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Strategies for Renewable Energy Adoption as Low-carbon Energy Technology in District Heating Systems in Mongolia

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Strategies for Renewable Energy Adoption as Low-carbon Energy Technology in District Heating Systems in Mongolia

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Abstract

The heating sector is strategically important for any country and creates primary conditions for that country's social, economic, and industrial development. The need to use thermal energy and technology in at least one stage of production inevitably arises. Therefore, one of the main tasks of the energy sector is to provide heat to residential, social, and service buildings in cities and towns, as well as to industries. The heating sector is even more critical for countries with harsh climates.

Mongolia has a unique climate with long winters; the reliability of the heat supply is a fundamental issue here. Notably, about 80% of the total solid fuel consumption in the country is used for heating, proving the vital role and importance of thermal energy for the country.

Since the foundation of the centralized district heating system was laid in Mongolia, it has continued to develop. Despite Mongolia's high potential for renewable energy sources such as solar, wind, and hydropower, 100% of district heating was produced from coal-fired heat and power plants. For this reason, further development cannot be achieved if the barriers to renewable energy adoption as low-carbon energy technology in the district heating system are not properly identified and removed.

Hence, this study identifies and ranks the barriers faced by renewable energy adoption as low-carbon energy technology in the district heating system of Mongolia. Based on previous research and the country's energy-use situation, 15 barriers were defined under four main criteria: technical, economic, social, and policy-political. The Analytic Hierarchy Process (AHP) methodology was used to estimate and assign priorities to these barriers. The priorities of barriers were determined by pairwise comparison based on the responses of directors who make the final decision-making in the main stakeholders of the district heating system: such as the Ministry of Energy, academia, and the major companies that handle the generation, distribution, and transmission network.

Policy implications were recommended to overcome the highest-ranked barriers to renewable energy adoption as low-carbon technology in district heating systems. The policy implications can be proposed more appropriately by focusing on these barriers regarding Mongolia's sustainable energy development.

Based on the result, economic barriers were the highest priority at 33.1%, followed by technical barriers at 32.2%, with nearly 66% concentrated on these two criteria among the four main criteria for renewable energy adoption. Notably, the top three out of fifteen important sub-criteria are high capital cost (14.7%), lack of knowledge and expertise (10.4%), and lack of infrastructure (10.3%).

Fundamentally, this study will help address the problems faced by renewable energy adoption as low-carbon energy technology in the district heating system. It will contribute to further research in district heating. Moreover, this study fills a knowledge gap by contributing to the literature and analyzing the barriers to renewable energy adoption as low-carbon energy technologies in district heating systems by using multi criteria decision-making analysis to prioritize barriers and provide policy recommendations.

Keywords: District heating system, Renewable energy, Low-carbon energy technology, Analytic Hierarchy Process (AHP), Barriers

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Chapter I
Introduction

1.1. Background

The heating sector is strategically important for any country and creates primary conditions for its social, economic, and industrial development. The need to use heat energy and technology in at least one stage of production inevitably arises. For this reason, one of the main duties of the energy sector is to provide heat to industries, residential, social, and service buildings in cities and towns.

Heat is the world's largest energy end-use, accounting for about half of total energy consumption. It includes heating residential buildings, water heating, cooking, industrial heating and other uses (IEA, 2021). Accordingly, heat accounts for 12 GtCO2, or 40% of the world's total greenhouse gas emissions. In addition, burning fossil fuels for heating increases local air pollution and is a major cause of global warming. The signing of the Paris Agreement commited the world to developing national climate change plans and updating them every five years to reduce air pollution and global warming. The signing of the Paris Agreement is a global agreement reached at the United Nations Framework Convention on Climate Change (UNFCCC) in December 2015, intending to limit global warming to well below 2 degrees Celsius above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 degrees Celsius (Vivid Economics, 2018). One of the key elements of the Paris Agreement is for countries to establish and submit their own Nationally Determined Contributions (NDCs), which are plans outlining the actions they will take to reduce their greenhouse gas emissions (Morgan & Waskow, 2014).

However, global heat consumption is expected to continue growing. With it, the consumption of fossil fuels is also expected to increase, it has become one of the major concerns of the energy sector. Increasing renewable energy production in the heating industry and decarbonizing the sector is necessary to solve this problem.

Countries around the globe aim to increase the share of renewable energy in heat production, focusing on fully decarbonized district heating systems (Werner, 2017).

Globally, district heating systems account for 11% of the total heat supply, but 3.5% of total greenhouse gas emissions come from district heating systems because almost 90% of it is derived from fossil fuels, mainly coal, natural gas, and oil (IEA, 2023).

Although the share of district heating systems in total heat consumption is small. However, it has a high share in European countries where heat consumption is important. The goal of increasing the share of renewable energy in the district heating system has been achieved by these countries.

Denmark, for example, aims to run all its district heating systems run on renewable energy by 2035 (J. Wang et al., 2019). Countries like Germany and Sweden have also implemented policies to support the transition to low-carbon district heating systems, including investments in combined heat and power plant systems and the development of district heating networks. Recently, more than two-thirds of the heat supply to the district heating systems are based on biomass and waste, and biomass alone accounts for about half of the heat supply in Sweden (Di Lucia & Ericsson, 2014; Ericsson & Werner, 2016). Germany aims to have a 100% renewable energy system by 2050. The state also regulates combined heat and power plants and district heating system law because Germany has specific laws for fuel cell CHPs (Mazhar et al., 2018).

However, the main challenge to decarbonization is moving away from the cheap energy sources of the country's natural resources. This challenge is also a problem for Mongolia, which has substantial coal reserves, and about 90% of its energy production comes from coal-fired combined heat and power plants (ERC, 2022). Mongolia has an extremely harsh climate with four seasons and an average annual temperature ranging from -8ºC to 8ºC. Therefore, two-third of the total energy production is used for heat supply. This demonstrates that the heating sector is a vital strategic sector for Mongolia.

Mongolia distributes heat to homes and buildings through a centralized district heating system, and coal-fired combined heat and power plants supply 100% of it. CO_2 emissions from these sources will equal 10.96 million tons by 2022. This amount was around 35% of the coal export in 2022, while Mongolia is one of the leading countries in coal export (ERC, 2022).

Due to a large amount of coal consumption, traditional district heating systems lead to significant air pollution in Mongolia. However, in recent years, the development of renewable energy adoption as low-carbon energy technologies in district heating systems is needed to transition to a more sustainable energy system and mitigate the effects of climate change globally.

1.2. Problem identification

As the population proliferates and rural-to-urban migration increases, the demographic structure of Mongolia is changing. As a result, meeting the growing energy demand is becoming increasingly urgent. However, due to the lack of significant investment in improving heat supply in recent years, the facilities are aging, and meeting the expected demand has become challenging. There is a pressing need to provide energy from cheap sources to meet these growing needs.

More than 80% of the energy production in Mongolia is used for heat supply; energy is provided by combined heat and power plants that burn coal (GGGI, 2020). In addition, more than 210,000 households that cannot access the centralized district heating system use solid fuels such as improved fuels (coal) and waste material for cooking and home heating.

This unfavorable situation has significantly increased air pollution and severely impacted public health. According to the World Health Organization (WHO), the average annual particulate matter (PM2.5) with a diameter of less than 2.5 micrometers in Ulaanbaatar is 7-35 times higher than the minimum permissible air quality standard set by them. Especially in the winter, when temperatures drop to -40 degrees Celsius, the air quality deteriorates, and pollution levels peak.

Mongolia's energy sector generates two-thirds of all greenhouse gases. According to domestic estimates, if current trends continue, greenhouse gas emissions will increase to 51.5 million tons of carbon dioxide by 2030, and the energy sector's share of total greenhouse gas emissions will increase to 81.5%. Therefore, by 2030, Mongolia intends to reduce greenhouse gas emissions by 7.3 million tons of carbon dioxide, including 4.9 million tons in the energy sector, 0.7 million tons in the industrial sector, and 1.7 million tons in the transportation sector (ADB, 2020).

However, Mongolia has a high potential for using renewable energy sources such as wind, solar, hydro, biomass, and geothermal energy. Nevertheless, the share of renewable energy was about 9.16% of the total energy production in 2022 (ERC, 2022). Moreover, renewable energy and low-carbon energy technology have yet to be integrated into the district heating system.

Due to the lack of policies and regulations, weak economic incentives, and lack of technical knowledge, the share of renewable energy in the district heating system cannot increase sufficiently. Furthermore, the country's cold temperature and harsh climate is another factor that negatively affects the widespread adoption of renewable energy.

As the impact of climate change is increasing nowadays, and related issues are becoming acute, the issue of financing projects for constructing new coal-fired combined heat and power plants and capacity expansion of the existing plants is becoming more and more difficult. Investments required to build new power plants and increase installed capacity are delayed. Meanwhile, the heating demand continues to grow, which is one of the most pressing problems in Mongolia.

1.3. Research questions and Research objectives

The demand for thermal energy will increase in the future with the growth of global population and industrial development. The future of district heating system development will be determined only by what methods and technologies will be used to meet that growing demand. The primary cause of global warming is greenhouse gas emissions. Due to the shortage of organic fuels, a policy to solve the problem of heat supply mainly by using new and renewable energy sources is planned to be implemented. However, depending on the situation of Mongolia, various barriers may be encountered in the development of renewable energy, and properly identifying these barriers will facilitate future development.

Research questions:

- What are the main factors and barriers to adopting renewable energy technology in district heating systems in Mongolia?
- What strategies can be derived from the prioritized barriers to facilitate the adoption of renewable energy as low-carbon energy technology in district heating systems?

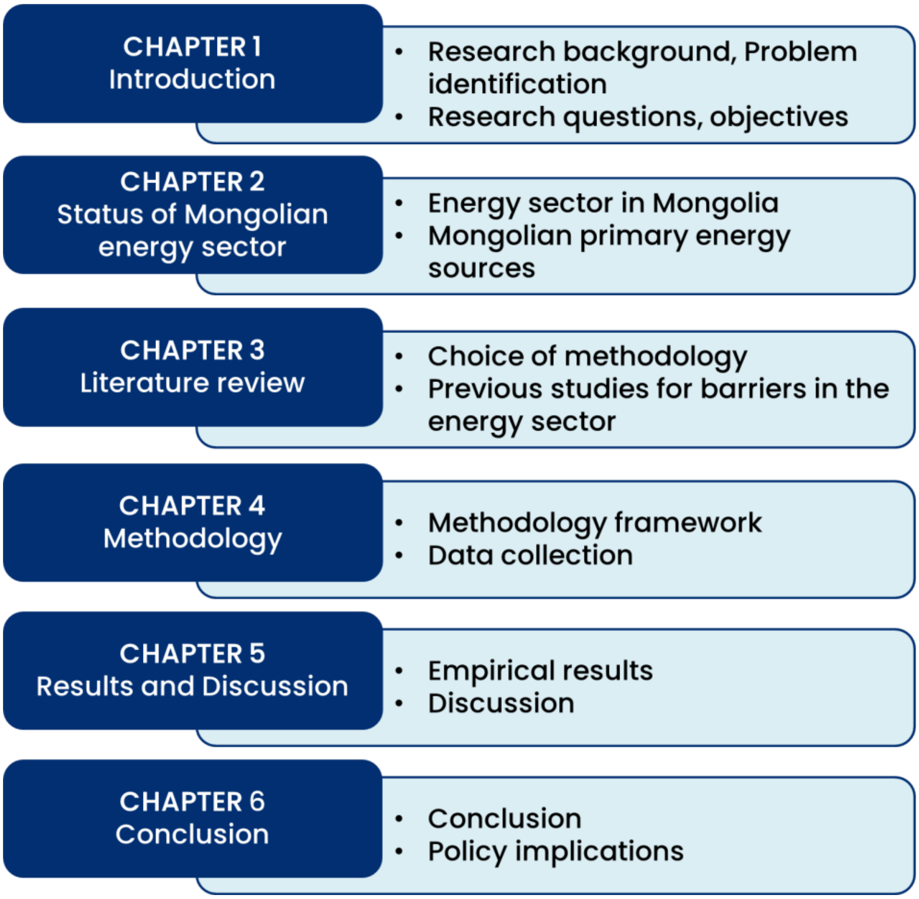
Research objectives:

- To develop a technical and cost-effective policy and strategy to integrate renewable energy and low-carbon technology into the district heating system based on Mongolia's sustainable energy development concept.
- To reduce Greenhouse gas emissions by increasing the share of renewable energy in the energy sector, especially the district heating system.

1.4. Thesis structure

This thesis consists of six main chapters. Chapter I discusses the global energy situation, including the status of the heating sector, especially the district heating system, and the current status and challenges of the heating sector in Mongolia. Research questions and objectives are also included in this chapter. Chapter II describes Mongolia's energy status, heating sector and district heating system indicators, and primary energy resources. Additionally, this chapter presents low-carbon technologies that can be introduced based on renewable energy resources. Chapter III reviews previous research that describes the reasons for choosing the research methodology and the barriers faced by renewable energy development. Chapter IV describes the research methodology and framework, detailing the steps of the Analytic Hierarchy Process (AHP) method. Based on the literature review, a hierarchical model is established in this chapter. Chapter V explains the data collection, empirical analysis, and results. Finally, Chapter VI presents the conclusion and policy recommendations.

Figure 1- 1. Thesis structure



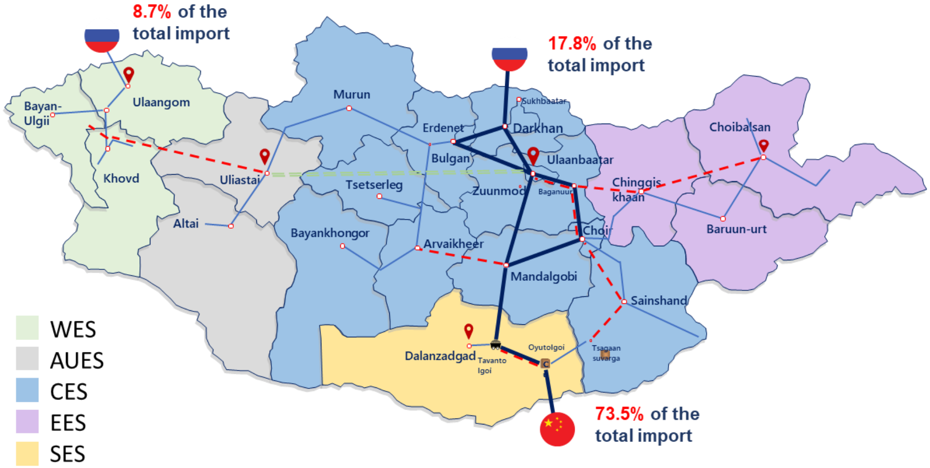
Chapter II

Status of the Mongolian Energy Sector

2.1. Energy sector in Mongolia

Mongolia's energy system is divided into five energy systems. It includes the Central Energy System (CES), Eastern Energy System (EES), Western Energy System (WES), and Altai-Uliastai Energy System (AUES), Southern Energy System (SES). The Mongolian energy sector structure is shown in Figure 2-1.

Figure 2- 1. Structure of Mongolian energy sector



Source: Ministry of Energy in Mongolia, 2022

Around 90% of the total energy supply is provided by the Central Energy System, which supplies to the capital city and the surrounding areas. The entire Mongolian network is in sync with the Russian network. The massive Oyu Tolgoi (OT) copper and gold mine and the Nuriin Sukhait coal mine are supplied with imported electricity from China, which is not connected to the Mongolian national grid.

Mongolia's total installed energy capacity was approximately 1560MW, and 8 billion kWh of electricity was produced in 2022, an increase of 3.4% from the previous year. Also, in order to meet the continuously growing energy demand needs every year, Mongolia imports electricity from Russia and China, and as of 2022, it is 2 billion kWh, which is a 16.1% increase from the previous year. Table 2-1 shows electricity and heat production for 2018-2022. The total installed renewable energy capacity has reached 286.8MW, accounting for about 9% of total energy production in 2022.

Table 2- 1. Energy generation

Sources	2018	2019	2020	2021	2022
Combined heat and power plants	6,152.4	6,346.6	6,493.6	7,109.6	7,428.5
Diesel station	3.7	3.0	2.7	1.1	1.2
Solar photovoltaics	51.5	109.0	108.9	156.9	178.7
Hydro power plants	78.2	85.4	83.3	83.1	61.7
Wind power plants	339.0	459.3	457.2	563.0	508.5
Total generation /GWh/	**6,624.8**	**7,003.3**	**7,145.7**	**7,913.6**	**8,178.6**
Import /GWh/	**1,683.6**	**1,715.8**	**1,705.6**	**1,861.9**	**2,161.5**

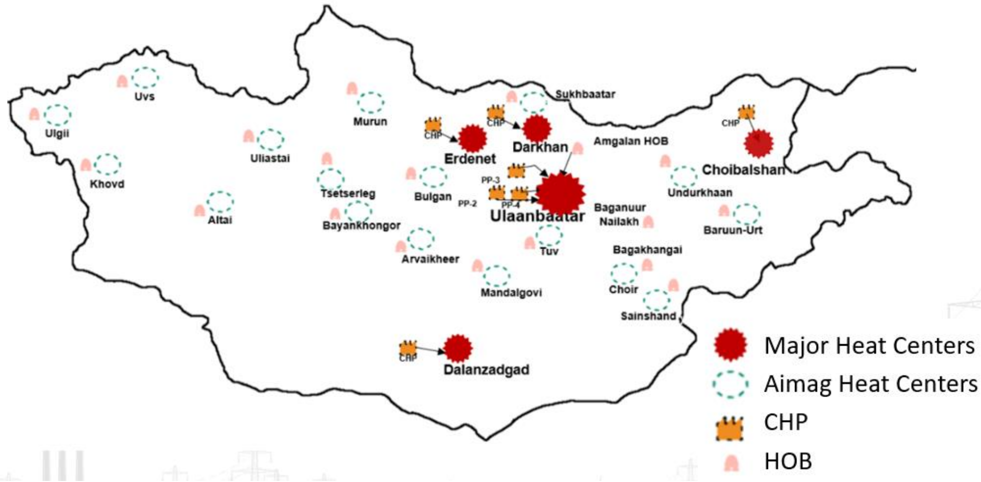
Source: Energy Regulatory Commission of Mongolia, 2022

2.1.1. Heating sector in Mongolia

The heat and electricity supply for the relatively harsh climate and long cold winter season plays a very important role in every Mongolian's life and social and economic prosperity.

Heat demand is met by combined heat and power plants (CHPs), heat only boilers (HOBs) located in the Central region, and raw coal burning in ger area in the city. Mongolia's thermal energy production is 11.9 million Gcal, of which 8.3 million Gcal is provided by combined heat and power plants located in the capital city and the Amgalan thermal plant in 2022. The Figure 2-2 shows the heating system in Mongolia.

Figure 2- 2. Heating system in Mongolia



Source: Copied from World Bank Technical Assistance on Mongolia Energy Sector Master Plan, 2020, page number:24

Of the 3 million or so people in Mongolia, about 25 percent are served by district heating systems, 5 percent by small heat systems, and 70 percent by individual coal fired stoves. Close to 60% of Mongolia's population are identified as urban and the access rate to centralized heating, including both district heating and small heat only boiler systems, in urban areas of Mongolia is about 50 percent. Ulaanbaatar city has about 1.5 million residents, and the rest of the urban centers have fewer than 50,000 residents. Also, Ulaanbaatar city accounts for nearly all of the urban growth in recent years. The number of heat consumers is shown in Table 2-2.

Table 2- 2. Number of heat consumers

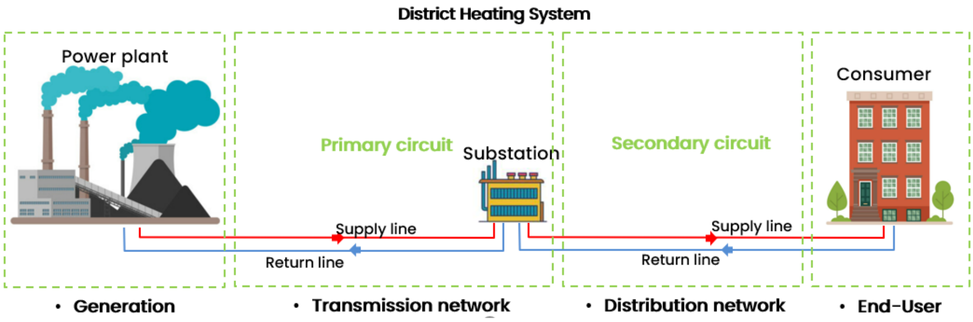
Region	Residential	Industry	Total	Share
Ulaanbaatar	282,917	20,034	302,951	73.3%
Orkhon	14,636	1,649	16,285	3.9%
Darkhan-Uul	15,116	1,680	16,796	4.1%
Dornod	7,426	487	7,913	1.9%
Dalanzadgad	1,439	335	1,774	0.4%
Rural areas	59,096	8,544	67,640	16.4%
Total	**380,630**	**32,729**	**413,359**	**100%**

Source: Energy Regulatory Commission of Mongolia, 2022

2.1.2. District heating system

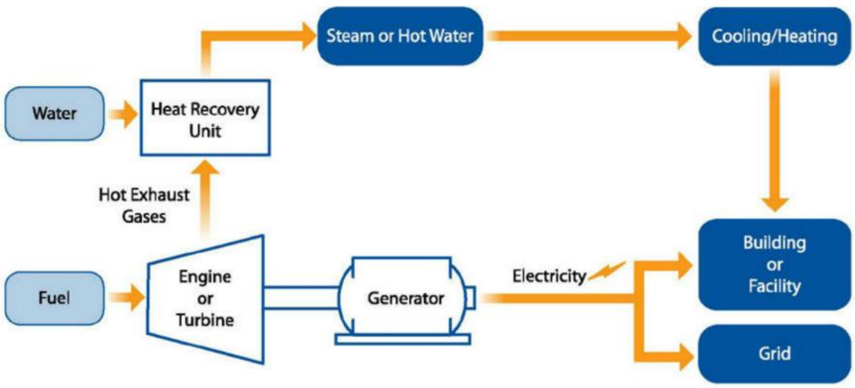
The district heating system distributes the heat produced by the heating plant to consumers through pipes (Sarbu et al., 2019). The district heating system consists of 4 main parts. These include Thermal plants, transmission and distribution, and consumers. The district heating system structure is shown in Figure 2-3.

Figure 2- 3. District heating system



All major heat sources in Mongolia are based on coal-fired combined heat and power plants. A combined heat and power plant (CHP) is a power generator based on advanced technology that combines electricity and thermal energy with relatively low fuel consumption. The combined heat and power plant schema is shown in Figure 2-4.

Figure 2- 4. Combined heat and power plant schema



Source: Adapted from Environmental Protection Agency, 2012

The foundation of the centralized district heating system was laid in Mongolia for the first time in 1934. Since then, heat consumption has grown rapidly. In particular, the district heating system of Ulaanbaatar, the capital city, where most of the population lives, is the largest. The heating network provides heat and domestic hot water to 45% of the total population of Ulaanbaatar.

Due to a large number of people moving from rural areas to settle down in the capital city, the population of Ulaanbaatar is increasing (with an increase of 3% per year), new consumption with an average load of 160-200 Gcal/h per year is increasing, heat distribution is increasing by 3%-5%, but the heating pipe the network is expanding at a very low rate of 1% per year.

Currently, the district heating system of Ulaanbaatar receives thermal energy from three coal-fired combined heat and power plants (CHP-2, CHP-3 and CHP-4) and Amgalan thermal plant. As of 2022, the total amount of thermal energy produced from those sources is 8.3 million Gcal. Table 2-3 shows detailed information on each source's heat generation.

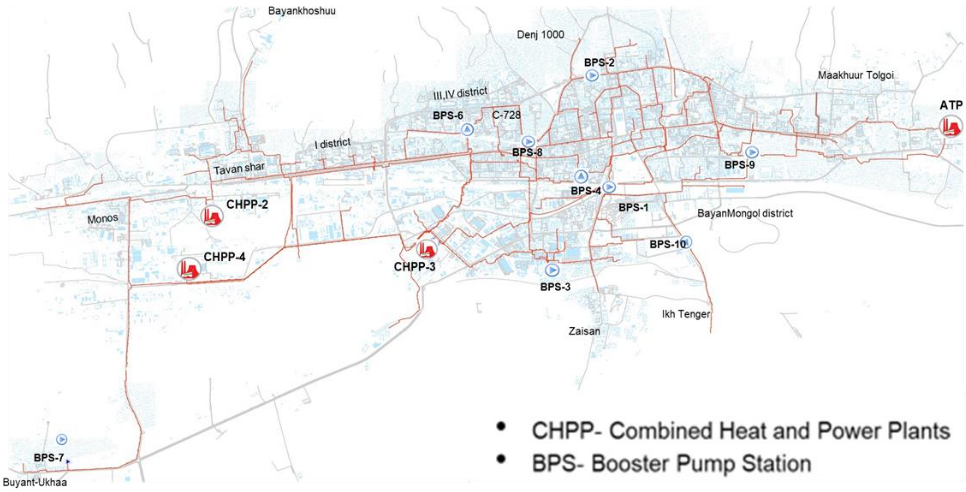
Table 2- 3. Heat generation by power plants

Generation set	Heat Generation /thou.Gcal/	Share
CHPP-4	4,551.4	38.2%
CHPP-3	2,642.1	22.1%
CHPP-2	251.1	2.1%
ATP	841.8	7.1%
LH-RA	1,152.8	9.7%
NTP	100.3	0.8%
BNTP	174.1	1.5%
Dz-CHPP	75.0	0.6%
Db-CHPP	362.35	3.0%
Eu-CHPP	464.3	3.9%
E-CHPP	692.7	5.8%
DCHPP	621.3	5.2%
Total	**11,929.3**	**100%**

Source: Energy Regulatory Commission of Mongolia, 2022

The "Ulaanbaatar District heating company" SOJSC is responsible for the centralized district heating system of the capital city. Also, control the district heating systems operation in rural areas. The company supplies 3,697 customers with business contracts connected to the centralized district heating system of Ulaanbaatar city with the thermal energy developed at "Amgalan Thermal plant" LLC, "CHP-2" SOJSC, "CHP-3" SOJSC, and "CHP-4" SOJSC. Thirteen main pipelines with a diameter of Φ150-Φ1200 mm owned by 16 customer service centers of 3 distribution centers belonging to OSNAUUG for heating, ventilation, and domestic hot water of more than 11,200 buildings have supplied through a pumping station and two heat transfer centers. The district heating system in capital city is shown in Figure 2-5.

Figure 2- 5. District heating system in Ulaanbaatar



Source: copied from Ulaanbaatar district heating company annual report, 2021

2.2. Mongolian primary energy sources

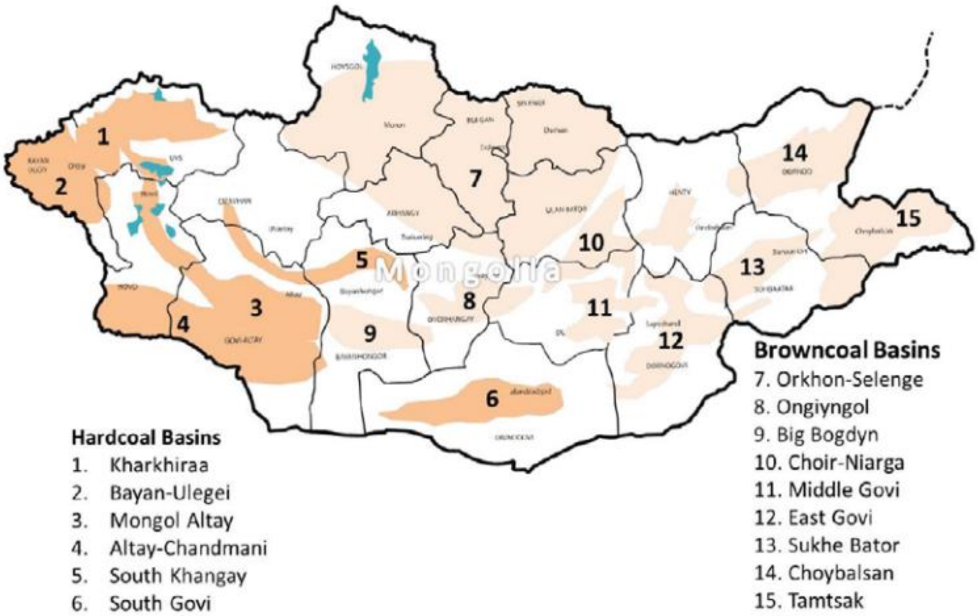
2.2.1. Fossil fuels

Coal

Mongolia has huge reserves of coal, and it is the main mineral for energy purposes. Also, the export products of mining origin are the main resource for economic development. Mongolia is among the top 10 countries in the world in terms of coal reserves.

Mongolia's estimated geological coal reserves are 173.3 billion tons (Chimed, 2019), and more than 21.5 billion tons of coal resources have been determined as a result of preliminary and detailed exploration. The coal basins in Mongolia are shown in Figure 2-6.

Figure 2- 6. Coal basins in Mongolia

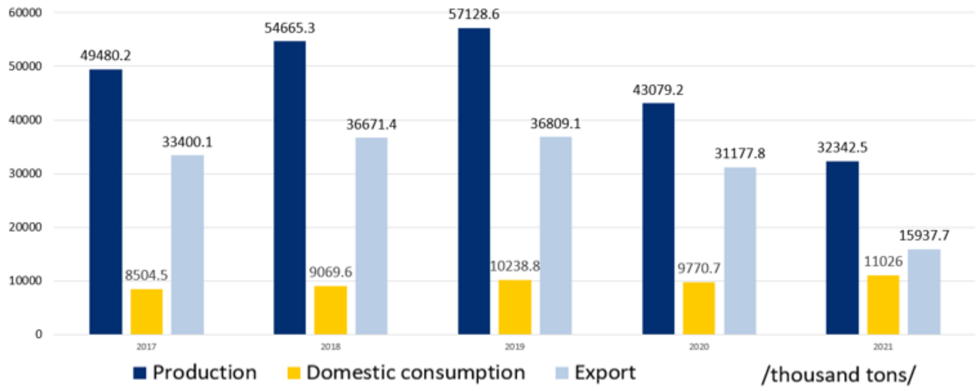


Source: copied from ADB 'Updating Energy Sector Development Plan, 2013

As of 2023, there are 43 active mines in Mongolia, including 29 hard-coal mines and 15 brown-coal mines. There are 9 major coal deposits of strategic importance.

Coal production and export: The coal sector accounted for 93% of mining exports and 4.8% of GDP in 2021 (Chimed, 2019). Since one-third of the total revenue comes from coal, Mongolia aims to increase its exports year by year. In addition, our country supplies 96 percent of coal exports to the Chinese coal market. The coal production, domestic consumption and exports in Mongolia between 2017-2020 are shown in Figure 2-7.

Figure 2- 7. Coal production, domestic consumption and exports in Mongolia



Source: Ministry of Mineral Resources and Energy of Mongolia, 2022

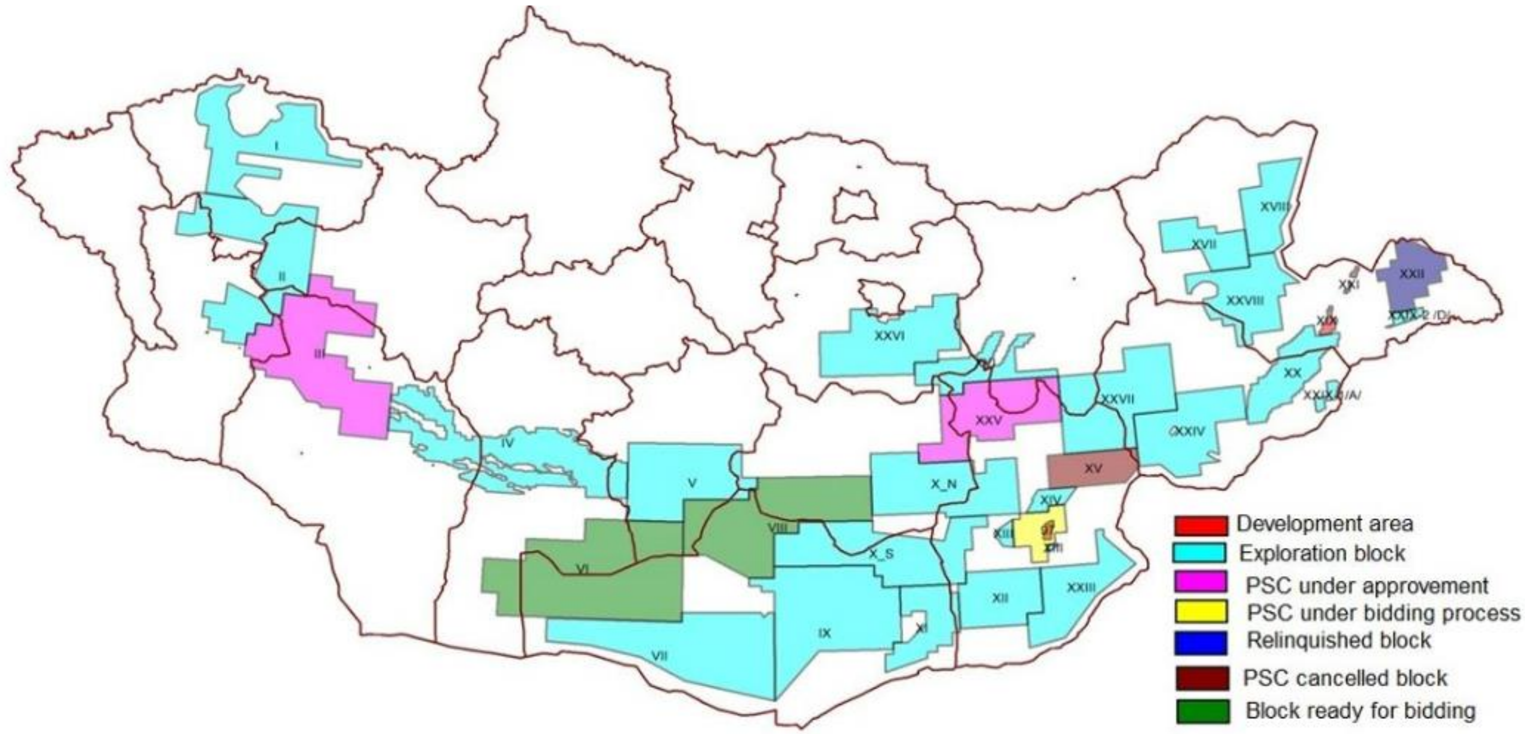
Mongolia's domestic coal consumption is about 8-10 million tons, but the number is likely to increase due to the CHP development projects.

Oil

The globe uses a lot of oil and gas to produce electricity. Oil still plays a significant role as a secondary fuel to support the burning of solid fuels in big boilers, despite efforts made globally to stop using it as a primary fuel for power.

For the purpose of petroleum exploration, 32 potential petroleum blocks have been identified in Mongolia. For 25 of these potential petroleum blocks, the Government of Mongolia has already inked a production sharing agreement with 21 businesses. The Petroleum exploration blocks in Mongolia are shown in Figure 2-8.

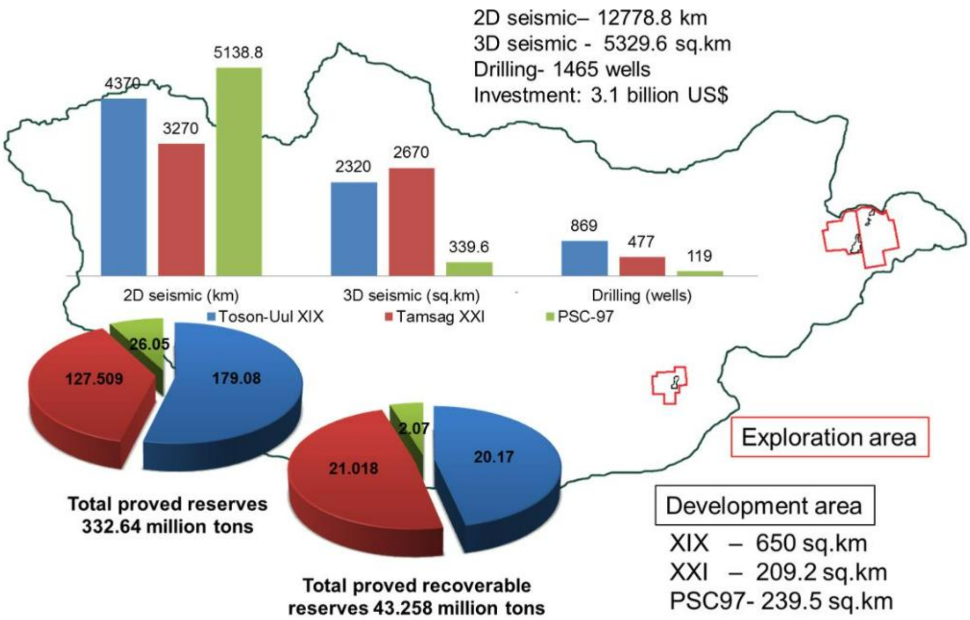
Figure 2- 8. Petroleum exploration blocks in Mongolia



Source: copied from Ministry of Mineral Resources and Energy of Mongolia, Annual report 2016, pg:47

Mongolia has been confirmed to have 332.64 million tons of estimated oil reserves. Between 1993 and 2016, Petro China Daqing Tamsag LLC and Dongsheng Petroleum (Mongol) LLC carried out 12,78 thousand km of 2D exploration (4,37 thousand km in the Toson-Uul XIX block, 3,27 thousand km in the Tamsag XXI block, and 5,14 thousand km in the PSC-97 block), as well as 5,33 thousand km2 of 3D exploration (2,32 thousand km). The oil exploration and potential reserves in Mongolia are shown in Figure 2-9.

Figure 2- 9. Oil exploration and potential reserves in Mongolia



Source: copied from Ministry of Mineral Resources and Energy of Mongolia, Annual report 2016, pg:48

Between 1996 and 2022, Mongolia produced over 75.98 million barrels (10.28 million tons) of oil, of which 72.81 million barrels (9.85 million tons) were shipped to China, bringing in 2.18 trillion MNT for the Mongolian government (MPRAM, 2016.).

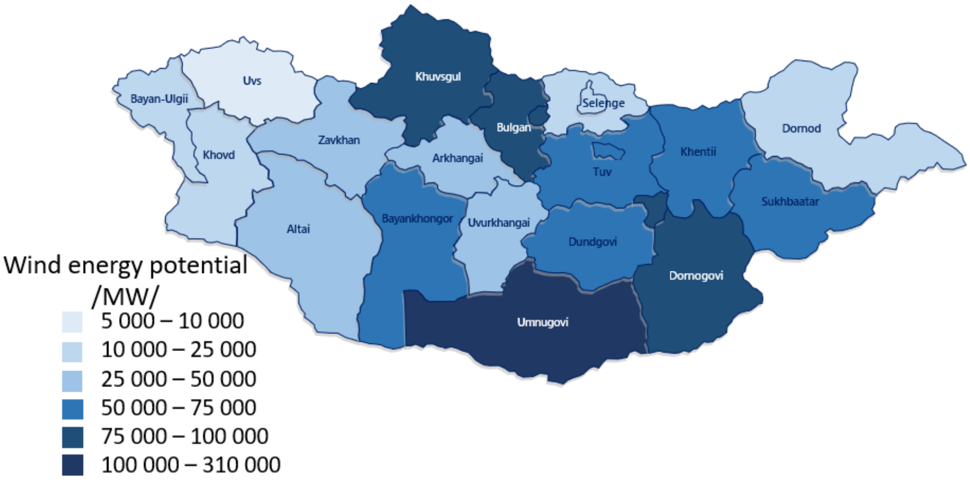
2.2.2. Renewable energy

Mongolia has high reserves of raw coal as well as a very high potential for renewable energy. Renewable energy resources alone can meet not only our own energy demand but also the energy demand of Northeast Asia.

Wind

Mongolia's wind energy reserves are estimated to produce 2.5 trillion kWh annually (Elliott et al., 2001). Mongolia's topography and barren steppes provide the world's best land-based wind energy resources. The wind energy resource map in Mongolia is shown in Figure 2-10.

Figure 2- 10. Wind energy resource map



Source: copied from IRENA, Renewable readiness assessment, 2001, pg:20

More than 20,000 households living in areas not connected to the power system throughout Mongolia meet their electricity needs using 50-100W wind turbines. Also, the first commercial wind farm with an installed capacity of 50MW was built in 2013 in Central Province. Since then, large-scale wind energy projects have been implemented, accounting for 67.9% of total renewable energy generation by 2022 (ERC, 2022). The information of wind power plants are shown in Table 2-4. There are also large-scale wind power projects scheduled to be commissioned in 2025.

Table 2- 4. List of wind power plants

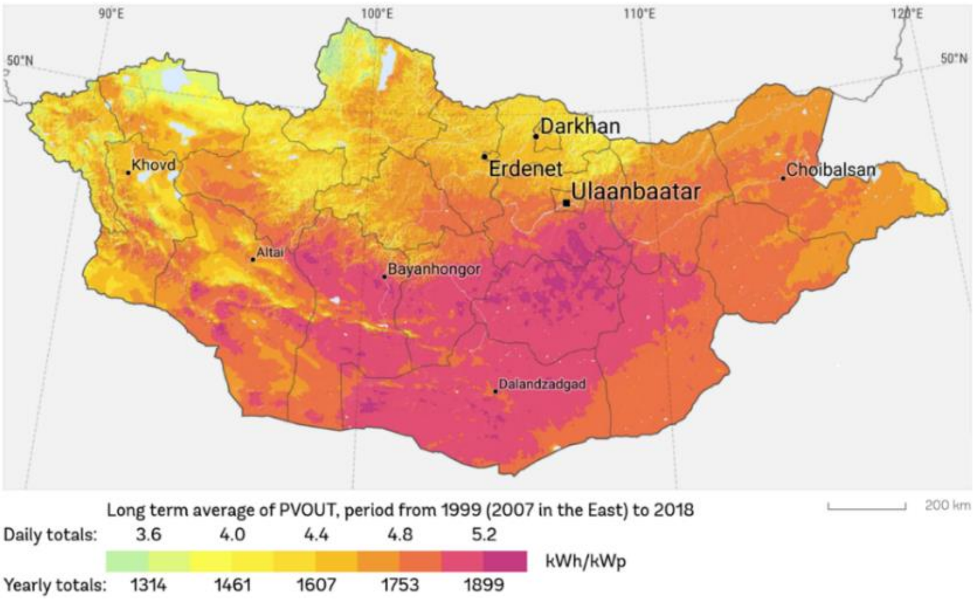
Name	Capacity /MW/	Year	Investment /million USD/
Salkhit	50	2013	100.0
Tsetsii	50	2017	120.0
Sainshand	55	2019	121.0
Total	**155**		**341.0**

Source: Ministry of Energy in Mongolia, 2022

Solar

Mongolia has 270-300 days of sunshine and approximately 2,250-3,300 hours of daylight. This figure shows that the availability of solar radiation is reliable. Mongolia's established solar energy resources are estimated to produce 4,774 TWh per year (IRENA, 2016). The Photovoltaic power potential map in Mongolia is shown in Figure 2-11.

Figure 2- 11. Photovoltaic power potential map



Source: copied from World bank, 2019; Global solar atlas 2.0

In Mongolia, solar panels have become common, especially at the level of rural herding families. Approximately 90% of Mongolia's 170,000 herder households use solar panels of up to 50W to generate electricity. The information of solar power plants in Mongolia are shown in Table 2-5.

Table 2- 5. List of solar power plants

Name	Capacity /MW/	Year	Investment /million USD/
Darkhan	10	2017	18.3
Monnar	10	2017	19.4
Bukhug	15	2019	27.0
Sumber	10	2019	17.2
Sainshand	30	2020	76.3
Gegeen	15	2018	26.9
Total	**80**		**185.1**

Source: Ministry of Energy in Mongolia, 2022

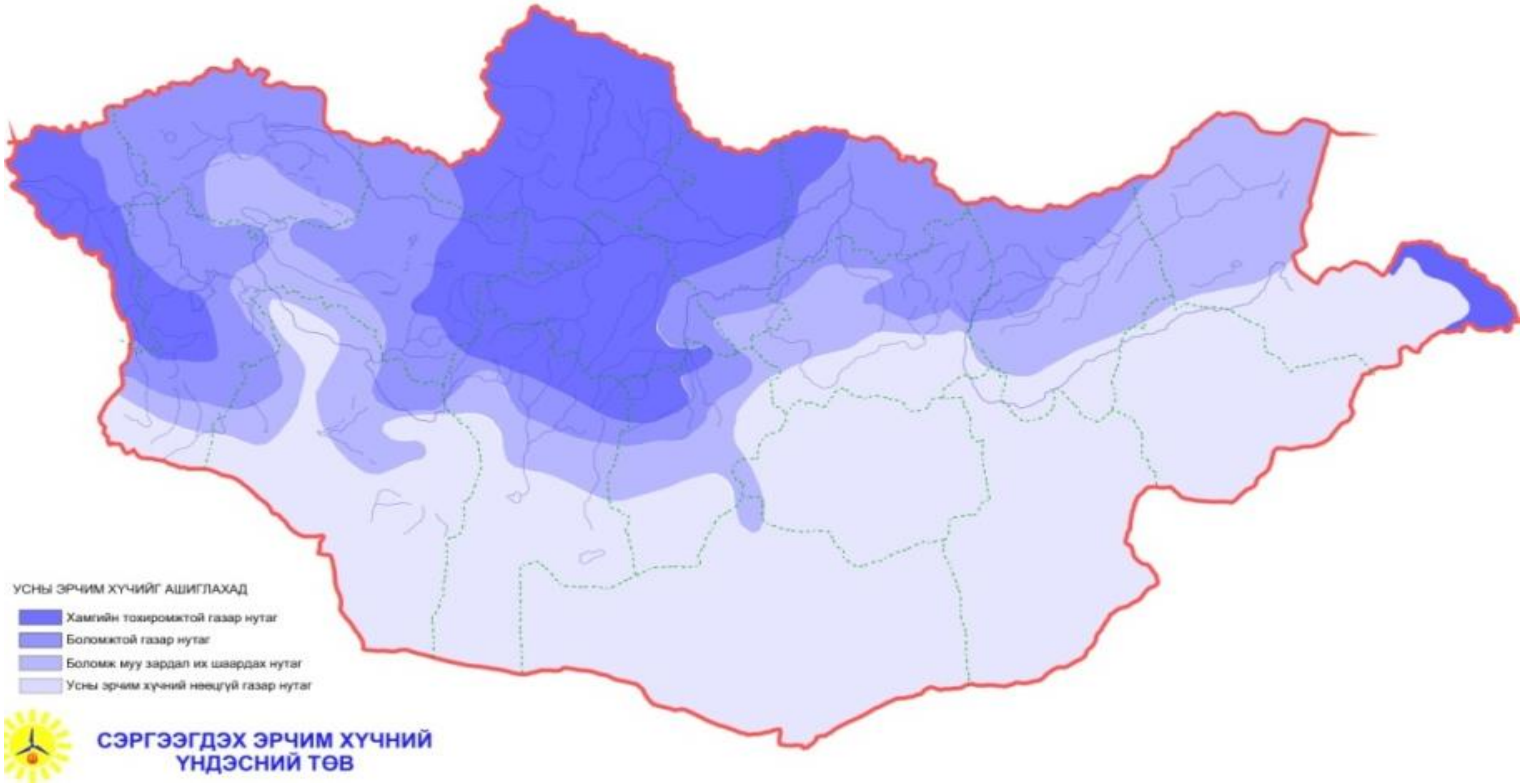
Gobi Desert as the third highest on the list of the world's deserts with high solar electricity generation potential. Solar energy generation accounts for 23.9% of total renewable energy generation by 2022. Large projects will be implemented in the future, and this indicator is expected to increase.

Hydro

The amount of precipitation that falls each year is typically minimal, and it is distributed in a digressive manner from north to south and from east to west. River development is more prevalent in the north due to its rugged geography. Rainfall fills rivers and streams to their maximum capacity in a year; precipitation is seasonal and greater in the summer. Autumn often has substantially less precipitation. All rivers, lakes, and streams freeze over in the winter, but the effect on electricity production varies.

There are more than 3800 large and small rivers and streams in Mongolia. Mongolia's identified water energy resources are estimated to produce 56.2 billion kWh annually (Matrenin et al., 2022). The hydropower potential map in Mongolia is shown in Figure 2-12.

Figure 2- 12. Hydropower potential map



Source: copied from Ministry of Energy in Mongolia, 2022

Several micro and small-scale hydropower plants have been established since the 1990s, and a large-scale hydropower plant was built and operated in 2008. These large power plants operate year-round, while other small hydropower plants operate only in summer and autumn. The information of large-scale hydropower plants in Mongolia are shown in Table 2-6.

Table 2-6. List of large-scale hydropower plants

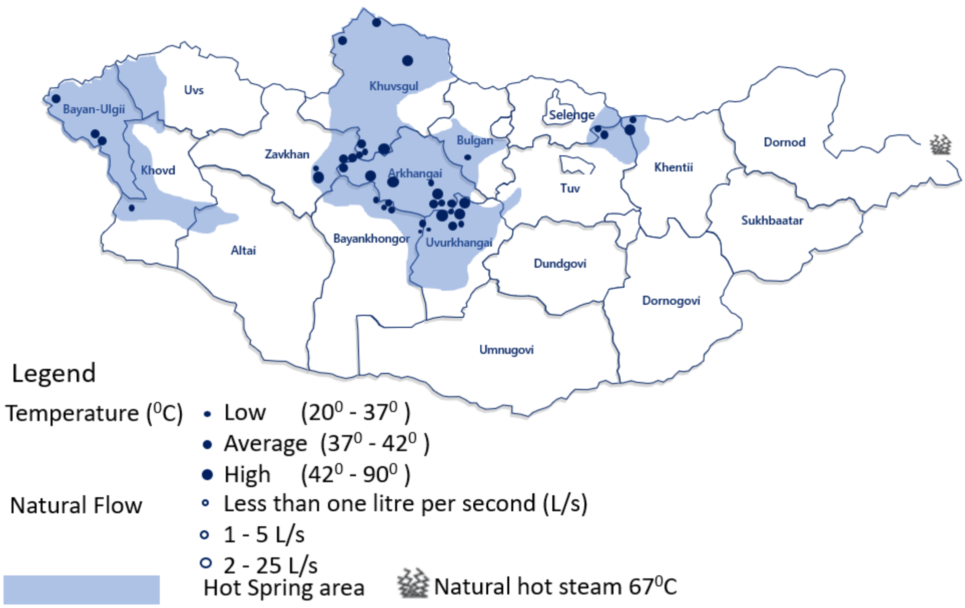
Name	Capacity /MW/	Year	Investment /million USD/
Durgun	12	2008	28.5
Taishir	11	2008	42.8
Total	**23**		**71.3**

Source: Ministry of Energy in Mongolia, 2022

Geothermal

The geothermal energy potential of Mongolia has not yet been determined. One manifestation of geothermal resources is hot springs. The geothermal potential map in Mongolia is shown in Figure 2-13.

Figure 2- 13. Geothermal potential map



Source: Renewable energy corporation of Mongolia, 2016

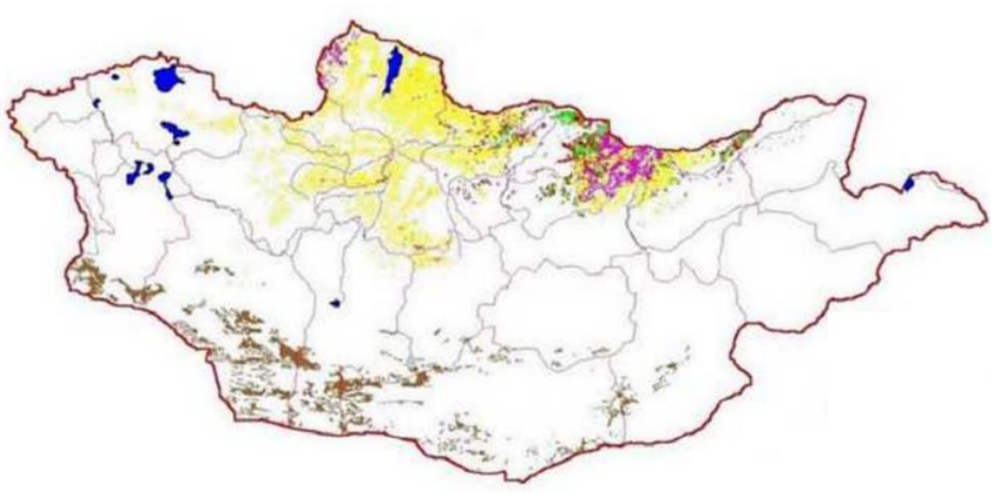
In contrast, a pre-feasibility study by Icelandic consultants found that geothermal energy in hot springs with more than 80 °C surface temperatures might be economically developed to supply heat to Tsetserleg and other towns in the Arkhanghai area. However, geothermal utilization is not yet widely developed. According to certain early research, the total flows of useable heat (heat that is more than 35°C) from hot springs at aimag levels range from 1 to 15 megawatts-thermal (MWth) (IRENA, 2016).

Biomass

Mongolians have a long tradition of herding livestock and using biomass as a source of fuel, and this tradition continues to this day. In Mongolia, there are many types of biomass, such as forest, , pellets, horse dung, khurzun (hardened dung and urine of sheep and goats, straw, shrubs, dry cow dung, biomass waste of urban settlements, Etc.)(Sarangerel, 2008).

Manure is the cheapest fuel that can be easily collected from any part of Mongolia at any time of the year. There are more than 67 million livestock (Chaorattanakawee et al., 2022) in Mongolia, which shows the potential for biomass sources in 2022. The biomass potential map in Mongolia is shown in Figure 2-14.

Figure 2- 14. Biomass potential map



Source: Ministry of Energy in Mongolia, 2016

2.2.3. Low-carbon energy technologies

Mongolia has highly renewable energy resources such as sun, wind, water, biomass and geothermal energy. The following low-carbon technologies can be introduced into the district heating system based on these renewable energy resources.

Solar thermal collectors/plant

Solar thermal collectors absorb sunlight, convert it into thermal energy and transfer it to a heat carrier. The heated fluid is then used directly for heating or stored for later use, providing a renewable and cost-effective solution for a variety of heating applications. In the case of a solar thermal plant, the amount of energy released from solar collectors depends on the selected operating temperature. In other words, the lower the operating temperature, the higher the efficiency of the solar collector and the larger the annual energy output. A solar thermal plant can preheat the incoming water through the return line of the district heating system.

Geothermal heat pumps

In any part of the world, the soil and air contain a certain amount of heat, and heat pumps can raise their temperature to provide heating for buildings and prepare hot water. Depending on the heat source used, heat pumps are classified as underground ground, underground water, and air. The geothermal heat pump works as a closed system with excellent energy efficiency. Energy efficiency is 3-6. This type of heat pump has a payback period of 2-10 years. The geothermal heat pump will not affect the exterior appearance of the building, and the underground pipe will work reliably for 40-50 years.

Countries where geothermal heat pumps are widely used include Sweden, the United States, Germany, Switzerland, Canada, Austria, and China. One of the main conditions for efficient heat pump operation is building a heated building with low heat loss, which is completely possible nowadays. Using heat pumps for district heating eliminates the use of coal, resulting in almost zero emissions of toxic and greenhouse gases. In many countries, the government actively supports using heat pumps, and various discount systems are in place (GGGI, 2020).

Wind turbines with electric boilers

Wind turbines combined with electric boilers offer a combination of renewable electricity generation and heating. Wind turbines use the power of the wind to generate electricity, which is used to run electric boilers and convert the electricity into heat for space heating, water heating and other heating purposes. Wind turbines are used to supply large-capacity electric boilers installed at combined heat and power plants with electricity through the main grid.

Electric boilers are small in size and do not require much space to install the stove and heat exchanger, usually 20-40 m2. Nevertheless, the installation area must have enough height to accommodate the stoves. Such furnaces are 5-8 meters high, so the room's height should be 8-12 meters. However, at this point, wind conditions at the wind turbine location must produce the minimum power required to operate the heat pump and electric heater[1].

Wastewater with heat pump

Extracting heat from wastewater using heat pumps is widely used to save energy in the field of heat supply. Sewage from various sources, such as residential, commercial, and industrial buildings, is collected through sewers and transported to sewage treatment plants. In wastewater treatment plants, heat pumps extract heat from wastewater. A heat pump system consists of a heat exchanger or heat recovery device that extracts heat energy from wastewater. A heat pump uses a refrigerant or working fluid to absorb heat from the wastewater. Refrigerant evaporates, absorbs heat energy, and then passes through the compressor to increase its temperature and pressure. After compression, the refrigerant releases the heat to a higher-temperature heating medium, such as water or air, through a heat exchanger. However, in this case, adjusting the return water temperature of the district heating system depending

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[1] COWI, *Ulaanbaatar district heating-Feasibility study,* 2021

on the wastewater consumption is necessary. Thus, the consumption of a centralized district heating system is sufficient. (IRENA, 2021)

Biomass-fueled CHP system

Biomass materials such as wood pellets, agricultural residues, energy crops, and forest waste are fed into CHP systems as fuel. Biomass is often processed and prepared to optimize combustion efficiency. Biomass fuels are burned in boilers or stoves, producing high-temperature flue gases and heat energy. The high-temperature flue gas passes through a heat exchanger, transferring the heat to a working fluid such as water or thermal oil. This recovered heat generates high-pressure steam or hot water for heating in district heating systems.

Because biomass is a renewable energy source, it will reduce greenhouse gas emissions compared to fossil fuel-based systems. When implementing a biomass-fired CHP system, it is important to consider factors such as biomass availability, biomass feedstock sustainability, emission control, and proper ash disposal. (“IRENA, 2021)

2.3. Government's current policy for renewable energy

The Law on Renewable Energy passed in 2007 was approved, and its main content is to set the tariffs for the purchase of energy produced by renewable energy sources in the transmission network in accordance with international standards. In the law, in 2015, provisions were included with the main content of the regulations on adding support tariffs to the electricity tariffs of consumers and customs and VAT exemptions. Also, in this law, 2019, the procedure for purchasing electricity from small-scale sources to the distribution network was established and approved.

In addition to laws to support and regulate renewable energy, several regulations have been approved and implemented since 2015. Table 2-7 shows the implementation documents and their main content.

Table 2- 7. List of Renewable energy regulations

Name	Year	Main content
Government's Programme of Action (2020-2024)	2020	In order to reduce greenhouse gas emissions, it is intended to undertake green production projects and develop renewable energy production in a sustainable percentage. Four solar energy projects were included, two wind energy projects, one hydropower project, and one charge storage project.
Regulations for the supply of energy produced by the consumer's renewable energy generators to the distribution network	2020	The amount of renewable energy that citizens may install is limited to 20 kW, or at most 50% of the electricity required by the technical requirements of the Enterprise.
Policy of the government on energy	2015	The installed energy capacity should have a 20% renewable energy share by 2020 and a 30% renewable energy share by 2030.
Mongolia joined the Paris and Glasgow Agreements of the United Nations Framework Convention on Climate Change	2015, 2021	By 2030, Mongolia wants to cut greenhouse gas emissions by 22.7%, or 16.89 million tons of CO2, and by 8.34 million tons, or 8.3 million tons, in energy supply and production.
"Vision-2050" long-term development policy of Mongolia	2020	Create a green economy that is productive, inclusive, and low in carbon to support global efforts to slow global warming.
New Revival Policy	2021	Erdeneburen 90 MW hydropower plant, Aegean River 315 MW hydropower plant, Renewable energy increase project /solar power plant-25MW, wind power plant-15MW, combined-0.5MW, geothermal-5 locations/, Green hydrogen, nuclear power projects

Source: Ministry of Energy in Mongolia, 2022

2.4. Chapter summary

This chapter covers the general energy structure of Mongolia, as well as the heating sector, including the district heating system. In addition, the types and resources of potential primary energy sources in Mongolia were presented. Then it introduced the low-carbon technology that can be used based on these primary energy sources.

Mongolia imports around 20% of its total energy consumption from Russia and China. Mongolia is the world leader in coal reserves and exports, so more than coal-fired combined heat and power plants produce 91% of the energy. However on the other hand, it is a country rich in renewable energy sources such as solar, wind, hydro, geothermal, and biomass. Nevertheless, renewable energy share in the energy system is only 9 percent, and renewable energy sources have not yet adopted the district heating system. Also, this chapter compiles and presents energy policies and regulations aimed at renewable energy development.

Chapter III

Literature Review

3.1. Overview of decision-making analysis

Globally, decision-making analysis is a rich field that integrates various fields such as politics, information technology, management, psychology, and economics. In response to social and environmental challenges, global decision-making has shifted to become more sustainable and inclusive (Waddock & Mcintosh, 2011). This point of view has been confirmed by other researchers who support participatory decision-making in global environmental governance (Bäckstrand et al., 2021). Furthermore, the world's sustainable development goals require responsible decision-making to promote sustainable development. In particular, it is demanded to solve complex energy management problems in energy planning (Pohekar & Ramachandran, 2004). Furthermore, many barriers must be overcome to introduce renewable energy technologies into conventional systems based on sustainable energy development. Identifying these barriers and challenges, studying their consequences, correctly determining the path of the renewable energy transition, and making the right policy decisions will further support of renewable energy development.

Various methods can be used in the decision-making process, and the right method depends on the situation, available information, time, and the difficulty of the decision. Various methodologies can be used in energy planning and sustainable development, including optimal decision-making processes for renewable energy adoption.

These include: Multi-criteria decision making (Oryani et al., 2021), life cycle assessment (Björklund, 2012), techno-economic analysis (del Río et al., 2017), scenario analysis (Wambui et al., 2022), linear programming (Gregg et al., n.d.).

Additionally, a widely used method for determining the barriers to renewable energy technologies adoption is include: Multi criteria decision making, case study, energy simulation modelling, literature methodology, techno-economic analysis, levelized cost of energy methodology.

Gillingham & Sweeney, (2012) used the levelized cost of energy method to review major barriers to low-carbon energy technology adoption, focusing on market failures to economic efficiency. Shujing, (2012) used literature methodology to summarize several key barriers to low-carbon technology transfer and highlights future actions in developed and developing countries. Kennedy & Basu, (2013a) used the case study method to consider the barriers of financial, regulatory, information frameworks, and institutional that may impact on low-carbon technologies development. Using the Techno-economic analysis, Zhu et al., (2023) developed a prototype to represent barriers such ask risk perception and inertia in energy system analysis with renewable heating technologies adoption. Del Río, (2011) used simulation modelling to analyze the situation and trends of electricity from renewable energy sources, based on several barriers to renewable energy technologies. Luthra et al., (2015a) used the Multi-criteria decision-making method to identify and rank the major barriers to green' energy technologies.

The most widely used method is the multi-criteria decision-making (MCDM) method, which is very effective when the barriers to being solved have many conflicting and subjective criteria. The method support to compare and prioritize different options (Fülöp, n.d.).

This advantage helps identify and prioritize technical, economic, social, political, and environmental issues that may arise when integrating renewable energy as low-carbon technologies with conventional sources in the energy system. It will help identify the system's most difficult problem and make the most appropriate decision to overcome it (J.-J. Wang et al., 2009).

Ghimire & Kim, (2018a) used MCDM method to identify and rank the barriers to renewable energy development in Nepal. Ziemele et al, (2014) used a multi-criteria decision-making method to assess companies' capabilities in district heating systems and develop tariffs that allow them to move towards low-carbon systems using MCDM methodology. Kamali Saraji et al, (2023) identified the most common problems in introducing renewable energy technologies in rural areas and developed appropriate policies to address them using MCDM methodology. Ren et al., (2009) identified that renewable energy systems in residential energy supply have poor competitive performance if they do not focus on the environmental impact of economic, energy and environmental criteria.

However, the MCDM method is used in several sectors such agriculture (Otgonbayar et al., 2017), export strategy (Hwu et al., 2015), landscape aesthetics (Erdenejargal et al., 2021) in Mongolia. Nevertheless, the MCDM method has yet to be widely used in Mongolia's policy recommendation for district heating systems. Usually, there are feasibility studies which Seureca (2015), COWI (2021) are recommended suitable renewable energy as low-carbon energy technology for district heating systems. However, the fact that these renewable energies as low-carbon energy technologies have yet to adopt the district heating system shows that finding the barriers to renewable energy development is important.

This study fills this knowledge gap by contributing to the literature and analyzing the barriers to renewable energy adoption as low-carbon energy technologies in district heating systems, using MCDM as a multi-criteria decision analysis to prioritize barriers and make policy contribution.

Table 3- 1. Review of renewable energy adoption as low-carbon technologies study

Author(s) and year	Title	Country	Method	Description of study
(Gillingham & Sweeney, 2012)	Barriers to implementing low-carbon technologies	USA	LCOE	To review major barriers to low-carbon energy technology adoption, focusing on market failures to economic efficiency.
(Shujing, 2012)	The Analysis on Barriers of Low Carbon Technology Transfer	China	Literature methodology	To summarize several key barriers to low-carbon technology transfer and highlights future actions in developed and developing countries
Sovacool & Griffiths, (2020)	The cultural barriers to a low-carbon future: A review of six mobility and energy transitions across 28 countries	UK	Literature methodology	To examine cultural barriers to a low-carbon technology future in transport, heating and cooling system across 28 countries.
Kennedy & Basu, (2013)	Overcoming barriers to low carbon technology transfer and deployment: An exploration of the impact of projects in developing and emerging economies	Ireland	Case study	To consider the barriers of financial, regulatory, information frameworks, and institutional that may impact on low-carbon technologies development.
Liu, (2014)	Barriers to the adoption of low carbon production: A multiple-case study of Chinese industrial firms	China	multiple-case study	To identify barriers to the adoption of low carbon production in cultural, structural, contextual, and regulatory categories.
Zhu et al., (2023)	Modelling barriers to low-carbon technologies in energy system analysis: The example of renewable heat in Ireland	Ireland	Techno-economic analysis	To develop a prototype to represent barriers such ask risk perception and inertia in energy system analysis with renewable heating technologies adoption.

del Río, (2011)	Analysing future trends of renewable electricity in the EU in a low-carbon context	Spain	Simulation modelling	To analyse the situation and trends of electricity from renewable energy sources, based on account of several barriers to the renewable energy technologies
Mata et al., (2021)	What is stopping low-carbon buildings? A global review of enablers and barriers	Sweden	peer-reviewed literature	To collect peer-reviewed evidence on adopting solutions for low-carbon buildings using a systematic mapping methodology.
Luthra et al., (2015)	Barriers to renewable/sustainable energy technologies adoption: Indian perspective	India	AHP	To identify and rank the major barriers in the green' energy technologies
Sindhu et al., (2016)	Identification and analysis of barriers in implementation of solar energy in Indian rural sector using integrated ISM and fuzzy MICMAC approach	India	AHP and fuzzy MICMAC	To examine the barriers to solar energy installation and development in rural areas, in context of India
Bhandari et al., (2019)	Prioritisation and evaluation of barriers intensity for implementation of cleaner technologies: Framework for sustainable production	India	AHP-GTA	To prioritize and measure the intensity of barriers to cleaner technology adoption
Shah et al., (2019)	Analysis of barriers to the adoption of cleaner energy technologies in Pakistan using Modified Delphi and Fuzzy Analytical Hierarchy Process	Pakistan	Modified Delphi and Fuzzy AHP	To weigh and rank the challenges to cleaner energy technology adoption
Tseng et al., (2021)	Multicriteria assessment of renewable energy sources under uncertainty: Barriers to adoption	Taiwan	Fuzzy Delphi, DEMATEL	To compare and rank the barriers to the adoption of renewable energy.

(Baumli & Jamasb, 2020)	Assessing Private Investment in African Renewable Energy Infrastructure: A Multi-Criteria Decision Analysis Approach	Denmark	TOPSIS	To prioritize the barriers to renewable energy projects in Africa
Siksnelyte-Butkiene et al., (2020)	Multi-Criteria Decision-Making (MCDM) for the Assessment of Renewable Energy Technologies in a Household: A Review	Lithuania	fuzzy AHP	To evaluate renewable energy technologies in households
Ghimire & Kim, (2018**)**	An analysis on barriers to renewable energy development in the context of Nepal using AHP	Nepal	AHP	To identify and rank the barriers to renewable energy development in Nepal
Oryani et al., (2021)	Barriers to renewable energy technologies penetration: Perspective in Iran	Iran	AHP	To evaluate and rank the barriers to the RET development of the 3 alternatives in Iran

3.2. Multi Criteria Decision Making (MCDM)

A procedure known as "multiple criteria decision making" (MCDM) enables decision-making when there are several, often opposing criteria (Gavade, 2014a). Many MCDM techniques have a specific function, however they vary widely in terms of the underlying information they employ, the nature of their queries, and the kind of output they provide.

MCDM methodologies have been applied to different applications and find the best solution to choose the best alternative. For example, this method is used for energy source selection (Xiaohua & Zhenmin, 2002),(Nigim et al., 2004),(Jaber et al., 2008), project management (Al-Harbi, 2001), traffic planning (Pogarcic et al., 2023), energy source allocation (Ramanathan & Ganesh, 1995).

MCDM methodologies suitable method for energy planning of combined energy system such as energy resources or energy carriers combined in complex network. Because it allows for a systematic and structured evaluation of multiple options and criteria and can consider both quantitative and qualitative factors (Løken, 2007).

The most widely used MCDM methods include AHP (Analytic Hierarchy Process), Elimination and choice translating reality (ELECTRE), Technique for order preference by similarity to ideal solutions (TOPSIS), Preference ranking organization method for enrichment evaluation (PROMETHEE), and Analytic Network Process (ANP) methods (Aruldoss et al., 2013).

It is crucial to consider the pertinent factors while selecting an MCDM method. The process needs to be simple to apply. The decision-makers must properly understand the methodology's suggestions (Løken, 2007).

3.2.1. Analytic hierarchy process (AHP)

Saaty developed the analytical hierarchy process (AHP), which is one of the most popular techniques for addressing complicated decision-making issues. This approach separates decision-making into objectives, standards, qualifications, and alternative hierarchies (Gavade, 2014a). An AHP hierarchy may have as many levels as necessary to represent a particular decision scenario accurately. AHP is a valuable approach since it contains several practical components. A few of these include the ability to handle situations with several decision-makers, subjective judgments, and consistency of preference measures (Gavade, 2014b). Users often regard the pair-wise comparison method of data entry as simple and straightforward.

3.2.2. Analytic Network Process (ANP)

The ANP method, which emerged as a result of Thomas Saaty's subsequent work, is seen as a more generic variation of the AHP approach. Although this system is simple to use, it does not cope well with the complexity of many different sorts of scenarios due to its freedom of movement. ANP, on the other hand, is based on a developed network of linkages with alternatives and criteria that allow for different connections.(Aruldoss et al., 2013).

3.2.3. Technique for order preference by similarity to ideal solutions (TOPSIS)

The distances of the chosen option are assessed using the TOPSIS approach. The chosen options should be the closest to the perfect solution on the positive side and the farthest away from the ideal solution on the negative side. The positive ideal solution is an imaginary solution where all attribute values are equal to the maximum attribute values in the database containing the satisfying solutions; the ideal solution is a hypothetical solution where all attribute values are equal to the minimum attribute values in the database. Therefore, TOPSIS offers a solution that is not only the most opposite of the ostensibly worst but also the closest to the ostensibly greatest (Gavade, 2014b).

3.2.4. Elimination and choice translating reality (ELECTRE)

Elimination and choice translating reality (ELECTRE) method allows decision makers to select the best suitable choice with least of various criteria. However, ELECTRE method was applied three major problems such as choosing, sorting and ranking. It developed into ELECTRE I and the evolutions have continued with ELECTRE II, ELECTRE III, ELECTRE IV, ELECTRE IS and ELECTRE TRI (electre tree). The decision-maker analyzes outranking relationships between numerous alternatives using concordance and discordance indices, then uses the crisp data to select the optimal alternative (Aruldoss et al., 2013).

3.2.5. Preference ranking organization method for enrichment evaluation (PROMETHEE)

The PROMETHEE method compares each alternative pair against each chosen criterion on a mutual basis. The PROMETHEE is most beneficial when teams work on complicated issues, particularly when there are several criteria, numerous human views and judgments, and long-lasting effects on the choices made. It has several advantages when important decision-making criteria are hard to compare or quantify or when departmental or team involvement is constrained by team members' skill sets or points of view.

The PROMETHEE I partial ranking, the PROMETHEE II full ranking, and the GAIA plane are the three primary PROMETHEE tools that decision-makers may employ to analyze the assessment issue (Macharis et al., 2004).

3.2.6. Selection of method

Depending on the research questions or expected outcomes, each of these Multi criteria decision making (MCDM) method approaches can be used for a variety of applications due to their individual strengths and weaknesses. Although AHP cannot handle uncertainty, it is a simple model that can handle various data types and can give criteria a weighted average. PROMETHEE handles data uncertainty well and can contain a variety of data kinds, however it is unable to rank the criteria. The model is comparatively simple to use and comprehend.

Regarding data uncertainty, accommodating various data kinds, and its inability to rank criteria, ELECTRE is similar to PROEMTHEE; nevertheless, the model is more difficult to comprehend and apply than PROMETHEE. The final model, TOPSIS, can accept various data kinds and is a simple model to comprehend and use, but it does not account for uncertainty and cannot rank criteria. The ability of the decision-maker to discuss results to guarantee that is achieved among all stakeholders is provided by AHP, which is the simplest of structures. Therefore, the AHP method was chosen in this study.

Table 3- 2. Summary of the PROS and CONS of MCDM methods

Name	AHP	ELECTRE	PROMETHEE	TOPSIS
Data uncertainty	-	+	+	-
Different data types	+	+	+	+
Model complexity	+	-	-	-
Weighting	+	-	-	+

Source: expanded and adapted from Wijnja, 2014

3.3. Previous studies for barriers in the energy sector using the Analytic hierarchy process (AHP) method

A number of researches using AHP have been conducted in the field of energy planning that identified barriers in renewable energy development.

- Social, cultural, and behavioral; Economic and Financial; Political and regulatory; Social, cultural, and behavioral; Technical; Institutional; Political and regulatory barriers are the main criteria for renewable energy technologies penetration (Oryani et al., 2021).
- Market, Economical & Financial, Ecological & Geographical, Awareness & Information, Technical, Political & Government Issues, Cultural & Behavioral are the main criteria for sustainable energy technologies adoption (Luthra et al., 2015b).
- Technology, Outsourcing, Financial, Knowledge, Involvement and support are the main criteria for green supply chain management implementation (Govindan et al., 2014).

- Political instability followed by transportation problems, absence of a coherent RE policy, scattered households, and corruption and nepotism are the top five barriers to renewable energy development (Ghimire & Kim, 2018a).
- The corruption, nepotism, & favoritism, High capital cost, Lack of a coherent RE policy are top three important RE barrier for renewable energy and sustainable energy development (Solangi et al., 2021).
- Lack of skilled personal, Corruption and nepotism, Renewable energy availability are the main three sub-barriers for development of renewable energy technologies (Pathak et al., 2022).

3.4. Chapter summary

This chapter consists of two main sections. The first section covers the decision-making methodologies used in energy planning and how the method chosen for the research question was selected based on previous research. In the second section, the barriers to introducing renewable energy are studied from previous research studies.

Globally, the most widely used method is the multi-criteria decision-making method, which is very effective when the barriers to being solved have many conflicting and subjective criteria. The method support to compare and prioritize different options. Among these methodology, the most widely used methods are generally presented and compared. In sum, the ability of the decision-maker to discuss results to guarantee that are achieved among all stakeholders is provided by AHP, which is the simplest of structures. Also, the MCDM, especially the AHP method has yet to be widely used in Mongolia's policy recommendation for district heating systems. Therefore, the AHP method was chosen in this study. This study fills this knowledge gap by contributing to the literature and analyzing the barriers to renewable energy adoption as low-carbon energy technologies in district heating system using the AHP.

Chapter IV

Methodology and Models

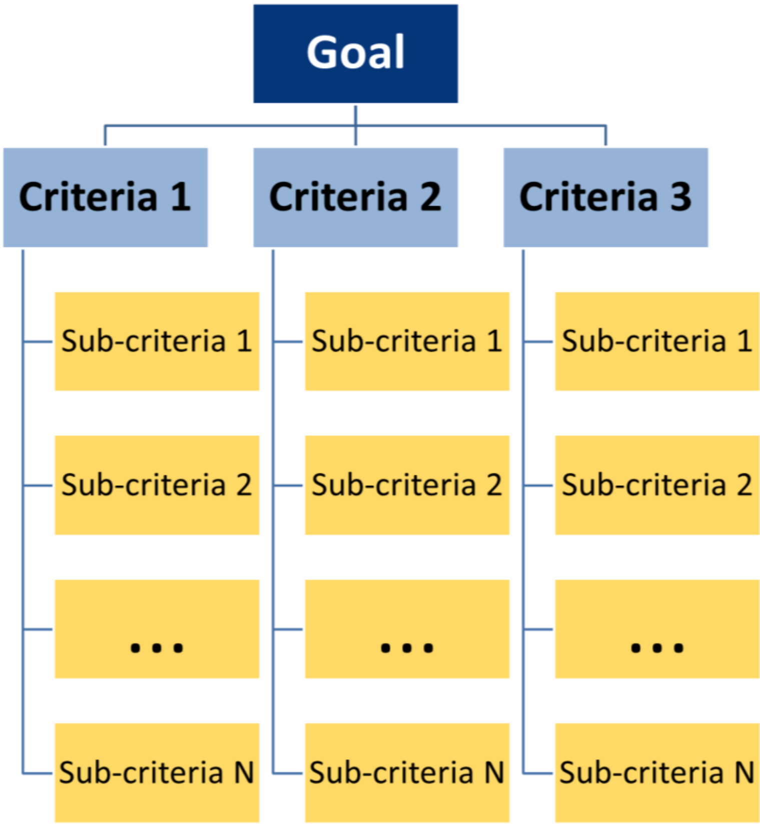
4.1. Methodological framework of Analytic hierarchy process (AHP) method

In the 1970s, Thomas L. Saaty created the AHP. As a discipline for multi-criteria decision-making, it generally follows three fundamental processes (T. L. Saaty, 1988). Primary identification of the criteria and alternatives is necessary for the lees at that to the primary objective; in the second plan, a quantitative is required for the evaluation of the components criteria X and alternatives. To finish the matrix evaluation of the alternative solutions made, resulting in numerical valuations for each, which potentially lead to ranking of alternatives and better decision-making.

The AHP model was established based on the requirements of this research and the literature review. The nature of the AHP technique allows for a natural pair-wise comparison of criteria for each other. The resulting comparison matrix can be used to rank barriers to renewable energy adoption in Mongolia. The following five steps could be used to rank barriers in the context of renewable energy adoption as low-carbon energy technologies in Mongolia.

The definition of the problem focused on the criteria, and particular barriers within each criterion led to the formulation of the hierarchical structure. It is the procedure of decomposing the barriers into a hierarchical tree. Relevant and related literature has been reviewed to create the hierarchical structure. Barriers were attempted to cluster in the criteria when the researcher had a significant number of them when ranking the barriers (T. L. Saaty, 1990).

Figure 4- 1. Example of hierarchical tree/Structure



Source: T. L. Saaty, 1990

After establishing the hierarchical structure, the pairwise comparison should be constructed for each level. The preference of the experts or respondents will assess the pairwise comparison. The number of pairwise comparisons is then determined using the total number of criteria (n), using the following formula (R. W. Saaty, 1987):

$$\binom{n}{2} = \frac{n!}{2!(n-2)!} = \frac{n(n-2)}{2} = \frac{n^{2-n}}{2} \qquad (1)$$

Experts or respondents must rank one factor in the pairwise comparison and provide a numerical judgment scale accessible to evaluate the pairwise comparison (R. W. Saaty, 1987). As indicated in Table 4-1, nine scale points make the respondent's judgments simpler. If there is a better way to demonstrate them than by using even numbers, the odd numbers are used when utilizing the AHP scale to establish a comparison. Criteria i and criteria j will be compared (Aij), where i.j=1,2…,n.

$$A_{ij} = 1 \text{ for } i{=}j\text{, and } i \text{ more } j$$

$$A_{ij} = \frac{1}{A_{ij}} \text{ for } i \neq j\text{, } i \text{ less than } j$$

Table 4- 1. Classification of nine-point scale

Judgments	Numeric Values
If Option A and Option B are equally important	**1**
If Option A is moderately more important than Option B	**3**
If Option A is strongly more important than Option B	**5**
If Option A is very strongly more important than Option B	**7**
If Option A is extremely more important than Option B	**9**
Use even numbers for intermediate judgments	**2,4,6,8**

Source: T. L. Saaty, 1986, 1990, 1994, 2008

In next step, pair-wise comparison matrix will be constructed with respect to each criteria level. Let us assume A is comparison matrix as below,

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{12} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{2}$$

$$\left({}^{W_i}\!/_{W_j} \right) n \times n = A \tag{3}$$

$$A = \begin{bmatrix} w1/w1 & w1/w2 & \cdots & w1/wn \\ w2/w1 & w2/w2 & \cdots & w2/wn \\ \vdots & \vdots & \ddots & \vdots \\ wn/w1 & wn/w2 & \cdots & wn/wn \end{bmatrix} \tag{4}$$

$$AW = \begin{bmatrix} w1/w1 & w1/w2 & \cdots & w1/wn \\ w2/w1 & w2/w2 & \cdots & w2/wn \\ \vdots & \vdots & \ddots & \vdots \\ wn/w1 & wn/w2 & \cdots & wn/wn \end{bmatrix} \begin{bmatrix} 1 \\ \vdots \\ n \end{bmatrix} = \begin{bmatrix} \lambda_{max} w1 \\ \vdots \\ \lambda_{max} wn \end{bmatrix} = \lambda_{max} W \qquad (5)$$

where n is the number of matrix rows, the Consistency Index (CI) value can be determined as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (6)$$

Franek & Kresta, (2014) claim that when the matrix is consistent, the consistency index value is zero.

The consistency ratio (CR), created by Thomas L. Saaty in 1980, can be used to detect inconsistency. The respondents' preferences are considered acceptable if the CR is less than 0.10. In this research, respondents are asked to do pairwise comparisons once more if their CRs are determined to be more than 0.10, until Saaty's 0.10 limit is reached. The following equation can be used to compute the consistency ratio:

$$CR = \frac{CI}{RI} \qquad (7)$$

Saaty's RI values are used in this research when referring to the random index (RI).

Table 4- 2. Random index values by Thomas L. Saaty (1977)

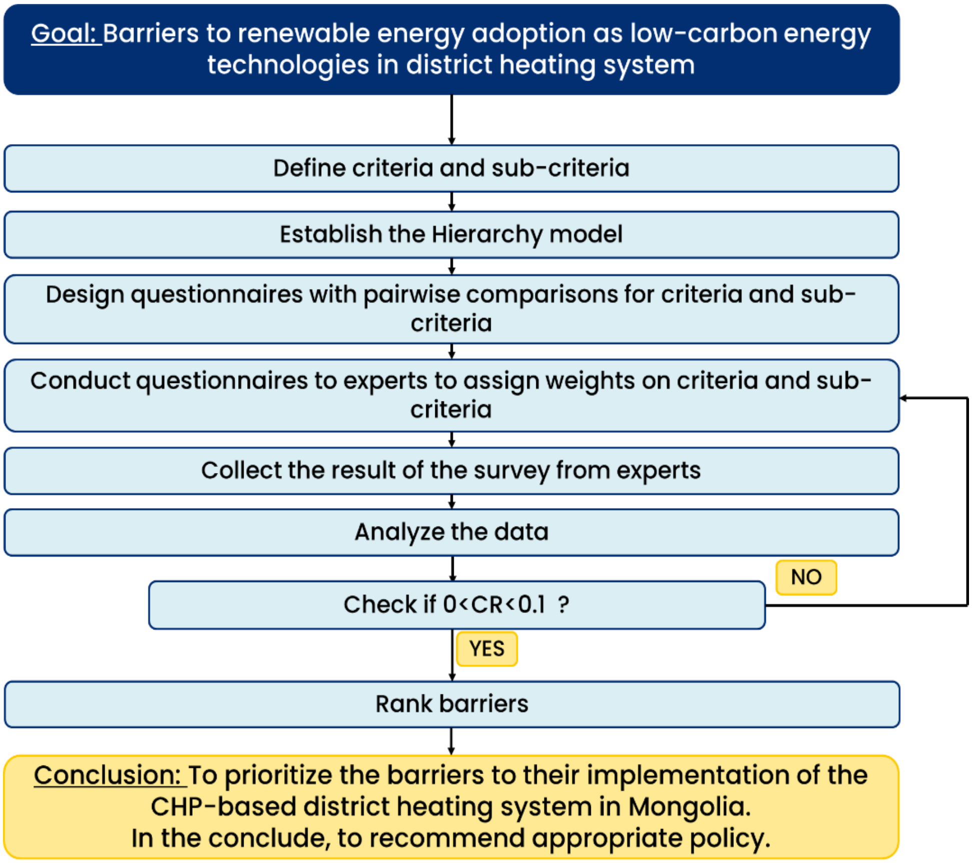
N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The geometric mean approach is often used in group decision-making processes to aggregate choices from a group of respondents. The geometric mean approach is used in this research to assess the preferences of a group of experts. The expert's aggregated choices using the geometric mean approach are as follows:

$$\text{Geometric Mean} = \sqrt[n]{\text{aijE1 aijE2} \ldots aijEn} \tag{8}$$

where aijEi is the result of expert (Ei)'s preferences on a pairwise comparison of element i against j.

Figure 4- 2. Methodology framework



4.2. AHP Criteria Selection

Criteria, sub-criteria are identified based on the literature review and the country's situation. The main factors are technical, economic, social and politics. The decision-making difficulty has been divided into 15 identified sub-barriers under four basic criteria, and a hierarchical framework has been built.

A. Technical barriers

A.1. Unreliable supply: The unreliability of the energy supply is an obstacle to adopting CHP and low-carbon technologies in district heating systems due to the instability of renewable energy. Production could be more unreliable and unstable than traditional energy sources in most renewable energy technologies. Therefore, it includes issues such as managing fluctuations in energy supply and balancing supply and demand.

A.2. System compatibility: This barrier is an operational challenge for introducing low-carbon technologies in district heating systems. Many district heating systems are already in place and may have limitations that make it difficult to integrate renewable energy sources. In particular, the newly integrated low-carbon technology must work smoothly with the existing district heating system without disrupting its general operation and efficiency.

A.3. Lack of knowledge and expertise /HR/: This barrier arises from needing more skilled human resources in the district heating system. Experienced personnel and experts are the main factors in the system's operation, and the lack of human resources will hinder the reliable operation of the system.

A.4. Lack of infrastructure: Integrating renewable energy sources based on low-carbon energy technology with the capital city's district heating system network may result in relocating residents in the region. In addition, the high land price and additional heat transmission lines may need to be built or upgraded, which may increase costs due to infrastructure.

B. Economic barriers

B.1. High capital cost. The high cost of installing new district heating systems based on low-carbon energy technologies and upgrading existing district heating systems such as pipelines, heat exchangers and control systems can be a significant barrier to adopting RE and low-carbon technologies in district heating systems.

B.2. Lack of access of credit. Government support is partial government support and cannot cover the project's total cost. Therefore, creating a market for these technologies and ensuring simple access to credit is essential. Lack of credit leads institutions to lend at higher interest rates.

B.3. Lack of subsidies. Low-carbon district heating systems have significant capital and operational expenses, but government subsidies can help offset these costs. However, in other circumstances, these subsidies may be absent, making it difficult for people, businesses, and governments to afford to adopt these technologies.

B.4. Power pricing scheme. Low power prices have historically made utilities' financial challenges worse by leaving insufficient funds for the infrastructure and system of district heating, which in turn causes a lower-quality or irregular supply of power.

C. Social barriers

C.1. Lack of public acceptance. Diverse viewpoints exist on renewable energy technology, and some individuals reject it. Resistance to altering energy consumption habits may result from a lack of public involvement, misunderstanding about renewable energy development, and preference for existing energy sources.

C.2. Lack of consumer paying capacities. A large percentage of the population in Ulaanbaatar, Mongolia, has incomes below the subsistence level and may not be able to pay the possible increase in tariffs. As a result, many people are unable to purchase renewable energy options

C.3. Lack of public awareness and understanding. It refers to barriers arising from a need for more general public knowledge and information about low-carbon energy technologies and the outcomes of their introduction into the system.

D. Policy& Political barriers

D.1. Corruption and nepotism and favoritism. This obstacle is caused by corruption, profiteering, and other favoritism that will negatively affect the adoption of RE and low-carbon technologies in district heating systems. These lead to problems such as lack of transparency, inefficient allocation of resources, and poor decision-making.

D.2. Political commitment and consensus. It is a problem of insufficient political commitment and lack of commitment. It includes setting targets for renewable energy use, providing financing and resources, and developing policies and regulations to support them. Without strong political commitment, renewable energy integration initiatives lack the stakeholder motivation to achieve their goals.

D.3. Lack of policy and regulatory. The current regulatory and policy framework for district heating systems may not suitable to adopt low-carbon technologies. Due to the current policy and its regulation, the implementation of projects may be delayed, and the stakeholders may need help in the project implementation stage.

D.4. Political instability. Political instability frequently changes priorities, policies, and regulations, making planning and implementing long-term projects difficult.

Table 4- 3. Classification of criteria

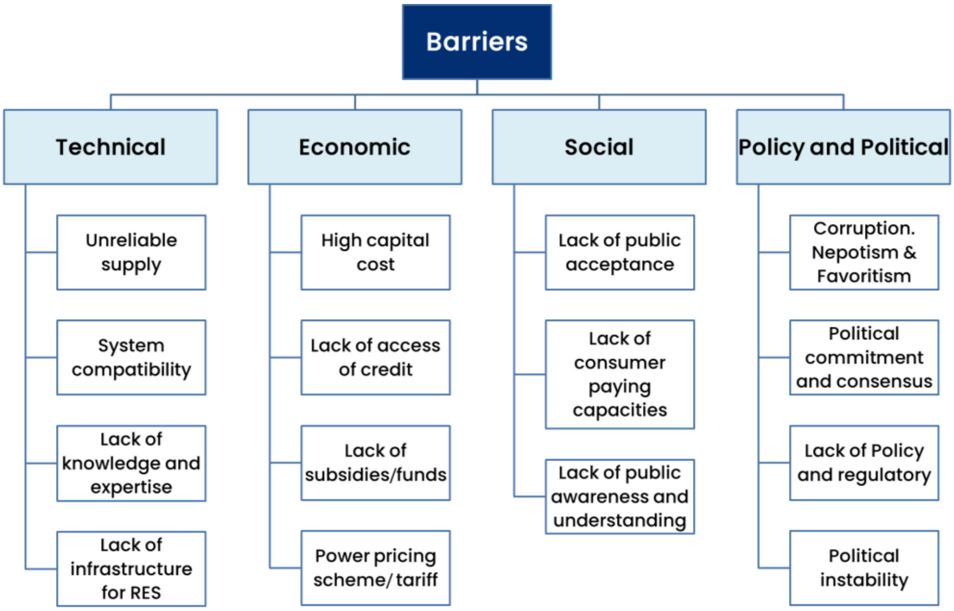
Criteria	Sub-criteria	References
Technical	Unreliable supply	(Ziemele et al., 2014), (Kamali Saraji et al., 2023), (Ghimire & Kim, 2018a)
	System compatibility	(Kamali Saraji et al., 2023), (Richardson et al., 2022), (Oryani et al., 2021)
	Lack of knowledge and expertise	(Dulal et al., 2013a), (Painuly, 2001), (Ikram et al., 2020)
	Lack of infrastructure	(Luthra et al., 2015b), , (Mirza et al., 2009a), (Farooqui, 2014)
Economic	High capital cost	(Mirza et al., 2009b), (Adhikari et al., 2008), (Solangi et al., 2021)
	Lack of access of credit	(Kamali Saraji et al., 2023), (Kahraman et al., 2009), (Punia Sindhu et al., 2016)
	Lack of subsidies	(Javadi et al., 2013), (Solangi et al., 2021), (Ghimire & Kim, 2018a)
	Power pricing schema	(Ziemele et al., 2014), (Karatayev et al., 2016)
Social	Lack of public acceptance	(Setyowati, 2021), (Ghimire & Kim, 2018a), (Darmani et al., 2014)
	Lack of consumer paying capacities	(Luthra et al., 2015b), (Ghimire & Kim, 2018), (Asante et al., 2022), (Solangi et al., 2021)

	Lack of public awareness and understanding	(Kennedy & Basu, 2013b), (Asante et al., 2022), (Punia Sindhu et al., 2016)
Policy & Political	Corruption and nepotism and favoritism	(Sovacool & Bulan, 2012), (Ghimire & Kim, 2018a), (Solangi et al., 2021),
	Political commitment and consensus	(Luthra et al., 2015b), (Brown, 2001), (Solangi et al., 2021)
	Lack of policy and regulatory	(Setyowati, 2021), (Luthra et al., 2015b), (Ghimire & Kim, 2018b), (Oryani et al., 2021)
	Political instability	(Dulal et al., 2013b), (Punia Sindhu et al., 2016), (Solangi et al., 2021)

4.3. Hierarchical structure

The research hierarchy structure was developed based on the defined goal of the research, identified main criteria, and sub-criteria. The main factors are technical, economic, social and politics. The decision-making difficulty has been divided into 15 identified sub-barriers under four basic criteria, and a hierarchical framework has been built.

Figure 4- 3. Hierarchical structure



4.4. Chapter summary

This chapter covers 2 sections. The first section covers the definition of the AHP method and how it can be used in research and analysis. The second section includes a detailed description of the chosen criteria and a hierarchy structure based on the literature review. The AHP model of this study consists of 15 sub-criteria within four main criteria: technical, economic, social and political.

Chapter V

Analysis and Results

5.1. Empirical Analysis

5.1.1. Analytic hierarchy process (AHP) survey

The survey was conducted using pairwise comparison questionnaires presented to the respondents with the objective of ranking the identified barriers. The survey was divided into three parts:

A. **Introduction.** The introduction contains the background of the study, an explanation of the questionnaire, and how to answer the questionnaire.

B. **Demographic Information.** It consists of information about the respondent, such as affiliation, position, experience in energy sector.

C. **The Pairwise Comparison Questionnaire.** The questionnaire for evaluating the barriers to renewable energy source adoption as low-carbon energy technologies in district heating systems has five sections.

The first section of the pairwise comparison questionnaire covers the main criteria, and the remaining four sections include a pairwise comparison questionnaire for each sub-criterion. The survey questionnaire as shown in Table 5-1.

Table 5- 1. An example of the pairwise comparison questionnaire

With Respect to Barrier Type																		
Options A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Options B
Technical	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Economic
Technical	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Social
Technical	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Policy & Political
Economic	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Social
Economic	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Policy & Political
Social	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Policy & Political

5.1.2. Data Collection

A. Allocation of survey

The study included representatives of all stakeholders in the district heating system structure. The survey was taken from the directors of these main stakeholders. There are 22 directors of the main offices and departments such as technical, economic and policy. The respondents are the final decision-makers of the district heating system.

Table 5- 2. Statistics by Experts' Organization

NO	Sub-criteria	Position	Number of respondents
1	Ministry of Energy	Directors	5
2	"Combined Heat Power Plant-4" SOJSC	Heads	5
3	"Ulaanbaatar district heating company" SOJSC	Heads	5
4	Department of Housing and Public utilities /OSNAAUG/	Heads	5
5	Academia	Dean and Vice-Dean	2
Total			**22**

The following stakeholders were responded to the study.

"Ministry of Energy"

Ministry of Energy is responsible for implementing an energy policy that will ensure the growth of Mongolia's social and economic development. The directors of the Department of Policy and Planning, the Department of Finance and Investment, the Department of the heating sector, the Department of Investment and Production, and the Department of Renewable Energy responded in this study.

"Combined heat and power plan-4" SOJSC

It is the coal-fired combined heat and power plant with the highest capacity in Mongolia. More than 60% of the total heat supply of Ulaanbaatar city is provided by itself. The directors of the Department of Production, the Department of Research and Development, Department of Economy and planning, the Department of Economy and planning, the Department of Maintenance and Utilization, and the Department of Safety and Monitoring responded in this study.

"Ulaanbaatar district heating company" SOJSC

The company is the main company responsible for transmission network. Also, it controls and monitors whole district heating systems. Responsible for the operation, policy, and connection of the centralized district heating system of the capital city, as well as the local district heating system mode's calculation, adjustment and control. The directors of the Department of Technical Policy, the Department of Safety and Monitoring, the Department of Supply and Purchasing, the Department of Emergency Management and Dispatching, and the Department of Technology Connection responded in this study.

"Department of housing and public utilities" /OSNAAUG/

This company is the main company responsible for the distribution network. The chief engineer and directors of the Eastern Distribution Center, the Western Distribution Center, and the Central Distribution Center responded in this study.

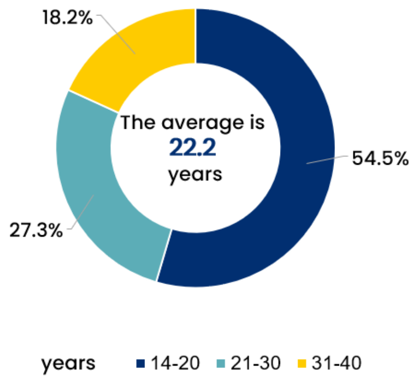
"Academia"

Dean and Vice-dean of the Thermal Engineering Department in Power Engineering school at the Mongolian University of Science and Technology, which is the largest Science, Technology and Mathematics Education university.

B. Experience

The respondents to this study have 14-40 years of experience in the energy sector, with an average of 22.2 years of experience. The statistics by experts' experience as shown in Figure 5-1.

Figure 5- 1. Statistics by Experts' Experience



5.1.3. Software

The AHP survey was obtained via Google Forms. The collected data was analyzed using Super Decisions software and the AHP priority calculator from Business Performance Management Singapore (BPMSG).

5.2. Empirical result of main criteria

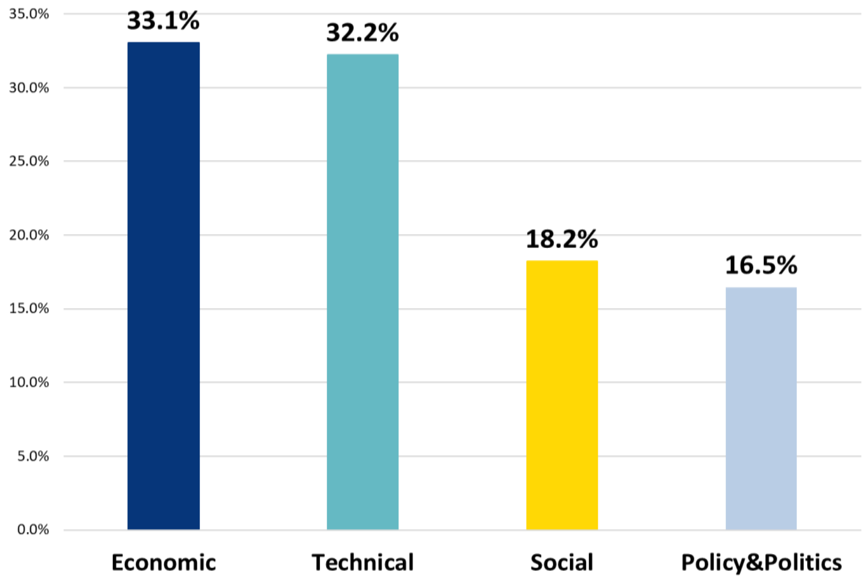
The requirement was met by being less than 0.1, when checking the consistency ratio of each participant in the study. The inconsistency of the main criteria is 0.0078.

The result shows that economic barriers (33.1%) have the greatest weight regarding the main criteria for renewable energy adoption as low-carbon energy technologies in district heating systems in Mongolia. However, it has only 0.9% more weight than technical barriers (32.2%). It is followed by social barriers (18.2%) and policy-political barriers (16.5%).

Table 5- 3. Ranking of barriers main criteria

Barriers	Share	Priority weigh	Rank
Economic	33.1%	0.33059	1
Technical	32.2%	0.32240	2
Social	18.2%	0.18234	3
Policy & Politics	16.5%	0.16467	4

Figure 5- 2. Synthesize of criteria and priority



5.3. Empirical results of sub-criteria

The barriers to the renewable energy adoption as low-carbon energy technologies in district heating system in Mongolia were calculated within criteria and ranked based on the results.

A. Technical barriers

The requirement was met by being less than 0.1, when checking the consistency ratio of each participant in the study. The inconsistency of the technical sub-criteria is 0.0043.

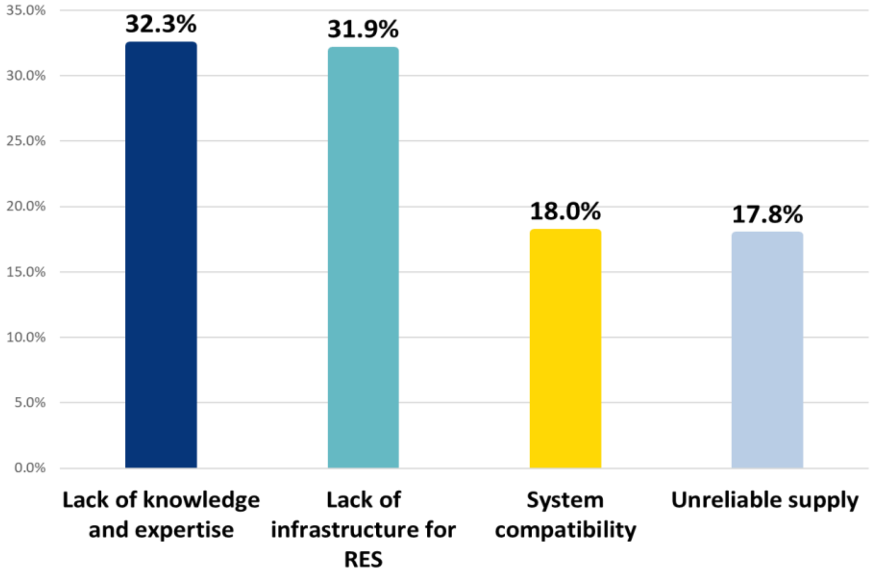
The result shows that Lack of knowledge and expertise (32.3%) have the greatest weight regarding the technical barriers for renewable energy adoption as low-carbon energy technologies in district heating systems in Mongolia. It is followed by Lack of infrastructure for RES (31.9%), System compatibility (18.0%), Unreliable supply (17.8%). The ranking of barriers in technical sub-criteria as shown in Table 5-4.

Table 5- 4. Ranking of barriers in Technical barriers

Barriers	Share	Priority weigh	Rank
Lack of knowledge and expertise	32.3%	0.32319	1
Lack of infrastructure for RES	31.9%	0.31918	2
System compatibility	18.0%	0.18002	3
Unreliable supply	17.8%	0.17761	4

The synthesize of technical barriers for renewable energy adoption as low-carbon energy technologies in district heating systems in Mongolia as shown in Figure 5-3.

Figure 5- 3. Synthesize of Technical barriers



B. Economic barriers

The requirement was met by being less than 0.1, when checking the consistency ratio of each participant in the study. The inconsistency of the economic sub-criteria is 0.0103.

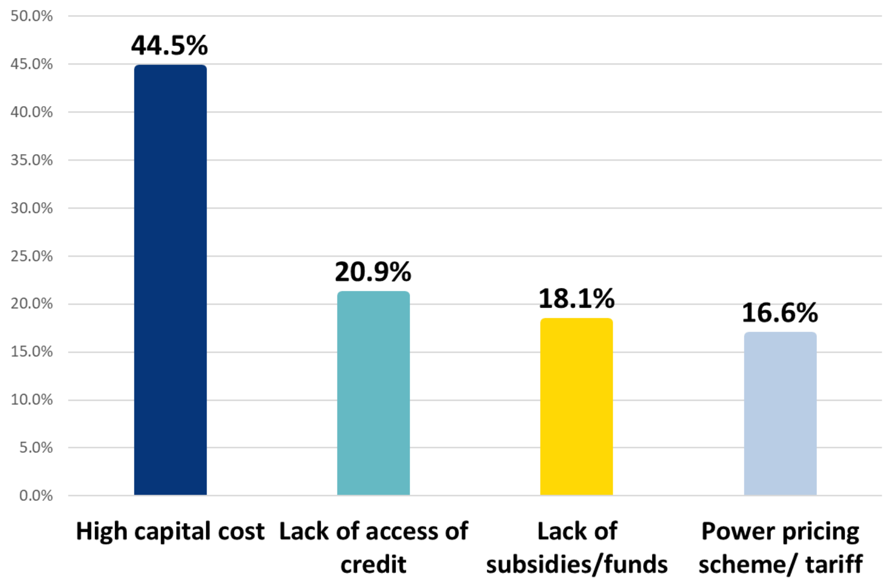
The result shows that High capital cost (44.5%) has the greatest weight regarding the economic barriers for renewable energy adoption as low-carbon energy technologies in district heating systems in Mongolia. It is followed by Lack of access of credit (20.9%), Lack of subsidies/funds (18.1%), Power pricing scheme/tariff (16.6%). The ranking of barriers in economic sub-criteria for renewable energy adoption as low-carbon energy technologies in district heating systems in Mongolia as shown in Table 5-5.

Table 5- 5. Ranking of barriers in Economic barriers

Barriers	Share	Priority weigh	Rank
High capital cost	44.5%	0.44459	1
Lack of access of credit	20.9%	0.20865	2
Lack of subsidies/funds	18.1%	0.18077	3
Power pricing scheme/ tariff	16.6%	0.16600	4

The synthesize of economic barriers for renewable energy adoption as low-carbon energy technologies in district heating systems in Mongolia as shown in Figure 5-4.

Figure 5- 4. Synthesize of Economic barriers



C. Social barriers

The requirement was met by being less than 0.1, when checking the consistency ratio of each participant in the study. The inconsistency of the main criteria is 0.0079.

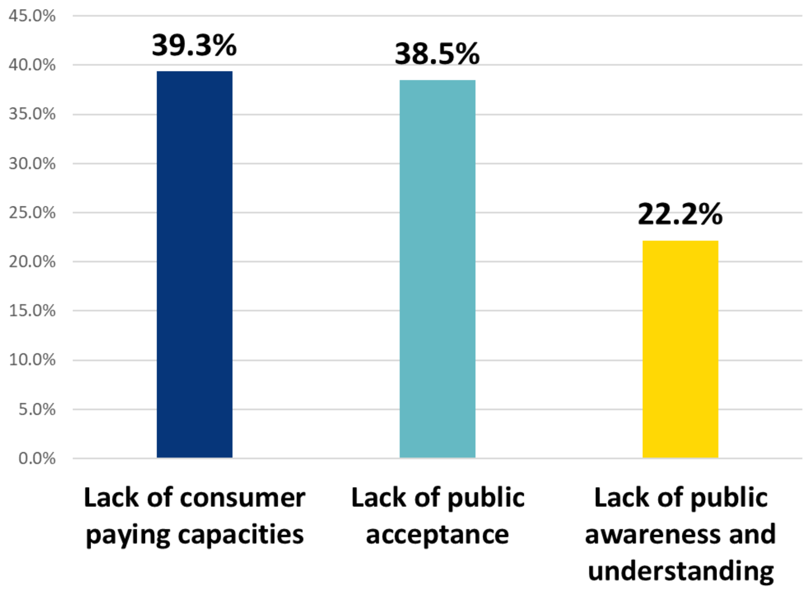
The result shows that Lack of consumer paying capacities (39.3%) have the greatest weight regarding the social barriers for renewable energy adoption as low-carbon energy technologies in district heating systems in Mongolia. It is followed by Lack of public acceptance (38.5%), Lack of public awareness and understanding (22.2%). The ranking of barriers in social sub-criteria as shown in Table 5-6.

Table 5- 6. Ranking of barriers in Social barriers

Barriers	Share	Priority weigh	Rank
Lack of consumer paying capacities	39.3%	0.39347	1
Lack of public acceptance	38.5%	0.38475	2
Lack of public awareness and understanding	22.2%	0.22178	3

The synthesize of social barriers for renewable energy adoption as low-carbon energy technologies in district heating systems as shown in Figure 5-5.

Figure 5-5. Synthesize of Social barriers



D. Policy & Political barriers

The requirement was met by being less than 0.1, when checking the consistency ratio of each participant in the study. The inconsistency of the main criteria is 0.0036.

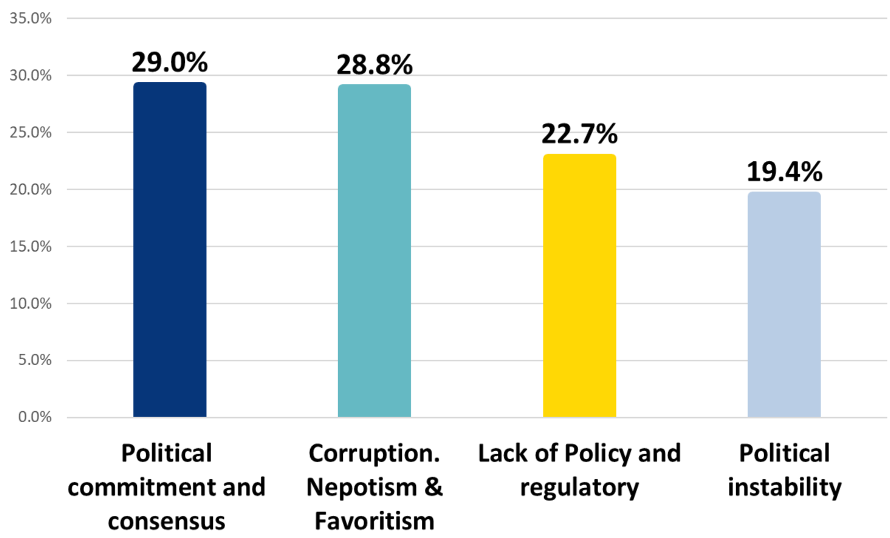
The result shows that Political commitment and consensus (29.0%) have the greatest weight regarding the Policy & Political barriers for renewable energy adoption as low-carbon energy technologies in district heating systems in Mongolia. It is followed Corruption. Nepotism & Favoritism (28.8%), Lack of Policy and regulatory (22.8%), Political instability (19.4%). The ranking of barriers in Policy & Political sub-criteria as shown in Table 5-7.

Table 5- 7. Ranking of barriers in Policy & Political barriers

Barriers	Share	Priority weigh	Rank
Political commitment and consensus	29.0%	0.29027	1
Corruption. Nepotism & Favoritism	28.8%	0.28807	2
Lack of Policy and regulatory	22.8%	0.22747	3
Political instability	19.4%	0.19419	4

The synthesize of Policy & Political barriers for renewable energy adoption as low-carbon energy technologies in district heating systems as shown in Figure 5-6.

Figure 5- 6. Synthesize of Policy & Political barriers



5.4. Overall result

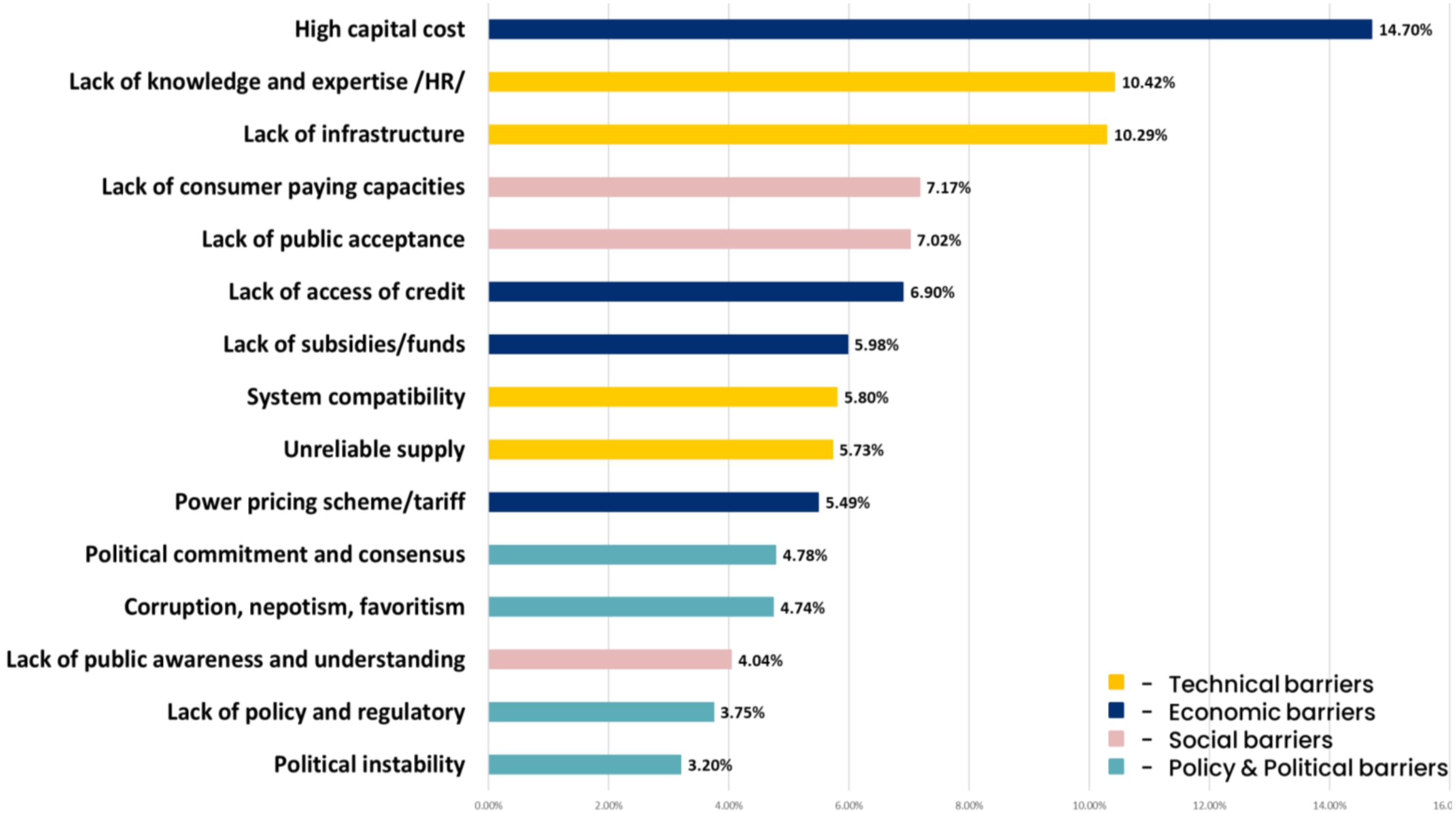
The total weight of barriers to renewable energy adoption as low-carbon technology in the district heating system was calculated by multiplying each sub-criteria's weight by the main criteria' priority weight.

In the overall results, “High capital cost” (14.7%) was estimated to be the highest barrier to renewable energy adoption as low-carbon energy technologies in district heating system in Mongolia. Therefore, High capital cost was ranked first in the overall ranking of barriers, followed by “Lack of knowledge and expertise /HR/” (10.42%), “Lack of infrastructure” (10.29%), “Lack of consumer paying capacities” (7.17%), and “Lack of public acceptance” (7.02). Also, “Lack of access of credit”, “Lack of subsidies/funds,” “System compatibility,” “Unreliable supply” and “Power pricing scheme/tariff” were ranked next five degree in the overall ranking. Each group of respondents had the results reviewed; however, there were no discernible differences in the rankings of the barriers that emerged.

Table 5- 8. Ranking of barriers in global

Criteria	Priority	Sub-criteria	Priority for sub criteria	Priority for overall	overall priority (%)	Rank
Technical	0.3224	Unreliable supply	0.1776	0.0573	5.7%	9
		System compatibility	0.1800	0.0580	5.8%	8
		Lack of knowledge and expertise /HR/	0.3232	0.1042	10.4%	2
		Lack of infrastructure	0.3192	0.1029	10.3%	3
Economic	0.3306	High capital cost	0.4446	0.1470	14.7%	1
		Lack of access of credit	0.2087	0.0690	6.9%	6
		Lack of subsidies/funds	0.1808	0.0598	6.0%	7
		Power pricing scheme/tariff	0.1660	0.0549	5.5%	10
Social	0.1823	Lack of public acceptance	0.3848	0.0702	7.0%	5
		Lack of consumer paying capa.	0.3935	0.0717	7.2%	4
		Lack of public awareness and understanding	0.2218	0.0404	4.0%	13
Policy & Political	0.1647	Corruption, nepotism, favoritism	0.2881	0.0474	4.7%	12
		Political commitment and consensus	0.2903	0.0478	4.8%	11
		Lack of policy and regulatory	0.2275	0.0375	3.7%	14
		Political instability	0.1942	0.0320	3.2%	15

Figure 5-7. Global ranking



5.5. Discussion of results

A literature review was used to identify and describe the barriers. According to the experts' responses, the most important barrier of main criteria is the economic barriers, followed by the Technical barriers.

Adopting renewable energy in the district heating system requires financially sustainable in the long run. Due to district heating projects having large-scale and long-term periods, securing adequate financing can be challenging in developing country, especially for Mongolia.

The development of Mongolia's district heating system is at the second generation stage. Moreover, it is aging, and the current system needs rehabilitation. By international standards, Mongolia's District heating system's technical and commercial losses are enormous, and the existing operating system may be challenging to manage a large-scale District heating and renewable energy combined system. In terms of the most important barriers for each sub-criterion:

Lack of knowledge and expertise

In Mongolia, there needs to be more experts to manage the large-scale renewable energy- district heating combined system. There is currently no experience in adopting renewable energy in the district heating system in Mongolia, which leads to a lack of renewable energy experts in the district heating system. There are usually general district heating experts or renewable energy experts in electricity generation. Experts in renewable energy who focus on district heating systems must understand the characteristics of heat distribution infrastructure, such as the organization of the structure of the system, the coordination of operations, and the integration of these systems into the existing city infrastructure, such as heat networks, heat exchange systems, and heat storage solutions.

Lack of infrastructure for RES

Transitioning from traditional, often fossil fuel-based district heating systems to renewable district heating systems requires significant changes to the existing infrastructure, such as upgrading pipes, pumps, and heat exchangers. Mongolian existing district heating infrastructure may require significant modification or replacement to be compatible with certain types of renewable energy or achieve the required energy efficiency due to aging facility. Moreover, unlike electricity, heat cannot be transported long distances without significant energy loss. As a result, renewable heat needs to be produced on-site or locally.

High capital cost

Mongolia's existing district heating system is financially unsustainable, and the investment for regular and reliable operation heavily depends on the government budget. Therefore, it can be challenging to invest in renewable energy projects up front when the existing district heating system needs to be repaired and rehabilitated due to aging.

Lack of consumer paying capacities

A large percentage of Mongolia's population has incomes below the subsistence level. It may be unable to afford the tariff increase due to the high capital costs of adopting renewable energy as low-carbon energy technologies in district heating system.

Lack of public acceptance

The public may not accept global warming, creating a situation where renewable energy is not accepted. Also, lack of public acceptance may be due to various factors, such as fear of changes that may result from integrating renewable energy while using heat at low prices.

Political commitment and consensus

In Mongolia, as most district heating systems are publicly owned, the lack of political commitment may hinder the transition to renewable energy. Lack of political commitment leads to unstable policies, insufficient funding, and an uncertain investment environment. Finally, the absence of political consensus may inhibit the long-term planning and interdisciplinary cooperation required for renewable energy district heating combined system.

Corruption. Nepotism & Favoritism

Corruption is particularly high in low-income countries. Similarly, Mongolia ranks 67th out of 180 countries in terms of corruption in 2022. It can distort decision-making, misdirect resources, deter investment, and undermine public confidence in such projects. They can also lead to inefficient or inequitable system design and operation, hindering the overall success and acceptance of renewable energy – district heating systems.

5.6. Chapter summary

This chapter consists of empirical analysis and empirical results. This section also includes a discussion of the results. According to the results, the economic criterion was ranked as the first priority to be considered in barriers to renewable energy adoption as low-carbon energy technologies in the case of Mongolia. The economic criterion was followed by technical, social and policy & political criteria.

Out of fifteen sub-criteria, the highest important sub-criteria is high capital cost. The least important sub-criteria is political instability with Mongolian renewable energy and district heating sustainable development.

Chapter VI

Conclusion

The objective of this study is to assess the barriers to renewable energy adoption as low-carbon energy technologies in Mongolia's district heating systems, determine the policy implication to overcome barriers, and ensure sustainable energy development. Some feasibility studies recommend suitable renewable energy as low-carbon energy technology for district heating systems. However, the fact remains that these renewable energy sources, such as low-carbon energy technologies, have yet to be adopted by the district heating system in Mongolia. This indicates that finding the barriers to renewable energy development is important. In addition, identifying the barriers to renewable energy adoption in CHP-based district heating systems in Mongolia and overcoming them has not been done yet.

Moreover, I have worked at a public enterprise in the heating sector in Mongolia. Therefore, my interest focuses on it, especially the district heating system. This study filled a knowledge gap by contributing to the literature and analyzing the barriers to renewable energy adoption as low-carbon energy technologies in district heating systems, using AHP as a multi-criteria decision analysis to prioritize barriers and make policy contributions.

In this study, the final decision-makers at the policy-making level of the main stakeholders in the district heating system identified and prioritized Mongolia's problems using the AHP method.

This study proposed two key research questions:

- What are the main factors and barriers to adopting renewable energy technology in district heating systems in Mongolia?

- What strategies can be derived from the prioritized barriers to facilitate the adoption of renewable energy as low-carbon energy technology in district heating systems?

The answers to these research questions and the findings of the research are briefly discussed below.

Regarding the first research question, the MCDM-AHP methodology was used to determine the barriers facing renewable energy adoption as low-carbon technology in the district heating system of Mongolia. Based on the literature review, 15 sub-criteria were developed under 4 main criteria: technical, economic, social, and policy-political. The weight of each criterion was determined based on a pairwise comparison questionnaire The main economic criteria have the highest priority, and then the high capital cost has the highest rank within overall barriers, according to the results of this study. Section 6.1 details other key findings.

Regarding the second research question, policy implications were recommended to overcome the highest-ranked barriers to renewable energy adoption as low-carbon technology in district heating systems. The policy implications can be suggested more appropriately by focusing on these barriers regarding Mongolia's sustainable energy development. Section 6.2 discusses policy implications in detail.

6.1. Key findings

The results in Chapter V illustrate that economic barriers (33.1%) have the highest priority in the main criteria. However, they are only 0.9% more than the technical barriers (32.2%). Lack of knowledge and expertise (32.3%) has the highest priority within technical barriers, followed by lack of infrastructure for RES (31.9%) as the second highest priority. High capital cost (44.4%) has the highest priority within economic barriers. Lack of consumer paying capacities (39.3%) has the highest priority within social barriers, followed by lack of public acceptance (38.5%) as the second highest priority. Political commitment and consensus (29.0%) have the highest priority within policy-political barriers, followed by corruption, nepotism &

favoritism (28.8%) as the second highest priority.

The top three out of 15 important sub-criteria are high capital cost (14.7%), lack of knowledge and expertise (10.4%), and lack of infrastructure (10.3%). The least important three sub-criteria are lack of public awareness and understanding (4.0%), lack of policy and regulation (3.75%), and political instability (3.2%) within overall barriers.

6.2. Policy implications

Decision-makers in the energy sector should consider economic issues when overcoming the barriers to renewable energy adoption in the district heating system because economic barriers have the highest priority in the result. After addressing economic barriers, considering the technical, social, and political aspects is important.

In addition, energy sector decision-makers should focus on high-ranked sub-criteria in each main criteria: high capital cost, lack of knowledge and expertise, lack of infrastructure for the renewable energy system, lack of consumer paying capacities, lack of public acceptance, political commitment and consensus, and corruption nepotism and favoritism. Based on these results, the following policy implications can be drawn.

First, according to the key findings in section 6.1, the economic criteria are the most important among the main criteria. The high capital cost is the highest-ranked sub-criteria overall, which shows more attention must be paid to economic issues. The policy implication to overcome these economic barriers can be proposed as follows.

Government subsidies and grants. Governments can lower the upfront cost of setting up renewable energy in district heating systems by providing subsidies and grants.

Public–Private Partnership. Governments and private companies can cooperate to split the expense and risk of the initial investment.

Green bonds. International investers support the issuance of green bonds to fund the initial costs of renewable energy into district heating projects.

Tax Incentives. Tax deductions, credits, or exemptions can lower initial costs and increase the financial attractiveness of renewable energy projects.

Second, lack of knowledge, expertise and infrastructure for the renewable energy system are the top sub-criteria in the technical barriers. The priorities of these sub-criteria were close to each other. Therefore, considering these criteria together, the following policies can be proposed to overcome these barriers.

Investment in Research & Development. Parties can invest in researching and developing more efficient, reliable, and cost-effective renewable energy sources as low-carbon technologies suitable for District heating systems.

Urban planning. Governments can develop and upgrade the infrastructure of the existing district heating system to make it compatible with various renewable energy sources and to ensure efficient heat distribution.

Training and education. Governments and companies create training programs to educate engineers, technicians, and other experts in properly installing, maintaining, and operating renewable energy in district heating integrated systems.

Technical assistance. Governments and companies obtain international assistance in project planning, implementation and maintenance to reduce technical risks and increase project success.

Technical transfer. International government and non-government organizations and companies may provide equipment, and training for local personnel in Mongolia.

Third, lack of consumer paying capacities and public acceptance are the top sub-criteria in the social barriers. The policy implications to overcome these social barriers can be proposed as follows.

Awareness campaigns. Governments and companies can develop and launch public awareness campaigns highlighting the benefits of District heating systems in terms of cost, comfort, and environmental impact.

Energy efficiency program. Energy efficiency may be promoted and supported to reduce total energy consumption and the associated costs for consumers. Energy audits, incentive schemes for efficiency, and educational initiatives can all help with the program.

Fourth, political commitment and consensus and corruption, nepotism, and favoritism are the top sub-criteria in the policy-political barriers. The policy implications to overcome these can be proposed as follows.

Long-term Planning and Consistent Policies. Energy infrastructure projects require long-term planning. Consistent policies and cross-party consensus on the value and necessity of DH systems can help protect these projects from changes in political leadership or priorities.

Procurement transparency. The criteria for evaluation and the reasons for decision-making should be public and well-documented.

Financial Disclosure. The public disclosure of budgets, costs, funding sources, and expenses related to renewable energy projects in the district heating system. Transparency discourages corruption and ensures that funds are being used properly.

6.3. Limitations and Further Research

This study uses the Analytic Hierarchy Process (AHP) method to rank the barriers to renewable energy adoption in Mongolia's district heating system. The study involved policymakers at the decision-making level of the Ministry of Energy and generation, distribution and transmission network companies, and academics, who are key stakeholders in the operation of the district heating system. The subjective judgments of the respondents were collected and analyzed.

Finally, the selected criteria, sub-criteria, and weights assigned by the responders all influence the barriers. Consequently, selecting a different set of criteria, sub-criteria, or responders may alter the outcomes. Further research in this area is possible by selecting other criteria and sub-criteria.

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Appendices

Appendix A – Survey questionnaire

The AHP survey was obtained via Google Forms. The survey was divided into three sections.

Section 1. Information

Strategies for Renewable Energy Adoption as Low-carbon Energy Technology in District Heating Systems in Mongolia

- I am a master's student in the International Energy Policy Program at Seoul National University in South Korea, and I am taking this questionnaire for my master's degree thesis.
- This research study used the Analytic Hierarchy Process (AHP) methodology, and the questionnaire is based on the Pairwise Comparison method to identify "the barriers to the renewable energy adoption as low-carbon energy technologies to district heating system".
- If you have any feedback or questions about this questionnaire, please contact me at 2021-20691@snu.ac.kr and todgerel0201@gmail.com. We are always happy to help you with any questions you may have.
- This survey will take 30 minutes to complete, and I appreciate you taking the time to participate.

Section 2. Demographic information

- All personal information you provide and your responses to the survey will be kept confidential and used for research purposes only. Once the data from the completed questionnaire has been analyzed and the results have been integrated into the research, it will be deleted.

  - **Gender**
  - **Affiliation**
  - **Position**
  - **Experience in energy sector**
  - **E-mail**

Section 3. The Pairwise Comparison Questionnaire

Section 3.1. Instructions

How to complete the Pairwise Comparison Questionnaire?

- This pairwise comparison questionnaire is based on four main criteria and 15 sub-criteria.
- Answering the questions in the questionnaire is not complicated, it is simple. Based on your experience, I ask you to judge the relationship and relative importance of the two criteria. For example: If you have 2 criteria options: TECHNICAL and ECONOMIC. Then, by comparing these 2 criteria, it will be determined which one is more important in terms of barriers to renewable energy adoption in district heating systems.

Example

With Respect to Barrier Type										
Options A	**Extremely**	**Very Strongly**	**Strongly**	**Moderately**	**Equally**	**Moderately**	**Strongly**	**Very Strongly**	**Extremely**	**Options B**
Technical	○	○	○	○	○	○	○	○	○	**Economic**

It shows option A (**Technical**) **extremely strong** than option B (**Economic**)

It shows option B (**Economic**) **very stronger** than option A (**Technical**)

Notes: If you assume 2 options are equally each other, select the "equally" option.

Judgments	Numeric Values
If Option A and Option B are equally important	1
If Option A is moderately more important than Option B	3
If Option A is strongly more important than Option B	5
If Option A is very strongly more important than Option B	7
If Option A is extremely more important than Option B	9
Use even numbers for intermediate judgments	2,4,6,8

Section 3.2. Pairwise comparison of main criteria

Description of each main criterion:

- **Technical -** Technical barriers refer to the adoption of CHP and low-carbon technologies in district heating systems. These may include issues such as the unreliability of energy supply, the difficulty of upgrading existing infrastructure, and the lack of technical knowledge and experience in creating, installing, and maintaining new systems.
- **Economic** - barriers are funding source constraints affecting the adoption of CHP and low-carbon technologies in district heating systems. Adopting new advanced renewable energy techniques and technologies can be costly.

- **Social** - barriers to the adoption of CHP and low-carbon technologies in district heating systems may include resistance or lack of understanding of energy efficiency depending on the characteristics of consumers (residential, commercial, community).
- **Policy & Politics** - Possible obstacles to the introduction of renewable energy in the centralized heat supply system may include: the laws and regulations in force in our country, the current government policy in the energy sector, political forces, such as the platform and decisions of the political parties that hold the government's rights.

<u>Questionnaire</u>

With Respect to Barrier Type																		
Options A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Options B
Technical	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Economic
Technical	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Social
Technical	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Policy & Political
Economic	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Social
Economic	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Policy & Political
Social	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Policy & Political

Section 3.3. Pairwise comparison of technical sub-criteria

Description of each sub-criteria:

- **Unreliable supply.** The unreliability of the energy supply is an obstacle to adopting CHP and low-carbon technologies in district heating systems due to the instability of renewable energy. Production could be more unreliable and unstable than traditional energy sources in most renewable energy technologies. Therefore, it includes issues such as managing fluctuations in energy supply and balancing supply and demand.
- **System compatibility.** This barrier is an operational challenge for introducing low-carbon technologies in district heating systems.

Many district heating systems are already in place and may have limitations that make it difficult to integrate renewable energy sources. In particular, the newly integrated low-carbon technology must work smoothly with the existing district heating system without disrupting its general operation and efficiency.

- **Lack of knowledge and expertise /HR/.** This barrier arises from needing more skilled human resources in the district heating system. Experienced personnel and experts are the main factors in the system's operation, and the lack of human resources will hinder the reliable operation of the system.
- **Lack of infrastructure.** Integrating renewable energy sources based on low-carbon energy technology with the capital city's district heating system network may result in relocating residents in the region. In addition, the high land price and additional heat transmission lines may need to be built or upgraded, which may increase costs due to infrastructure.

Questionnaire

With Respect to Technical Barrier																		
Options A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Options B
Unreliable supply	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	System compatibility
Unreliable supply	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Lack of knowledge and expertise /HR/
Unreliable supply	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Lack of infrastructure
System compatibility	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Lack of knowledge and expertise /HR/
System compatibility	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Lack of infrastructure
Lack of knowledge and expertise /HR	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Lack of infrastructure

Section 3.4. Pairwise comparison of economic sub-criteria

Description of each sub-criteria:

- **High capital cost.** The high cost of installing new district heating systems based on low-carbon energy technologies and upgrading existing district heating systems such as pipelines, heat exchangers and control systems can be a significant barrier to adopting RE and low-carbon technologies in district heating systems.

- **Lack of access of credit.** Government support is partial government support and cannot cover the project's total cost. Therefore, creating a market for these technologies and ensuring simple access to credit is essential. Lack of credit leads institutions to lend at higher interest rates.
- **Lack of subsidies.** Low-carbon district heating systems have significant capital and operational expenses, but government subsidies can help offset these costs. However, in other circumstances, these subsidies may be absent, making it difficult for people, businesses, and governments to afford to adopt these technologies.
- **Power pricing scheme.** Low power pricing has traditionally added to the financial issue of utilities, resulting in inadequate funding for district heating infrastructure/system, leading to decreased quality or inconsistent power supply.

<u>Questionnaire</u>

With Respect to Economic Barrier																		
Options A	**Extremely**		**Very Strongly**		**Strongly**		**Moderately**		**Equally**		**Moderately**		**Strongly**		**Very Strongly**		**Extremely**	**Options B**
High capital cost	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	**Lack of access of credit**
High capital cost	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	**Lack of subsidies**
High capital cost	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	**Power pricing scheme**
Lack of access of credit	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	**Lack of subsidies**
Lack of access of credit	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	**Power pricing scheme**
Lack of subsidies	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	**Power pricing scheme**

Section 3.5. Pairwise comparison of social sub-criteria

Description of each sub-criteria:

- **Lack of public acceptance.** People have different opinions about renewable energy technology, and some people do not accept such technology. Lack of public participation and ignorance in renewable energy development and preference for traditional energy may create resistance to changing energy consumption patterns.
- **Lack of consumer paying capacities.** A large percentage of the population in Ulaanbaatar, Mongolia, has incomes below the subsistence level and may not be able to pay the possible increase in tariffs. As a result, many people are unable to purchase renewable energy options
- **Lack of public awareness and understanding.** It refers to barriers arising from a need for more general public knowledge and information about low-carbon energy technologies and the outcomes of their introduction into the system.

<u>Questionnaire</u>

With Respect to Social Barrier																		
Options A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Options B
Lack of public acceptance	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Lack of consumer paying capacities
Lack of public acceptance	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Lack of public awareness and understanding
Lack of consumer paying capacities	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Lack of public awareness and understanding

Section 3.6. Pairwise comparison of policy& political sub-criteria

Description of each sub-criteria:

- **Corruption and nepotism and favoritism.** This obstacle is caused by corruption, profiteering, and other favoritism that will negatively affect the adoption of RE and low-carbon technologies in district heating systems. These lead to problems such as lack of transparency, inefficient allocation of
- **Political commitment and consensus.** It is a problem of insufficient political commitment and lack of commitment. It includes setting targets for renewable energy use, providing financing and resources, and developing policies and regulations to support them. Without strong political commitment, renewable energy integration initiatives lack the stakeholder motivation to achieve their goals.
- **Lack of policy and regulatory.** The current regulatory and policy framework for district heating systems may not suitable to adopt low-carbon technologies. Due to the current policy and its regulation, the implementation of projects may be delayed, and the stakeholders may need help in the project implementation stage.
- **Political instability.** Political instability frequently changes priorities, policies, and regulations, making planning and implementing long-term projects difficult.

Questionnaire

With Respect to Policy&Political Barrier																		
Options A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Options B
Corruption, Nepotism & Favoritism	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Political commitment and consensus
Corruption, Nepotism & Favoritism	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Lack of policy and regulatory
Corruption, Nepotism & Favoritism	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Political instability
Political commitment and consensus	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Lack of policy and regulatory
Political commitment and consensus	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Political instability
Lack of policy and regulatory	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Political instability

Abstract (Korean)

몽골 정부는 모든 다른 국가의 정부와 마찬가지로 에너지 부문의 중 과제 중 하나로 열 에너지의 안정적인 공급을 들고 있다. 열에너지는 사회, 경제, 산업 발전에 필요한 기본 에너지 공급방식이기 때문에 에너지 부문의 주요 과제가 도시와 마을의 주거용, 상업용 및 공공 건물뿐 만 아니라 산업 공정에 열을 공급하는 것이다. 특히 겨울이 긴 몽골의 경우, 난방 공급의 안정성은 아주 중요한 문제이며, 몽골 내 총 고체 연료 소비의 약 80%가 난방 부문에 투입되고 있어 열 에너지의 중요성과 역할이 증대되고 있다.

몽골에서는 중앙집중식 지역난방 시스템을 구축하기 시작한 이후로 계속해서 이를 발전, 보급되어 왔다. 한편 몽골은 태양에너지, 풍력, 수력과 같은 재생가능 에너지 원의 잠재력이 높다. 이에 지금과 같이 지역 난방을 100%를 석탄 또는 복합 열병합발전 설비 등 중앙집중식 시스템에 의존하는 것에 대하여 다양한 대안을 추구할 필요성이 제기되 어 왔다. 또한 저탄소 에너지 기술로서 열 공급원으로서의 재생에너지원의 채택에 대한 장애는 무엇인지 식별하고 분석함으로써 재생에너지의 도입 및 활성화 정책에 기초 자료를 마련할 필요가 있다.

본 연구에서는 설문조사 기법을 적용하여 몽골의 지역난방 시스템에서 저탄소 에너지 기술로서 재생에너지원의 채택에 대한 장애요인을 식별하고 순위를 매겼다. 기존 문헌 및 몽골의 에너지 여건을 참고하여 기술적, 경제적, 사회적, 정책책정치적 등 네 가지 주요 부분을 채택하고 다시 세부적으로 15가지 장애요인을 정의하였다. 분석에 사영한 설문기법으로는 다기준의사결정 방법론(Multi-criteria Decision Making: MCDM)의 한 방법론인

계층화분석법(Analytic Hierarchy Process: AHP)이 사용되었다. 설문에 참여한 응답자는 정부 관련 부처 공무원, 학계, 그리고 발전, 송배전 네트워크를 총괄하는 공공/민간 업체 주요 이해당사자들(최종 의사결정권자)로 구성되었으며 이들의 참여와 답변을 계층화분석법을 적용하여 분석, 순위를 결정하였다.

네 가지 중 부문 중에는 경제적 장애요인이 33.1%로 가장 크게, 그리고 기술적 장애 요인이라고 응답한 비율이 32.3%로 다음으로 나타나 이 두 부문에 66% 가까이 집중되었다. 15개 장애 요인들 중에는 높은 자본비용 (14.7%), 지식 및 경험부족(10.4%) 그리고 인프라 부족(10.3%) 등 3가지가 가장 높게 나타났다.

본 연구의 결과는 몽골의 지역난방 시스템에서 저탄소 에너지 기술로서 재생 에너지 채택에 직면하는 문제들을 파악하고 해결하는 데 도움을 줄 것이다. 이는 지역 난방 분야의 전문 연구진에게 향후 연구 방향과 분야 선정에 많은 참고가 될 것이며 AHP 분석에서 나타난 장애요인에 초점을 맞추어 정책적 함의를 보다 적절하게 제시할 수 있다. 이는 몽골의 지속 가능한 에너지 발전 측면에서 핵심적 정책방향이 제시될 것이다.

키워드: 지역난방 시스템, 재생에너지, 저탄소 에너지 기술, 다기준의사결정분석(MCDM), 계층화분석법(AHP), 장애요인

학번: 2021-20691

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