging from Government and academia to the private sector. Despite the international consensus on the significance of transitioning global energy systems towards renewables, Mongolia exhibits a distinct discussion on energy transitions. Policies supporting power generation from large-scale renewable energy systems have been implemented over the past decade (Lee et al., 2019).

In 2008, a joint conference organized by the Ministry of Energy and the National Renewable Energy Center (NREC), in collaboration with the National University of Mongolia, the Mongolian University of Science and Technology, and the Physics and Technology Institute of the Mongolian Science Academy, disseminated 19 papers. This conference proved to be a valuable resource, enumerating articles from journals, papers in the proceedings, and project proposals on renewable energy from 1973-2007 (Н.Энэбиш, 2008).

2010 witnessed the joint organization of the 2nd National Renewable Energy Forum by the Ministry of Mineral Resources and Energy of Mongolia and the Government Implementation Agency of Energy. The forum involved discussions on 19 papers, proposing nine recommendations for the Agency of Energy (Г.Пүрэвдорж et al. II форум, 2009).

In 2018, MUST organize a conference commemorating the 20th anniversary of the Energy Management Program, discussing 19 working papers, including four related to renewable energy (Г.Бэхбат, 2018).

Lastly, in 2021, a joint conference on "Renewable Energy and Modern Technology" discussed 27 scientific papers from affiliates of the National University of Mongolia, the Mongolian University of Science and Technology, the Association of Renewable Energy Engineers, the Mongolian Renewable Energy Center, and Mongol Energy Club (О.Бавуудорж, 2021).

Methodology

The methodology employed desk/enumerative reviews. The peer review applied a multiple-method approach to data and document collection, including desk reviews of documentation produced by different stakeholders of renewable energy, the parliament, the Government, and relevant sources published by a broad range of these stakeholders. Group and individual interviews via phone and email were conducted with public and private institutions. Observation of renewable energy project results and geographic distribution within the country, along with assessing the feasibility of reaching them within a reasonable period, formed an integral part of the methodology. The review process consistently tested the validity and reliability of the documents and data collected by critically peer-reviewing their consistency across different sources and by triangulation, seeking to identify knowledgeable sources who could corroborate the information. References were made to reviews that provided the most concrete evidence of accomplishments and the circumstances that may have affected review outcomes.

3. Results

3.1 Literature Review

Renewable Energy Industry Development Policy

The development policy for the renewable energy industry is guided by criteria aligning with an "investment grade," emphasizing key considerations:

- Clarity: Clearly defined policy objectives with enforceable provisions.
- Regulation: Streamlined policies and regulations across all aspects, from planning approval to delivery.
- Support: Well-designed incentive mechanisms to attain targets or objectives.
- Stability: Ensuring policy stability relevant to the project's time horizon.
- Simplicity: Minimizing complexity and variables to reduce risks.
- Infrastructure: Prioritizing near-term attention to infrastructure planning, integration, and regulatory needs, optimizing the overall system for Demand Side Management and high shares of electricity from renewables (Maidowsk, 2012).

The renewable energy industry development policy, including economic, socio-cultural, institutional, and policy barriers, impacts various barriers.

- Economic barriers: Market failures, such as underinvestment due to natural monopolies, intellectual property rights, or failure to internalize environmental costs, pose challenges. Immature financial markets and higher risks hinder renewable energy investments, particularly in developing countries like Mongolia (Maidowsk, 2012).

- Socio-cultural barriers: Tradeoffs between short-term costs of large-scale renewable energy technologies and long-term costs of conventional technologies arise during permitting and promotion schemes.
- Institutional and policy barriers: Transparent regulation, stable government support, and legal security are critical for renewable energy investments.

In alignment with the MDGs-based Comprehensive National Development Strategy (CNDS), Mongolia aims to reduce greenhouse gas emissions and increase energy efficiency. The energy sector goals include a 20% increase in energy efficiency by 2030 and a 20% renewable energy target in total production by 2020, rising to 30% by 2030. The strategy involves renewing energy production, reducing consumption and losses, and optimizing pricing policies.

The "State Policy on Energy," implemented in two phases (2015-2023 and 2024-2030), outlines six strategic objectives and 26 targets. Article 3.2.6 focuses on increasing renewable energy, emphasizing the need to define and database renewable resources, boost the share of renewable energy in installed capacity, create a favorable legal and taxation environment for investment, and utilize various sources to meet energy consumption needs (PAGE, 2018).

Through economic planning, the Government specifies the location and capacity of renewable projects and aims to ensure project developers have access to finance, preventing licensed projects from going unrealized (Frederic Hans, 2020).

Table 2. Chronology of Policy Documents Related to Renewable Energy

	Approval	Policy Documentation	Identified issues
1	Resolution No. 158 of the Government of Mongolia	100000 solar ger program 1999-2012	Rural electricity supply using renewable energy.
2	Renewable Energy Science and Industry Corporation	Master Plan for Rural Electrification Using Renewable Energy of Mongolia 2000	Master Plan designed with JICA support, assisting Nippon Koei Ltd and Power Consultation Ltd.
3	Resolution No. 43 of the Mongolian Parliament	the Green Development Policy of 2014	Invalid
4	Resolution No. 63 of the Mongolian Parliament	The State Policy on Energy of 2015	Improving the legal and institutional framework of the energy sector, managing utilization of primary energy resources, constituting fuel reserve, guiding electricity and heat generation and power supply activities, introducing PPPs in the energy sector, providing a regulated competitive market framework for the sector, and introducing capacity building & capacity reinforcement guidelines.
5	State Great Hural Resolution 2016/2/5 No.19	Mongolia Sustainable Development Vision 2030	Objective 2 - Increase the share of renewable energy in total energy consumption and seek new energy sources. Phase I (2016-2020): Increase the share of renewable energy in the consumption of total energy to 20 percent, and Phase III (2026-2030): Increase the share of renewable energy in the consumption of total energy to 30 percent and begin to use energy from a nuclear power plant.
6	Resolution No. 325 of Mongolian Parliament, 2018	The Mid-Term National Program to Develop the State Policy on Energy (2018-2023)	Invalid
7	Resolution No. 52 of Mongolian Parliament, 2020	Development Vision 2050	Vision 4. Inclusive energy
8	Resolution No. 106 of Mongolian Parliament, 2021	Recovery Policy 2030	2.2. Develop renewable energy in an appropriate ratio, build water and storage stations, and ensure the reliability and stability of the integrated energy system.

Author's elaboration.

The Renewable Energy Development Policy in Mongolia presents various opportunities and challenges for the Government.

Opportunity 1: Between 2008 and 2013, Mongolia completed its first 50 MW Salkhit wind farm, marking its entry into private power production. The subsequent Tsetsii wind farm in 2017 and the ongoing expansion of the Salkhit wind farm with a 24 MW solar project highlight Mongolia's progression toward hybrid renewable plants.

Opportunity 2: The National Program 100,000 Solar Gers, initiated in 1999, aimed to provide electricity access to nomadic herders, rural institutions, and government agencies. By 2005, with assistance from donor countries and the World Bank's Renewable Energy for Rural Access Project (REAP), over 30,000 solar home systems were distributed to herder households.

Opportunity 3: Renewable energy development aligns with the Government's vision of "Electricity for all" and is crucial for enhancing energy security. The Government's energy sector priorities emphasize safety, economic capability, environmentally friendly technologies, and private sector involvement, indicating a holistic approach to sustainable energy.

Opportunity 4: Allocating financial resources for renewable energy promotion in the government budget is crucial. Maintaining support policies, forming public-private partnerships, securing grants from international institutions, and utilizing income from various sources, such as taxes on air pollution or fossil fuels, demonstrate a commitment to financial sustainability.

Challenge 1: Despite ambitious targets, implementing subsequent renewable projects faces challenges. Political support for existing coal-fired generation, underfunded FIT budgets, and poorly implemented Power Purchase Agreement (PPA) rules contribute to hurdles in project execution. A moratorium on new renewable licenses with PPAs exists due to funding constraints and a focus on hydroelectric and coal-fired plants.

Challenge 2: Comprehensive analyses of Mongolia's power sector need to be improved, and existing data reliability issues hinder secure system operation, efficient planning, and effective regulation. The need for adaptive reforms, strong political will, and a sound regulatory framework is emphasized to address challenges and optimize power sector performance.

Challenge 3: Power flow and stability analyses are essential for engineering and energy planning, particularly concerning integrating variable renewable sources. Improved understanding of grid responses to solar and wind generation inputs and identifying controlling programs and operational skills are critical for successfully integrating renewable electricity.

In summary, while Mongolia has made

strides in renewable energy development, challenges persist in political, financial, and regulatory aspects, highlighting the need for strategic and coordinated efforts to realize the potential of renewable energy in the country entirely.

Legal Framework for Renewable Energy

The legal regulation of the renewable energy industry in Mongolia is governed by specific provisions outlined by the state parliament, cabinet, state administrative authority, governors, and the Energy Regulatory Commission (ERC). The critical aspects of the legal environment include:

1. State Parliament's Role:
   - The state parliament is responsible for defining state policies related to renewable energy.
   - Decisions regarding the construction of power-generating facilities financed from the state budget fall under the purview of the state parliament.

2. Cabinet Responsibilities:
   - The cabinet is tasked with ensuring the implementation of the law.
   - It has the authority to designate soums (administrative units) where consumers are eligible for power from stand-alone renewable sources.

3. State Administrative Authority for Energy:
   - The state administrative authority overseeing energy has the following powers:
   - Develop state policies on renewable energy.
   - Conduct feasibility studies.
   - Draft standards for the operation, safety, and maintenance of renewable energy equipment.
   - Develop and approve rules and procedures for implementing the Renewable Energy Law.

4. Governors' Authority:
   - Governors of aimags, the capital city of Ulaanbaatar, soums, and districts have the authority to:
   - Include renewable energy facilities in land development plans.
   - Allocate land plots for the construction of these facilities.

5. Energy Regulatory Commission (ERC):
   - The ERC plays a crucial role in the regulatory framework:
   - Reviews tariff applications submitted by generation license holders.
   - Approves a template for agreements between generation and transmission companies.

The legal foundation for renewable energy in Mongolia was established with the approval of the Law on Renewable Energy in 2007. Subsequently, in 2019, amendments were adopted to adjust the feed-in tariff for various technologies and solidify principles for a renewable auction scheme. This scheme considers factors such as location, capacity, and technology specificity.

Table 3. Chronology of Documents on Institutional Environment 1992-2019

	Laws and Regulations	Status	Time Horizon	Market Coverage
1	Order No. 117 of the Ministry of Energy	Establishment of the Renewable Energy Institute	3rd July, 1992	Restructuring Renewable Energy Science and Industry Corporation for Renewable Energy Institute.
2	Resolution No. 31 of the Government of Mongolia	Establishment of the Renewable Energy Corporation	From 1997 to 26th October 1998	Renewable Energy Corporation was registered with the State Registration Authority.
3	Resolution No. 32 of the Mongolian Parliament	National Program on Renewable Energy (2005-2020)	9th June 2005	-
4	Renewable Energy Law	Enforced. The purpose of this law is to regulate the generation and supply of energy based on renewable sources and applies to legal entities generating and delivering heat and electricity. Specifically, the law defined participants' roles, rights, and privileges in constructing renewable energy power sources, issuing special licenses, defining tariffs, and negotiating power purchase agreements.	11th January 2007	• Regulates the generation and supply of energy from renewable sources. • Defines participants' roles, rights, and privileges in constructing renewable energy sources. • Addresses the issuing of particular licenses, tariff definition, and power purchase agreement negotiations. • Establishes the Renewable Energy Fund. • Mandates preparing and approving grid code and regulatory requirements for renewable energy integration. • Sets standards for equipment, operation, and maintenance of renewable energy.

5	Law on Renewable Energy amendment	Enforced. A support tariff. A renewable power mandate for the Ministry of Energy. Three new mandates for the Energy Regulatory Authority. Guidelines for PPAs.	19th June 2015	• Introduces a support tariff. • The Ministry of Energy mandates renewable power. • Specifies three new mandates for the Energy Regulatory Authority. • Provides guidelines for Power Purchase Agreements (PPAs). • Resolves financing for the Egiin Gol Hydropower Plant (HPP), indicating positive changes in the renewable energy sector.
6	Law on Energy Conservation	Enforced	26th November 2015	

Author's elaboration.

The Energy Regulatory Authority has been granted three crucial mandates, including:

- Approving a model agreement between generators and transmitters and monitoring its implementation.
- Setting the amount of a support tariff for consumers.
- Estimating energy tariffs after the expiration of a power purchase agreement.

In recent years, Mongolia has experienced dynamic social and economic growth, intensified market relations, legal reforms in the investment environment, and increased interest from domestic and foreign investors in the energy sector. This surge in activity has necessitated improvements in the legal and policy framework within the energy sector.

However, despite the introduction of Mongolia's Renewable Energy Law, effective implementation remains a challenge, impeding the creation of necessary conditions for renewable energy investment and development. Key obstacles related to feed-in tariffs (FiTs) under the Renewable Energy Law include:

1. Limited Duration of FiTs:

- The original law stipulated FiTs for ten years, dissuading investors from engaging in power purchase agreements (PPAs) for more extended periods.
- Longer-term FiTs can mitigate risks associated with renewable energy investments, facilitating more straightforward access to bank loans.
- The June 2015 amendment addressed this issue by extending the price-guarantee period.

2. Currency Risk:

- FiTs are payable in US dollars, encouraging foreign investors but transferring currency exchange risk to the Government.
- Mongolian currency depreciation against the US dollar poses financial pressure on the Government.
- This situation calls for a balance to ensure a stable investment environment while managing currency risks effectively. (Yong Chen, 2016)

3.2 Benefits from International Projects and Societal Progress

The renewable energy industry in Mongolia has derived significant benefits from international projects supported by organizations such as UNDP, EU, NEDO, JICA, NREC, CDM – Japan, World Bank, ADB, UNIDO, USAID NREL, GIZ, KfW-Germany, DANIDA, TASIC, and more.

Furthermore, the renewable energy sector plays a crucial role in contributing to Mongolia's societal progress. Societal progress, a normative concept (Noll, 1994), can be defined as the positive change or advancement in primary conditions of societies and people's lives. In the Mongolian context, the population in rural areas now has access to renewable energy, signifying that future conditions are envisioned to be better than present times. This alternative approach, beyond GDP, measures improvements in living conditions, societal characteristics, and life quality, considering factors beyond economic terms. The "Measurement of Economic Performance and Social Progress" has triggered a new discourse on societal progress in the present era.

This review emphasizes the nexus between societal progress, the emerging renewable energy industry, and the industry's contribution to enhancing the population's living standards.

The UNDP-supported activities in Mongolia encompassed an evaluation of the potential market for PV systems conducted by IT Power in 1990, with an assessed capacity of 5.2 MWp. Furthermore, the project facilitated the establishment of a joint venture, "Monmar," between the UK company Marlec Ltd and the Government of Mongolia, focusing on manufacturing small 50W wind turbines for nomadic herding families. This collaboration received technical support from UNIDO. Another UNDP project, Mon/86/006, supported the Institute of Physics and Technology (IPT) for pioneering work on manufacturing photovoltaic cells and modules for portable power for nomadic herding families. This initiative resulted in the laboratory production of PV cells with an efficiency exceeding 13%. The pioneering work of IPT and the Academy of Sciences in the 1970s and early 1980s played a crucial role in gaining acceptance for the potential use of solar energy in Mongolia, establishing the background for the utilization of renewable energy.

A training and tools development program could be encouraged to enhance the capacity for energy and climate mitigation planning at national, provincial, and municipal levels. This program ideally involves customizable but standard tools used nationwide. Additionally, regular GHG inventory preparation and mitigation action planning could be instituted to ensure the maintenance of skills in using such tools. This process could be coordinated with preparing national and regional Master Plans and Power Development Plans, aligning with the evolving requirements for biennial update reports to National Communications under the UNFCCC (Institute, 2015).

In 2002, the Government of Mongolia established the National Committee on Climate Change, chaired by the Minister of Nature & Environment, with high-level representation from various ministries. The committee included three working groups focused on public-private partnerships, the Clean Development Mechanism (CDM), and energy efficiency. Designated national authorities within the CDM included the Ministry for Nature and Environment, Ministry of Fuel & Energy, Ministry of Industry and Trade, Ministry of Finance and Economics, various scientific organizations, NGOs, and the private sector. CDM projects can fall into five categories: heat efficiency, renewable energy, technology transfer, greening or reforestation, and environmental pollution. In 2012, renewable energy programs constituted 71% of nine CDM projects, while energy efficiency accounted for 29%. Two hydropower projects registered under the CDM, including those in Tashir and Durgun, are estimated to reduce emissions by 30,000 tons of carbon dioxide annually. The Joint Crediting Mechanism was initiated by Japan (Dagvadorj, 2012).

An initial poverty and social assessment (IPSA) was prepared for the "Mongolia: Upscaling Renewable Energy Project" by ADB (2016, Project Number: 50088). The Government of Mongolia has set ambitious targets for integrating renewable energy into the power system under the State Policy on Energy 2015–2030, aiming for a renewable energy share of 20% in the total generation capacity by 2023 and 30% by 2030. Consequently, the Government, in collaboration with multilateral development banks, has devised the Renewable Energy Investment Plan to strategize investments in renewable energy.

The private sector becomes the primary driver for the central energy system, characterized by high affordability and a track record of private sector-led renewable energy projects with a feed-in-tariff system. Multilateral development banks such as the International Finance Corporation, European Bank for Reconstruction and Development, and private sector operations from ADB may provide financial support for private sector-driven renewable energy development. On the other hand, investments in renewable energy for other energy systems covering relatively poor regions will be managed by the Government, with sovereign financing from ADB and the World Bank.

The proposed project aims to demonstrate a distributed renewable energy supply in three batches focusing on relatively poor regions. The first batch will concentrate its investment on the Western energy system, which heavily relies on power supply (73%) imported from the People's Republic of China and the Russian Federation. The remaining 27% is supplied by the Durgun hydropower plant (12 MW installed capacity) located in Durgon soum, Khovd Aimag. The proposed core subprojects in the first batch will invest in (i) the construction of a 10 MW solar photovoltaic plant each in Myangad soum, Khovd aimag, and Omnogovi soum, Uvs aimag, (ii) the construction of a 5 MW wind power plant in Ulaangom, Uvs aimag, (iii) the rehabilitation of the currently non-operational Uench small hydropower plant (installed capacity of 0.96 MW) in Uench soum, Khovd aimag, and (iv) the installation of a heat pump heating system in schools and hospitals in aimag centers of Khovd and Uvs. A total of 26 MW of installed capacity in renewable energy will supply 40 gigawatt-hours in the western region grid system, potentially reducing dependence on power imports from neighboring countries from 73% to 46%. Additionally, it will contribute to increasing the renewable energy share in the power system from the current 10% to 13%. Non-core subprojects in the second and third batches will replicate a similar application in Mongolia's middle-western and eastern regions. Detailed project sites will be identified during the implementation of the first batch of the project. The proposed project aligns closely with (i) the Midterm Review of Strategy 2020, which identifies environmentally sustainable growth as a priority for helping developing member countries move onto a low-carbon growth path by introducing renewable energy; (ii) the Mongolia country partnership strategy (2012–2016), which supports energy access in remote rural areas; and (iii) ADB's Energy Policy (2009), which prioritizes renewable energy development (ADB, 2016).

GTZ is a German government-owned corporation for international cooperation. GTZ has been active in Mongolia for many years, with most of its energy-related activities concentrated in the north-western Aimags Zavkhan and Huvsgol. Additionally, GTZ has implemented various capacity-building measures. For Zavkhan and Huvsgol Aimags, GTZ has developed a preliminary supply concept, assessing the renewable energy resources in these Aimags. The first step of the supply concept involves the individual supply of single Soum Centers. The next step is the connection of neighboring Soum

Centers to form local grids, followed by the interconnection of the local grids. GTZ is building a 375-kW hydropower plant in Tosontsengel, which a private operator will later operate. The hydro plant will supply Tosontsengel Soum Centre and will later be interconnected with neighboring Soum Centres. A 6 kW PV-wind hybrid scheme was implemented in Tsagaanchuluut, detailed below (see section 0). Another small PV-wind hybrid scheme supplies a very remote Bag center west of Zavkhan Aimag, consisting of a 400 W wind turbine and a 200 W PV array. A private operator runs the hybrid system and supplies 3-4 families, a primary school, and the Bag hospital. A 5 kW PV battery charging station is currently being planned.

Support under the EU TACIS Program: A project under the EU TACIS Program (EMON 9601) supported the Mongolian energy sector for using renewable energy sources in isolated rural areas. The project's objectives were to assist the Mongolian industry and authorities in energy savings in the short and long term by implementing and monitoring several cost-effective and representative energy-saving pilot and demonstration projects, providing training and public awareness initiatives, and establishing joint ventures. The project aimed to provide beneficiaries with defined and viable RE projects and promote RE manufacturing joint ventures. The project also included three demonstration projects of hybrid wind/PV/diesel power plants of about 5kW in different Soum Centers. The hybrid systems were installed and tested in Soum hospitals and school dormitories. The project led to better medical service by providing lighting for Soum hospitals. Living conditions in dormitories were also improved. About 40 to 80 pupils from Herdsman families living in areas some distance from the school live at each dormitory. Experience gained from this project included specific weather conditions in Mongolia causing problems for the wind generators. Problems with maintenance and local production of generator parts were also experienced (Benjamin et al., 2011).

In 2007, the Government of Mongolia expanded the transmission and distribution network further, and the renewable energy law came into force in January 2007. A 2008 World Bank study evaluated the system configuration, operation, and condition of eight hybrid power plants in Mongolia. Due to the continuing performance problems of the existing systems, the Ministry of Fuel and Energy requested a further investigation of the system. As part of the GIZ-funded project "Utilization of renewable energy," eight hybrid systems were visited and evaluated through the project on the development of renewable energy sources in Mongolia (GIZ, 2009).

As of July 2017, there were eight different renewable energy license holders: Sainshand Wind Park LLC, AB Solar Wind, Aidiner Global, Cleantech, Clean

Energy Asia, Desert Solar Power Wind, Huduggiin tsahilgaan, and the Ulaanbaatar Usan tseneg power plant. The total capacity of these license holders is 642.4 MW. Renewable energy in Mongolia exists in the form of hydropower plants, wind turbines, and photovoltaic (PV) systems (Lee, "Accounting for Intermediaries and Transnational Linkages in the Multi-Level Perspective: Mongolia's Renewable Energy Transition," 2019).

4. Discussion

As the use of renewable sources rises, equipping officials in governmental energy authorities, practitioners, researchers, university graduates, politicians, and political advisers with updated knowledge on subjects such as cost reduction, technological advancement, subsidy issues, policy schemes, and potential environmental concerns has increasingly become important. This requires enhancement of the institutional and human capacities of the Mongolian renewable energy sector (Yong Chen, 2016).

Data availability for energy and environmental analysis in Mongolia is quite good. However, some areas where periodic surveys would benefit future planning efforts and make analyzing energy and environmental policy options more straightforward and accurate (Institute, 2015).

Review of heat and power options incorporating renewable electricity generation. Rich solar and wind energy resources could be tapped to yield clean energy for Mongolia. These energy sources are intermittent, meaning that other, likely fossil-fueled resources, electricity storage on a large scale, or a combination of the two would need to be employed for renewable power generation to operate effectively in Mongolia's energy system. Further research is needed to address intermittency through storage and balancing services, including the role of hydro and pumped storage hydro, in meeting peak loads and to recommend pricing reforms that allow for on peak and off-peak power that allow full cost recovery. Another area of research is how to provide heat for residential and other buildings using renewable energy. One advanced option is using ground-source heat pumps to turn electricity into heat at very high efficiency. It can also generate and store heat for hours, days, or even between seasons. Heat would then be released to the district heating system (or an individual home or building) when needed. Lastly, a simple (though less efficient) option may be installing inexpensive resistance heaters in homes and businesses or adding resistance coils to district heating systems so those systems can use renewable electricity when it is available as surplus.

Continued research on residential and commercial energy efficiency financing and implementation structures, in partnership with the existing local and international institutions working on this topic, including information on building owner and tenant attitudes, barriers, and decision-making processes regarding energy efficiency upgrades.

Research on possible legal and market instruments for reducing GHG emissions in Mongolia. Other countries have been exploring and implementing various emissions limits, trading, and pricing systems, including coal caps and emissions trading systems (ETS) in China and Kazakhstan and intensity-based trading in industrial sectors in India. Research could explore the application of similar mechanisms in Mongolia. The legal framework for ensuring dispatch priority of renewables is still missing – an issue causing curtailments in the power output from the first wind farm installed near Ulaanbaatar (Yong Chen, 2016).

The country needs fully functional institutions for renewable energy. Although renewable energy is a familiar sector in Mongolia, only a few skilled employees can undertake management and planning functions and perform financial analyses. Over the past years, it has been evident that there is a growing need to enhance the technical and coordination capacities of energy sector institutions in Mongolia to address the emerging issues arising from the increasing deployment and integration of renewables into the energy system. This much-needed capacity enhancement would also help the MoE as well as other governmental authorities involved in renewable energy development in Mongolia to gain a better understanding of the root causes of the issues they encounter and mobilize necessary resources to not only address them but also prevent the occurrence of future challenges through strategic energy planning. However, public funding cuts imposed by the Government for research, development, and demonstration of renewable technologies, as well as for resource assessment, have weakened the capacities of energy institutions in Mongolia (Yong Chen, 2016). The strategies should address the sector's evolving needs in the short-term (1-2 years) and medium-term (3-5 years) and at different levels regarding institutional and human capacities.

A comprehensive feasibility study with a focus on techno-economic analysis is needed. The notion of exporting low-cost, renewable-based electricity from the Gobi Desert to neighboring countries through the ASG has increasingly attracted interest from investors and developers. However, due to the large geographical extent of the Gobi Desert region and the projected high upfront costs, the ASG project faces an extraordinary set of technical and political challenges that hinder the project's progress beyond its preliminary phase. Severe considerations of the technical, political, and socioeconomic requirements, barriers, and implications must be carefully studied to realize the potential of the ASG successfully. A few preliminary studies on the issue of grid integration in northeast Asia have been completed by the Asia Pacific Energy Research Centre (APERC), the Korean Electrotechnology Research Institute (KERI), the Siberian Energy Institute of Russia, and the Energy Charter. These reports identify the potential benefits and barriers to grid interconnection but do so mainly from a research perspective. Initial studies indicate that Gobi Tec/ASG is technically and economically feasible. However, a comprehensive feasibility study to present different options with detailed techno-economic analysis has yet to be conducted, ideally with the involvement of the relevant countries' governments. With increasing pressure on reducing carbon emissions and conventional pollution from coal-fired power plants, the need for renewable electricity has grown substantially over the past few years. This has been coupled with growth in electricity demand. Therefore, the governments in each ASG country are on the verge of being engaged (Pevzner, "Mongolian Energy futures: Repowering Ulaanbaatar," 2019).

5. Conclusions

The adoption of renewable energy brings about both positive and negative impacts. A key concern for Mongolian energy experts and grid operators is the potential challenges associated with the increased deployment of variable renewable energy and the need to address flexibility constraints. Effectively communicating and finding appropriate solutions for this concern is essential.

To harness renewable energy optimally, there is a need for in-depth assessments of renewable energy resources. This involves determining the best land use, evaluating grid conditions, and strategically locating dispatch centers.

Establishing a renewable energy market in the aimag requires significant effort and negotiations to overcome physical, trade, and regulatory barriers.

Disseminating awareness among the population about renewable energy and its applications and advocating for rehabilitation efforts is crucial for meeting societal needs nationwide.

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Appendix

Appendix 1. National Renewable Energy Projects

Name of projects	Implanted and supported by	Results
Demonstration of New Sources of Energy in Rural Development MON/75/006	UNDP Academy of Sciences	Solar and Wind Technologies demonstrated Government and public support.
Applied research and development for rural use of renewable energy MON/86/005 (1986-1990)	UNDP REC	Wind generator factory Renewable energy laboratory
Development of Photovoltaic cells MON/86/006 (1986-1990)	UNDP IPT	PV Cell and Module manufacturing expertise developed
Transfer of Technology to produce PV Cells and modules (1991)	EU Soltech/ABE	Transfer of PV Module Laminators for commercial Pv Module production (now discontinued)
Research of portable type photovoltaic power generation system for demonstration (1992-1997)	NEDO REC	On-site experiment and test of 3 types of 200Wp Pv systems for herders' households in all areas of Mongolia
Technical assistance in Wind Generator Manufacturing	UNIDO Monmar	Improved Wind Generator Manufacture
Study on the utilization of solar and wind energy in Mongolia rural areas (1992-1993)	DANIDA	Study and advice on the electrification of bag centers and local centers using renewable energies
Photovoltaic manufacturing plant	ADB, HF PTA	Photovoltaic Manufacturing plant with an annual production capacity of 5 MW of PV modules
Rural electrification from renewable energy sources in Mongolia (1998-2000)	TACIS NREC	Assessment of solar and wind energy resources in 5 soum centers in GOBI region. On-site experiment and test of hospital, school, and dormitory electricity supply in 3 soum centers using solar and wind energy.
Master plan study for rural power supply by renewable energies in Mongolia (1998-2000)	JICA NREC	Master plan study of renewable energy development in the period of 2005,2010,2015 5kW solar and wind pilot plant in 3 soum centers
Wind energy resource assessment of Mongolia (1998-2000)	USAID, NREL REC	Wind measurement in the Gobi region Atlas of wind energy resource in Mongolia

Utilization of renewable energy in rural areas of Mongolia (1999-2007)	GTZ NREC	On-site experiment on utilization of renewable energies in Zavkhan province
Research and experimental project on photovoltaic power plant(2002-2004)	NEDO MoI	Photovoltaic power plant with capacity of 200kW bas built in Noyon soum, Umnugovi province
Rehabilitation of HPP on Bogd River, Zavkhan province (2003-2004)	KfW	Repair work of head-race channel of HPP on Bogd River
Nomadic electrification (2003)	JICA	Distribution of 11,500 PV systems with a capacity of 62 W
Erdenebulgan (2003)	DANIDA	Hydro Power Plant with a capacity of 200 kW
Development of renewable energies utilization in rural areas (2003)	ADB	Research project
Hydropower plant on Eg River	ADB	On-site study of HPP and techno-economic feasibility study, Drafts and blueprints
Construction of Taishir Hydro Power Plant	KF FEA	Drafts and blueprints of HPP on Zavkhan River with a capacity of 12MW were made.
Study on HPP in Orkhon River	JICA FEA	Techno-economic feasibility study on HPP on Orkhon River with capacity of 100MW
Taishir Hydro Power project	CDM Japan	Hydro energy -The government of Mongolia and the Abu Dabu" development fund.
Durgun Hydro Power project	CDM Japan	Hydro energy - The group "Shanghai" of foreign economic and technology cooperation of China.
"100000 solar ger program	Government subsidy/WB	Solar PV system - The Government of Mongolia
Promotion of Renewable Energy Resources	Grant Aid	Wind energy, Solar PV system, Hydro energy- GTZ (German Technical cooperation)
Development of renewable energy resources	GTZ Germany	Rehabilitation of Bogdiin Hydro Power Project Rehabilitation of Uliastai Electricity Network project.
Wind Park project with 50MW	Private ownership	Wind energy - group "Newcom" LLC
Renewable energy and rural electricity access project	Grant Aid	Wind energy - Solar Energy - The WB

Appendix 2. International Projects

Name of projects	Implanted and supported by	Results
Sophisticated utilization of solar and wind energy in the state economy, construction of equipment and plants(1989-1990)	MoI REC	The Solar collector, biogas digester, and movable type of wind generator were constructed and tested.
Solar energy (1991-1993)	MoI REC	Greenhouse and solar collectors were constructed and tested. The renewable energy testing field was built.
Biogas (1991-1993)	MoI REC	100m3 biogas digester was constructed.
Wind energy (1991-1993)	MoI NREC	Wind energy measurement in Manlai soum, Umnugovi province.
Electrical chemistry (1991-1993)	MoI NREC	A techno-economic feasibility study on the accumulator manufacturing plant was carried out. The production technology of the accumulator was chosen.
Solar and wind energy (1994-1996)	MoI NREC	Alternative ways to provide herders' families electricity using renewable energy technologies were developed and tested under natural conditions.
Production technology of biogas and bio-fertilizers based on cattle-breeding wastes, inventing and disseminating some equipment and plants. (1994-1996)	MoI NREC	Biofertilizer and briquette production technology was developed using sludge from a biogas digester.
Utilization technology of hydro energy of Mongolian small rivers as energy sources for small consumers (1996-1999)	MoI NREC	Design of a portable type of hydropower plant (HPP) with a capacity of 1 kW. Review the plan for the utilization of hydro energy on 12 rivers.
Assessment of solar and wind energy resources in Mongolia and technology of its utilization (1997-1999)	MoI NREC	Mongolia's solar and wind energy resource assessment was determined, and the resource map was produced. A further development plan for renewable energy utilization in Mongolia was produced. A drawing of a solar house was produced.

Production technology of biogas and biofertilizer based on hot springs (1999-2000)	MoI NREC	A map of the possibility of biogas and biofertilizer production in the hot spring region was produced.
Small scaled electricity-generating solar-wind hybrid system (1999-2000)	MoI NREC	The selection of a small wind generator that can be used under Mongolian conditions was made. On-site experiment of supplying rural small users with solar and wind energy.
Study on the provision of herders' families with electricity, communication, and information (2002-2003)	MoI NREC	Inputs to 100,000 Ger Program.
Study on possibilities to build a wind farm with a capacity of 25-30MW (2002-2003)	MoI NREC	Potential for Wind farm identified.
Using vacuum collector in a solar bathhouse in soum center (2002-2003)	MoI NREC	Technology demonstrated.
Improved channels for reservoirs and rural development (2002-2003)	MoI NREC	Techniques developed.
Energy supply for some techniques and equipment in military tactical units (2003-2004)	MoI NREC	Application of renewable energy

Appendix 3. Ongoing and Proposed Renewable Energy Projects in Mongolia

Name	Capacity	Condition and Electricity tariff
Salkhit WF (2012)	50 MW	Signed a contract. 9.5 c/k Wh
Choir WF (2015-2017)	50 MW	Signed a contract. 9.5 c/k Wh
Sainshand WF (2015-2017)	50 MW	Under development
Oyutolgoi WF (2013-2014)	102 MW	Signed a contract. 9.5 c/k Wh
Khurmen WF (2015-2017)	-	Under development
Bayanteeg Solar PP (2015-2017)	7.8 MW	Under development
Sainshand Solar PP (2018-2020)	50 MW	Under development
Proposed projects		
Name	Capacity	Status
Erdeneburen hydropower project	60 MW	Technical and economic feasibility study completed
Egiin Gol hydropower project	200 MW	Technical and economic feasibility study completed
Chargait Hydro Power project	24.6 MW	Technical and economic feasibility study completed
Khust Aral Hydro Power project	15 MW	Pre-Feasibility study completed
Orkhon Hydro Power project	100 MW	Pre-Feasibility study completed
Taishir Wind Park project	10 MW	Pre-feasibility study ongoing
Large-scale solar power plant project	25 MW	Pre-feasibility study ongoing

Source: Author elaboration through different sources

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Enumerative bibliography / Desk Study