M.S. Thesis in Engineering

The Long-Term Forecasting of the Mongolian Energy Demand and Supply Using the Long-Range Energy Alternatives Planning System (LEAP) Model

장기 에너지 대체 계획 시스템(LEAP) 모델을 사용한 몽고의 에너지 수요와 공급에 대한 장기 예측

February 2014

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이 논문을 공학석사학위 논문으로 제출함

2014 년 02 월

서울대학교 대학원

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Abstract

The long-term forecasting of energy supply and demand is one of the most important topics in relation to Mongolia due to the country's abundant natural resources, which offer great opportunities for achieving independent, sustainable, and green energy development if managed properly. In this thesis, an overview of the current situation of Mongolia's energy sector and its role and contribution in the country's economy and environment, and a comprehensive assessment of the sector, are provided. Most importantly, the long-range energy alternatives planning system (LEAP) model was used to forecast the future energy supply and demand and to build and compare possible scenarios that could sustain economic development, environmental sustainability, and energy security in the country.

In this thesis, three scenarios for long-term energy development in Mongolia by 2040 were built using the LEAP model, and 2010 was set as the base year. The forecasting of the energy demand and supply was shown as a business-as-usual (BAU) scenario, based on the existing national energy plans and trends, and a configuration based on the renewable energy resources available in Mongolia, such as hydro, wind, and solar energy, were suggested as the

renewable energy (REN) scenario while improving the energy efficiency in every way that makes economic sense was assumed and analyzed in the energy efficiency (EE) scenario. Each scenario can represent a distinctive development pathway with different characteristics, which can be applied to Mongolia's energy sector.

Student No. 2012-22599

Keywords: *LEAP, energy planning, scenario, Mongolia, BAU, EE, and RE*

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Chapter 1 - Introduction

1.1 Purpose of the Study

> The word "energy" incidentally equates with the Greek word for "challenge." I think there is much to learn in thinking of our federal energy problem in that light. Further, it is important for us to think of energy in terms of a gift of life.
>
> - Thomas Carr

Energy is one of the factors underlying the social and economic development of any country. Due to the environmental impact of energy production activities, the governmental policies on the issues of energy security and energy planning have been drastically shifting to more sustainable, efficient, cleaner, and safer energy production.

Regardless of the amount of wealth and power of any country, the transition from a fossil-fuel-based energy system to a green energy system entails various economic, social, and technical challenges and problems that require effective, committed, and clear planning and interventions, and solutions to the problem of resources.

As World Energy Council[1] (WEC) defined the three energy goals as accessibility, availability, and acceptability, national development plans for long-term design investments in the energy sector should be assessed on whether they could accomplish all the aforementioned goals and meet the

[1] World Energy Council is the world's principal network of energy leaders and practitioners. It has been headquartered in London since its founding in 1923. <http://www.worldenergy.org>

requirements of the three fundamental dimensions and keep an appropriate balance among them.

Driven by an economy based on natural resources and infrastructure development, the Mongolian energy demand is expected to increase substantially over the next few decades, particularly in the southern part of the country, where there are many mega natural resource projects being implemented and planned to be started in the coming years. The development of mega projects involving coal, copper, gold, iron ore, and uranium mining can dramatically increase the energy demand in the following decades but can also play a vital role in facilitating economic and social development.

The energy security issue is the first priority among the energy concerns associated with Mongolia's energy sector development as due to the country's high dependence on fossil fuel (98% of its oil is being imported from Russia, whose future pricing and long-term availability are always uncertain) and aging energy facilities, especially those of the power generation sector, such issue is more serious than the others in the country. In addition to the above issue, the environmental impact of energy industry production and its significant contribution to the country's CO_2 emission are raising more concerns.

Investment in the energy sector requires a huge amount of money and long-term planning to get a return on investment, which is complex, capital-intensive, and largely irreversible. A simple example of this is the fact that the energy sector cost investment efficiency can increase through overinvestment, which is frequently caused by overestimating the energy demand; in contrast, inadequate investment, which is often caused by underestimating the energy demand, can result in an imbalance between the demand and supply of energy, which can affect the economy adversely.

Considering the foregoing, any policy decision and investment planning on energy sector development has to be done while keeping in mind that the existing energy consumption and the forecasted future energy demand can fulfill all the investment requirements. It is critical and challenging, however, to make such policy decisions in a country that has no national energy sector development plan, which must be formulated based on the precisely forecasted long-term energy demand, which is influenced by various factors, such as the demographic changes, natural-resource development, and infrastructure.

Coal for power generation and oil for transportation are the primary fuels being used by the Mongolian energy industry. The fact that such fuels' prices are in a state of uncertainty has been stunting the growth of the Mongolian economy, which has been heavily dependent on the export and import of fossil fuels in areas that had been full of volatility and uncertainty over the last decades. Moreover, the abundant renewable energy sources in Mongolia can enable the country to diversify its energy resource mix, which is the fundamental principle of energy security for the long term.

Thus, the development of a scenario for a long-term energy planning system that can benefit both the environment and the people is crucial in Mongolia.

In this context, this research aimed to forecast the future energy demand of Mongolia and to identify alternative supply options that include different energy resource combinations and policy implications by building scenario. All the assumptions made in this study were analyzed in terms of energy demand and CO_2 to determine the benefits of such assumptions to Mongolia's energy sector and environment.

1.2 Research Motivation

Energy dependence issue

One hundred and 11% of the oil and electricity consumed in Mongolia, respectively, are imported from Russia, China, and other countries (Ministry of Energy, Mongolia, 2012). The reason that Mongolia is dependent for its energy needs on other countries is not the lack of resources in the country but the Mongolian government's lack of political will to address such issue, and the lack of accurate planning by the government for the energy sector. Mongolia has great potential to supply 100% of its current energy demand at all the scenarios built in this thesis in terms of energy resources. It has significant coal resources (approximately 173 billion tons), and according to the National Renewable Energy Programme of Mongolia (NREP), it has 6.2 GW renewable-energy potential; a high wind density (400-600 W/m^2), which covers almost 10% of the total land area, with an estimated potential of 1100 GW; applicable solar energy resources for both solar power and heating amounting to 5.5-6.0 kW/m^2 per day in the Gobi area for the 270 sunny days in a year; and 74,000 tU in reasonably assured resources plus inferred resources.

Coal-fired CHPs produce 98.1% of the power generated, causing an increase in CO_2 emission

Although Mongolia has sufficient amounts of primary energy resources to supply a sustainable energy system over the next decades, the environmental and ecological issues caused by the use of the conventional energy system should be taken into account in the energy policy formulation and planning, in line with the global trends of the use of environment-friendly energy systems.

As it has a small energy market, Mongolia is not a large greenhouse gas (GHG) emitter; its contribution to the global GHG emission is not as considerable as those of its neighbor countries China and Russia, but its total GHG emission generally increased in line with the global trend for the past eight years, growing steadily at 3.62% from a total of 7.9 million metric tons in 2005, down from the record high of 11.37 million metric tons in 1991 (Madrigal, 2008).

Looking for and developing renewable energy sources and improving energy efficiency are significant ways of mitigating the problems

The availability of renewable energy sources in Mongolia and the country's relatively small energy market can enable the country's energy sector to become more eco-friendly, green, and efficient. The diversification of energy resources is an important issue in energy planning for the long term. This will result in significant energy security and economic benefits.

1.3 Research Questions

- What are the most suitable solutions to sustainable economic growth and green energy, and what are the results of their implementation?
- What are the institutional and legislative implications of the successful

implementation of such solutions, and the essential changes needed from the government of Mongolia?

1.4 Mongolia's Geographic, Economic, and Government Policies

Geographic policies

Mongolia is situated in central Asia and is bordered on the north by Russia and on the south by China. It is located at approximately 106.5 degrees east longitude and 47.6 degrees north latitude, and its land area is approximately 1.567 million km^2.

The population of Mongolia is estimated to be 2.8 million (2010). Its capital is Ulaanbaatar, with a population of more than 1.2 million.

Mongolia has a continental climate. In general, the winter season is cold and dry whereas the summer season is warm, with occasional precipitation. The climatic conditions vary across the country and with elevation. There are large variations in the seasonal and diurnal temperatures. In Ulaanbaatar, January (the coldest month of the year) has an average temperature of -26^{o}C, with an average low of -32^{o}C and an average high of -19^{o}C. In July (the warmest month of the year), the average temperature is 17^{o}C, with an average low of 11^{o}C and an average high of 22^{o}C.

Population

The population growth (annual %) in Mongolia was last reported at 1.62% in 2010, according to a World Bank report released in 2011. Two thirds of the Mongolian population is below 30 years old, and two fifths of the population is 14 years old or below. Much of the population growth of Mongolia has been absorbed by the urban areas, but a significant part of the urban population still lives in gers/national dwellings/habitations in the town peripheries. While the average population density of the country is just over 1 person per sq. km, the population density of Omnogov' aimag is only 0.2 per sq. km.

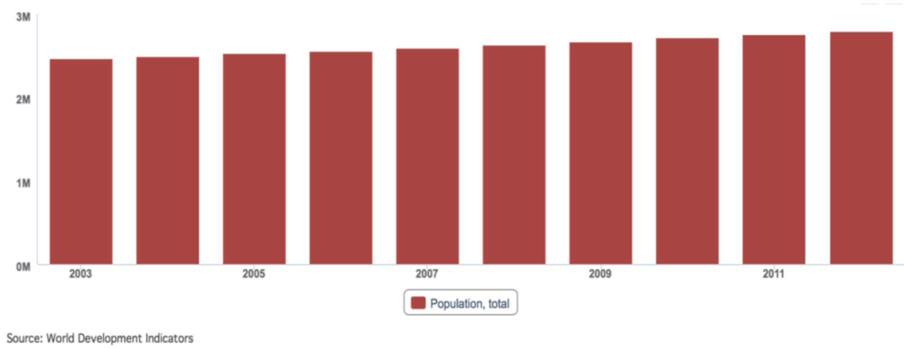

Figure 1-1. Population of Mongolia (2003-2011).

Economy and energy

Historically, the Mongolian economy and its activities have been based on agriculture and herding; Mongolia's extensive mineral deposits, however, have attracted foreign investors. The country holds copper, gold, coal, molybdenum, fluorspar, uranium, tin, and tungsten deposits, which account for a large part of its foreign direct investment (FDI) and government revenue

(Forbes, 2011).

As shown in Figure 1-2, mining and agriculture are the main industries of Mongolia and have large shares in the country's GDP. In 2011, mining production accounted for 22% of the total GDP, and agricultural production, 13%.

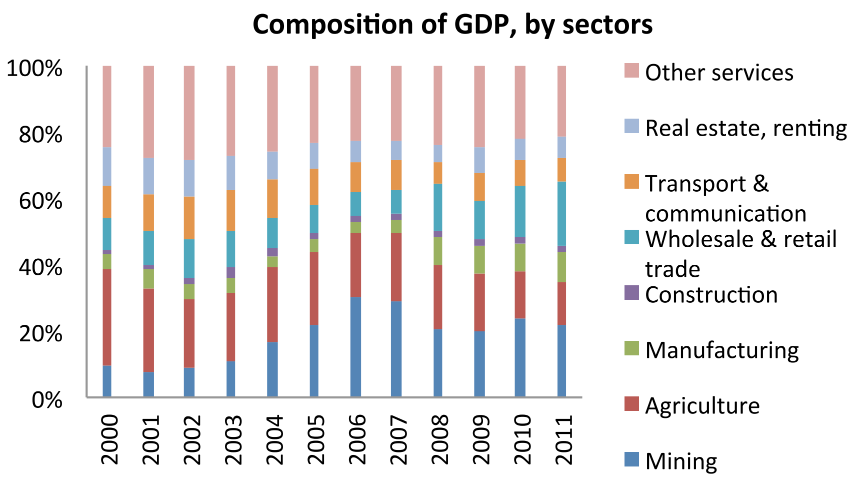

Figure 1-2. Mongolian GDP composition by sector

The total foreign trade turnover was USD11.4 billion in 2011. The main exports are mineral products, and the main imports are mineral products, machinery, equipment, vehicles, and food products. The Mongolian exports experienced significant growth in value and in volumes in the last few years. The coal exports went from virtually zero in 2000 to over 21 million tons in 2011 (National Statistical Office of Mongolia, 2012).

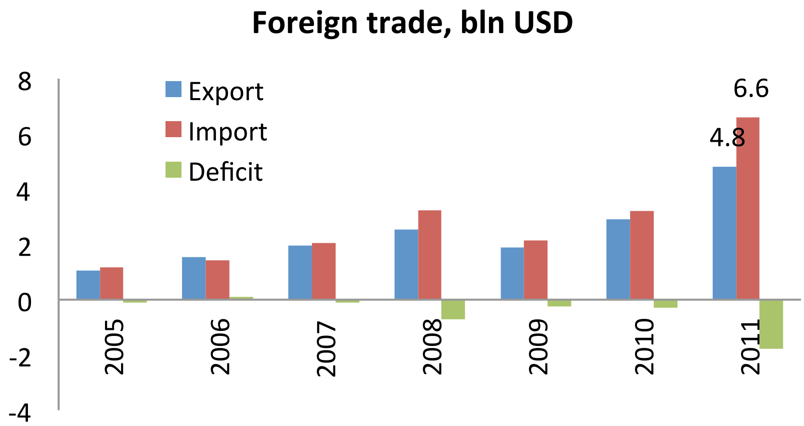

Figure 1-3. Foreign trade balance of Mongolia (2005-2011)

Traditionally, the great majority of Mongolia's exports are intended for China (85% in 2010, up from 64% in 2008), and the dominance of this market is illustrated in Figure III-2 below. The remaining 15% of the exports go to the EU member states (27 countries) and Russia.

Source: National Statistical Office of Mongolia

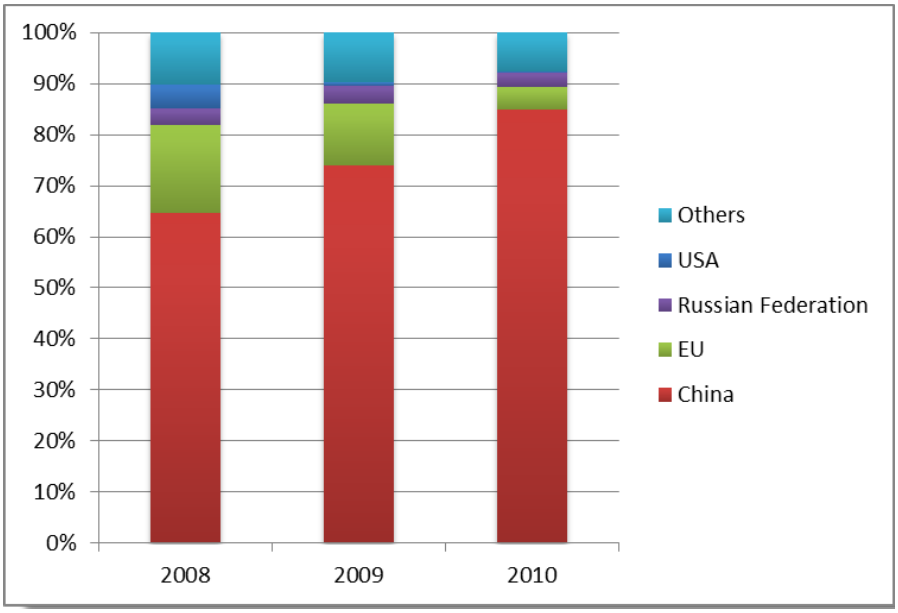

Figure 1-4. Mongolia's exports y country or region (2008-2012)

Even if the industries and agriculture that have significant contributions to the GDP are not yet mature or labor- or resource-intensive, most of them depend on conventional, mature technologies. Therefore, much government support is needed for such industries to sustain their production and to be able to compete in the market.

There are several official documents that have been approved by the Mongolian parliament for the infrastructure development plan, including the Millennium-Development-Goals-(MDG)-based Comprehensive National Development Strategy of Mongolia, the Action Plan of the Government of Mongolia for 2012-2016, the Action Strategy and Formation Plan of National Development, and the Plan for the Establishment of the Innovation Committee.

The Mongolian energy sector is one of the strategic sectors in the country, with the changes in the electricity and oil prices dictating the prices of all the commodities in the country.

Environment and energy

According to the World Bank data, the per-capita energy consumption and the GHG emission from energy production (Figure 1-4) in Mongolia are constantly increasing due to the country's rapid resource-based economic development. This situation has elicited warnings that clean, green energy systems, which have environment-friendly and efficient energy production technologies, are fundamental elements that must be considered to solve the country's environmental issues. Mongolia has no obligation to reduce its CO_2 emission under the Kyoto Protocol, but voluntarily efforts and initiatives to reduce CO_2 emission have been intensely promoted in the country in the last few decades due to the increasing air pollution in Ulaanbaatar.

Therefore, the government of Mongolia has been trying to support a more eco-friendly energy system. It established a policy that aims to shift from the use of highly polluting fossil fuel to low carbon energy resources like hydro, solar, and wind energy. A particular target has been set in the National Renewable Energy Program: 20% of the country's energy base has to come from renewable-energy production by 2020-2025. In addition, the feed-in tariff (FIT) was inserted in the Mongolian Law on Renewable Energy as an incentive to support the provision of additional capacity in the medium term.

Another environmental issue in the energy sector is water usage for power generation. Coal-fired generators are intensive water users, and while the regional imbalances can be improved through water infrastructure development, the long-term impact on the whole water balance in the country is usually studied during the feasibility study stage of specific power plant development projects.

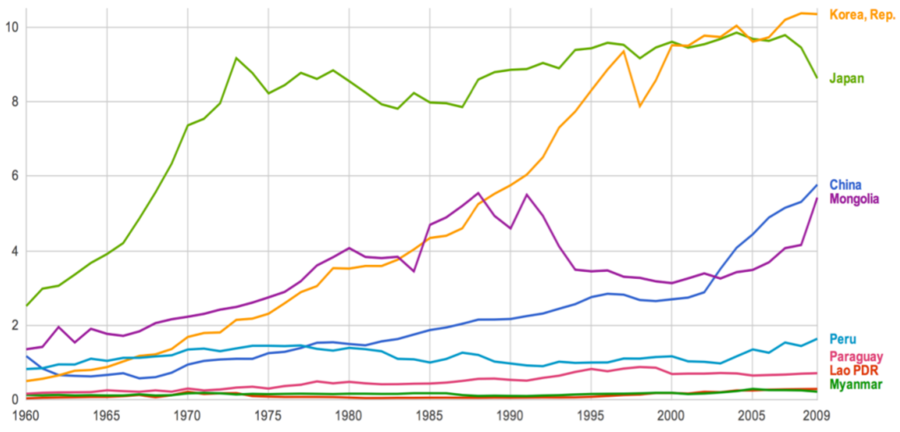

Figure 1-5. Country comparison in terms of per-capita energy consumption and CO_2.

Existing policy and strategies for sustainable energy

"A green economy will not materialize through incremental changes. A shift towards green growth requires a fundamental system change, restructuring both the visible (physical infrastructure) as well as the invisible aspects of the economy (market prices, fiscal policies, institutions, governance, and lifestyles) (UN report "Low Carbon Green Growth Roadmap for Asia and the Pacific," 2012).

For developing countries like Mongolia, the lack of technical and financial resources could serve as a barrier to the pursuit of green growth or development, but on the other hand, the country's less integrated market with global and beginning-stage market structuring can offer great opportunities for the country to create policies and a business environment based more on environment-friendly technologies while supporting its economy and lifting its population out of poverty as system change for green growth requires changing the "invisible" structure of the economy, including the market prices, fiscal policy, financial systems, institutional arrangements, regulations, and lifestyles (UN report).[2]

Since 1990, Mongolia has well transitioned from a centrally planned economy to a market economy, and the government of Mongolia incorporated the fundamental principles of sustainable development in its subsequent development policy documents.

The comprehensive national development policy has synergized the perspective, goals, and targets that have been stated and formulated in 304

[2] UNESCAP's report "Low Carbon Green Growth Roadmap for Asia and the Pacific" <http://www.unescap.org/esd/environment/lcgg/documents/Roadmap_FINAL_15_6_12.pdf>

policy documents developed and approved in the last 15 years ("Mongolia's Sustainable Development Agenda" report).

The following are the main basic policy framework documents on Mongolia's sustainable development strategy:

Mongolia's Sustainable Development Program for the 21st Century

This was adopted through a resolution of the government of Mongolia on May 27, 1998. This program was further incorporated with other policies, programs, and strategies into a policy paper called "MDG-based Comprehensive National Development Strategy of 2007-2021" and was adopted by the State Great Khural of Mongolia[3] and is now in effect.

Millennium-Development-Goals-based Comprehensive National Development Policy (2007-2021)

This puts emphasis on good governance, export-oriented economic development (Mongolia should focus on its advantages, like mining), rural development, poverty reduction, and human development issues. Mongolia has developed the Transportation Sector Development Strategy and has submitted it to State Great Khural for approval. In addition, the Ministry of Road, Transport, Construction, and Urban Development has developed the Road Sector Master Plan "Transit Mongolia" for implementation in 2008-2020, and a 15-year investment plan.

Government Action Plan for 2012-2016

This is the main official document that shows that the government is

[3] The highest organ of state power and the supreme legislative power is vested only upon the State Great Khural <http://www.parliament.mn/en>.

willing to implement all the policies and activities reflected on the action plan. This document contains several objectives that have been set for the adaptation and promotion of the green development concepts in the national strategies on sustainable development programs and plans.

The new government's policy and strategy on green development

One of the main objectives of the Mongolian "Reform" government is to identify and develop its national strategy on green growth. To achieve this goal, the government started to change its intuitional structure that was designed to develop and implement the national strategy and action plans on green growth. It restructured the existing Ministry of Nature, Environment, and Tourism into the Ministry of Environment and Green Development (MEGD), which was established according to the law on government structure promulgated on August 16, 2012, with the status of core ministry. The new ministry has six departments, one being the Department of Green Development Policy and Planning, which is designed to develop strategies for and policies on green growth.

The new ministry recently prepared a draft form of the National Green Development Strategy of Mongolia, and it is being discussed at the level of the government-commissioned working group and international consultant groups (e.g., UNDP) to include the plausible pathways, priority measures, realistic targets, and needs for developing the necessary capacities at various levels to shift to a green economy.

1.5 Mongolian Energy Sector

Mongolia has abundant energy resources that could meet its energy demand in the next decades. Coal is the most dominant energy resource for electricity and heating in the country, and the existing energy supply system has thus been built on this capacity of the resource.

Coal export is one of most important revenue streams of the country. The huge demand for coal in the Asian countries, especially in China, can enable Mongolia to export its coal to the Asian markets for the next few decades.

Solar, wind, and hydropower are renewable energy resources that can play important roles in the energy system. The potential capacity of each of these resources is huge compared to the existing capacity of the country's energy system. Due to the high initial investment and other technology-inadequate factors, however, the renewable energy sources could not compete with the cheap domestic, subsidized coal power plants. Mongolia has legal documents on renewable energy promotion and deployment and has successfully implemented several renewable energy projects, mainly in rural area electrification, with assistance from international aid organizations. Also, the first 50MW wind farm project, the first project that used FIT since its establishment in 2007, has been implemented by the private sector.

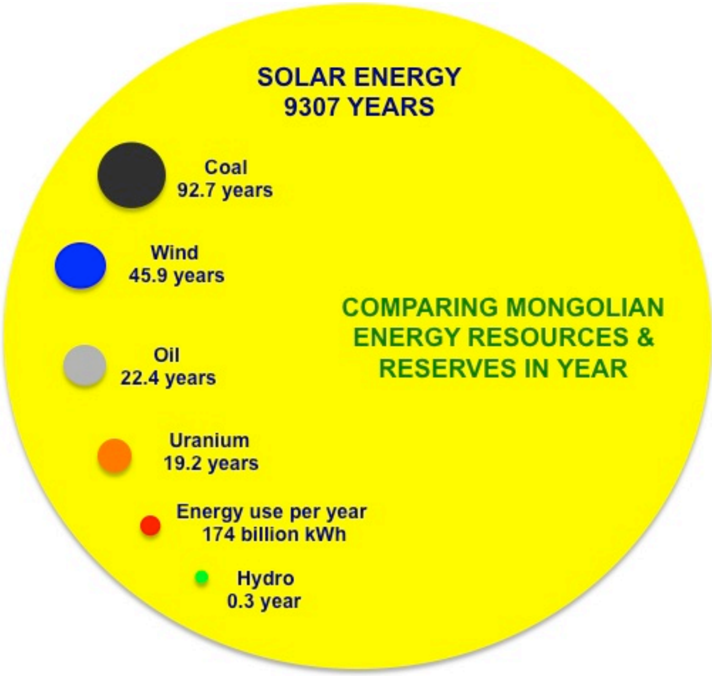

Figure 1-6. Comparison of Mongolia's energy resources and reserves.

The natural gas resource is not in the list of the country's energy sources, and importing the resource would be very costly due to Mongolia's geographic location as a landlocked country and the high energy security risk due to the country's dependence on its neighboring countries' gas supply capacity. Besides the energy sources mentioned above, there are other energy sources available for use in the energy system, such as uranium, geothermal energy, and coalbed methane gas.

1.5.1 Fossil fuels

A. Coal

Mongolia has abundant coal resources around the country, especially in the Gobi area in the south, with a total estimated resource of approximately 173 billion tons found within 15 coal basins. Bituminous coal is found in the south Gobi and western basins. Most of the resources in the central, northern, and western regions are subbituminous or lignite. The coal deposits in Mongolia are typically suitable for open cast mining because of their geological conditions.

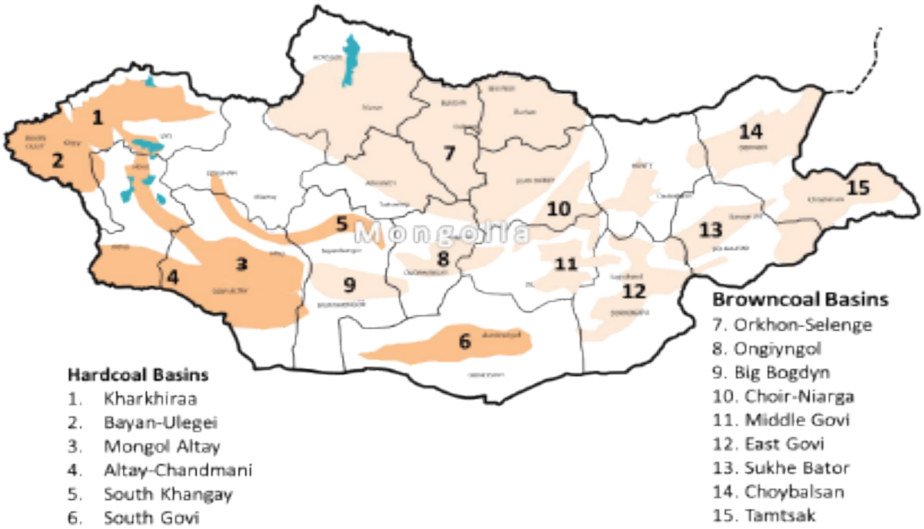

Figure 1-7. Locations of the coal deposits in Mongolia.

The coal resources were found in a total of 85 deposits, and in over 370 identified occurrences and findings, the coal reserves were measured as about 22 billion tons. Thanks to the increasing exploration activities, the amount of coal reserves is even increasing yearly. The share of high-calorific-value thermal and coking coal is estimated at 7-8 billion tons. The proven reserves are at 12 billion tons, including 2 billion tons of coking coal and 10 billion tons of thermal coal (ADB, 2013). The importance of coal in Mongolia is high, and its contribution to the economy and energy system is becoming even more significant.

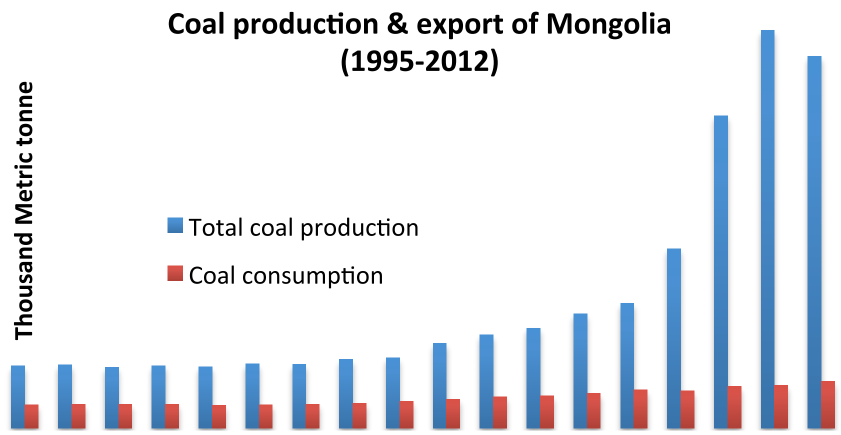

Figure 1-8. Mongolian coal production and export (1995-2012).

Today, coal provides primary energy for 65% of Mongolia's total energy use, and for over 90% of the country's power and heat generation. Coal represents 40-50% of Mongolia's export revenues (47% in 2011), and according to the Mongolian Economic Research Institute, over 10% of the budget revenues and 80% of the FDI. Mongolia's domestic coal consumption is about 5-6 million tons, but the number is likely to increase due to the CHP development projects. Millions of tons of cheap coal, which is shown in Figure 1-7, is being exported to China, the biggest raw material market in the world, every year.

B. Oil

Mongolia's oil reserve in east Gobi was estimated by a Soviet geologist for the first time to be 6.2 million tons. A total 10.58 million barrels of oil have been produced, 9.89 million barrels of which have been exported to China for refining as there is no refining factory in Mongolia. Mongolia officially became an oil-producing country in 2010, with a combined total of

272 million tons of proved reserves (Petroleum Authority of Mongolia, 2012).

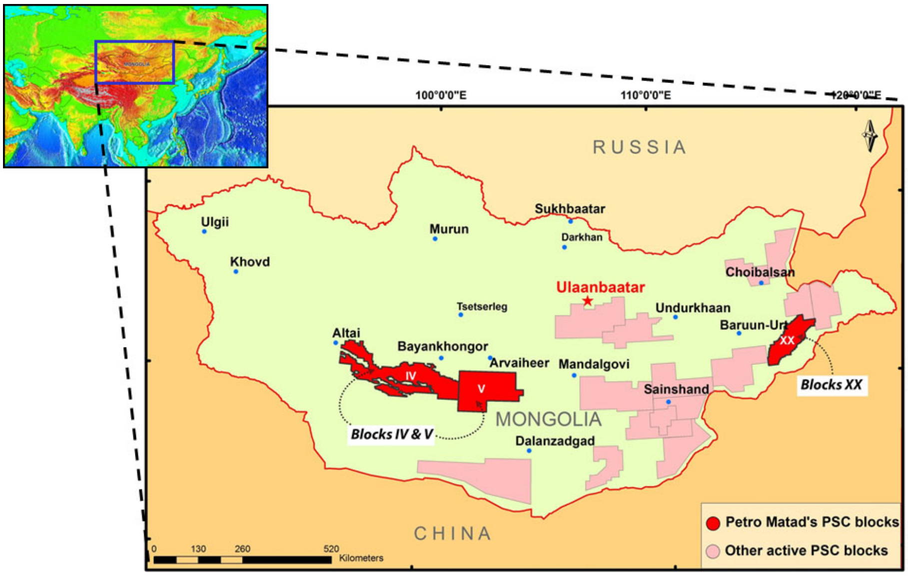

Figure 1-9. Oil blocks in Mongolia.

Today, there are 14 companies conducting oil-related businesses on 18 blocks with a product sharing contract, but only two of them, both Chinese companies, are actively participating in oil production in Mongolia, and the production increased 11 times over the last five years.

Zuunbayan and Tamsag are also the only two basins that produce crude oil in Mongolia. Both are located in the southeast Gobi Desert. Zuunbayan engaged in crude oil production from 1953 to 1969 and resumed it in 2007. Tamsag started to produce crude oil in 1998, and its production significantly increased in the last five years, with approximately 2.07 million barrels recovered by 2011. In that year, Mongolia's crude oil production reached 2.60 million barrels, and the annual growth was around 10% (Petroleum Authority of Mongolia, 2012).

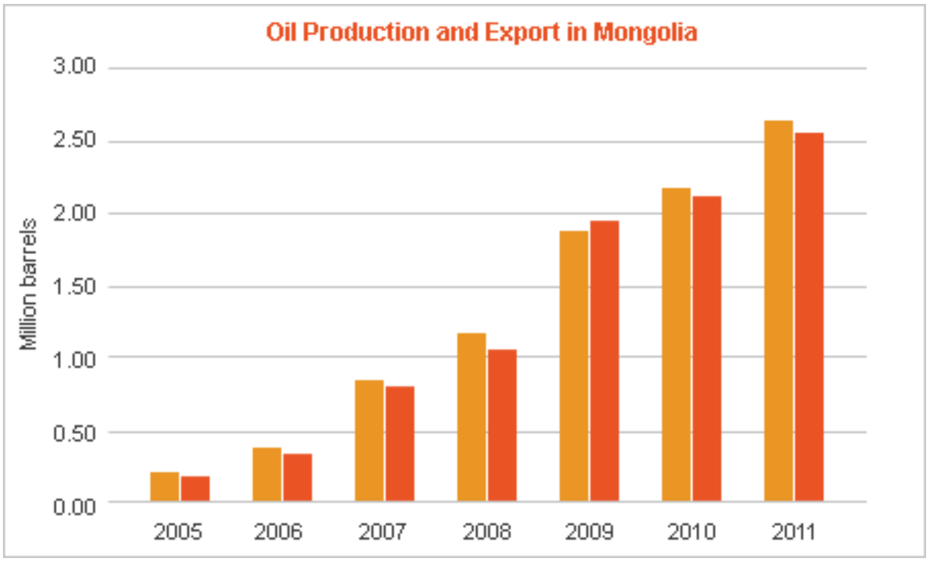

Figure 1-10. Oil production and export in Mongolia

Mongolia's potential oil reserve has not yet been discovered fully and remains unknown. Some experts from the U.S. estimate that its recoverable oil reserves can reach from 4 to 6 billion barrels. Nevertheless, more detailed studies and analyses have to be done on the presence of source and quality reservoir rocks, and more seismic data acquisition and geological analyses should be conducted to assess and determine the country's actual potential reserves.

1.5.2 Renewables

Mongolia also has significant potential renewable energy resources that could replace fossil fuels as the country's main energy source. According to the U.S. National Renewable Energy Laboratory (Elliott et al., 2001) and the Mongolian National Renewable Energy Center (NREC), Mongolia's potential renewable energy generation capacity is estimated at 2.6 million MW.

There are various types of barriers, however, to renewable energy development in Mongolia, such as the high initial cost, the lack of a legal framework and policy for promotion, and technical conformity issues. In the last decade, the renewable energy usage in Mongolia was focused on electrification in the country's rural areas, for which several renewable energy projects were implemented by the government of Mongolia with international financial support to supply the people in the remote areas with electricity using renewable energy resources such as solar, wind, and hydro energy.

A. Hydro energy

Hydropower is another important primary energy resource that could be a big contributor to the reduction of the electricity imported from Russia. Therefore, the significance of this resource to midterm energy system security in Mongolia is considerable.

Mongolia has an estimated 3,800 small rivers with a total length of 6,500 km, which theoretically have a potential of about 6.2 GW. The major big rivers are in the northern and western parts of the country, which are mountainous areas. A total of 13 small-scale hydro plants are being operated in Mongolia, with a capacity range of 150 kW to 12.0 MW (Ministry of Energy, 2005).

Table 1-1. Small HPPs in operation in Mongolia

Location	Capacity	Operation Start Year
Kharkhorin	525 KW	1959
Ondorkhangai	200 KW	1989
Guulin	480 KW	1998
Mankhan	150 KW	2003
Monkhairkhan	150 KW	2003
Bogdiin	2.0 MW	2005
Tosontsengel	375 KW	2006

Uench	930 KW	2006
Erdenebulgan	200 KW	2006
Zavkhanmandal	110 KW	2009
Tsetsen-Uul	110 KW	2009
Dorgon	12 MW	2009
Taishir	11 MW	2009

The National Renewable Energy Program that was approved by the Mongolian Parliament in 2005 includes the construction of several big-scale hydropower plants, such as the Orkhon 100 MW, Egiin 220 MW, and Artsat 118 MW hydropower projects until 2020.

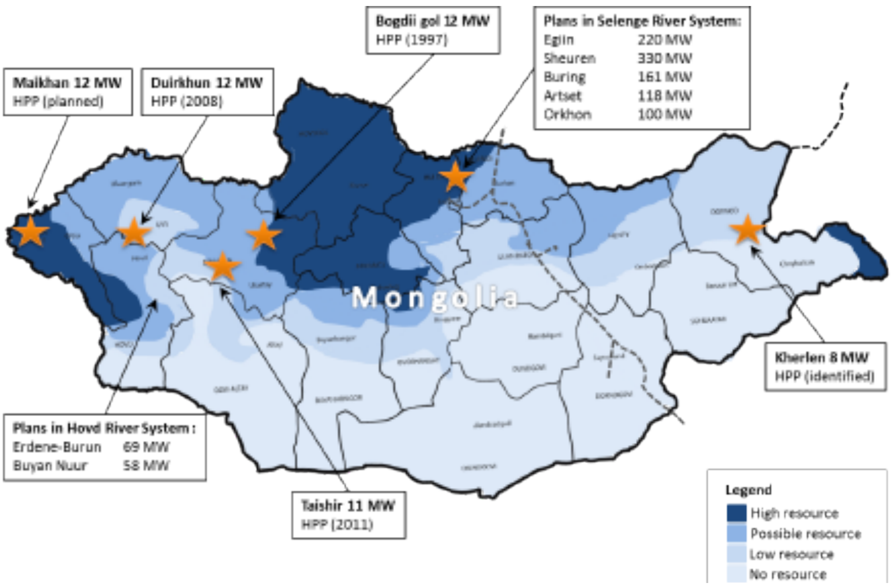

Figure 1-11. Sites of large-scale HPPs in Mongolia.

The necessity of constructing large-scale hydropower plants has become more important of late due to the electricity shortage in the central energy system. The Shuren 330 MW hydropower plant project is the option most considered to be built first among the candidate projects. The government of Mongolia has been working with international organizations and with Russia as a neighboring country to ensure the successful implementation of this project by 2020. The building of HPP in the central energy system will bring some important benefits and contributions to the energy system. For instance, it will be a good opportunity for and support to CES's normal operational system adjustment, including increased independence, while enabling the initial wind park project in the Gobi Desert area.

B. Solar energy

Mongolia has substantial solar potential for both solar power and solar heating as it has around 270 sunshine days in a year (2600-2900 sunshine hours per year) with a solar intensity[4] rate of 5.5-6.0 kWh/m^2 per day in approximately 71% of the country's total land area (Ministry of Energy, 2005).

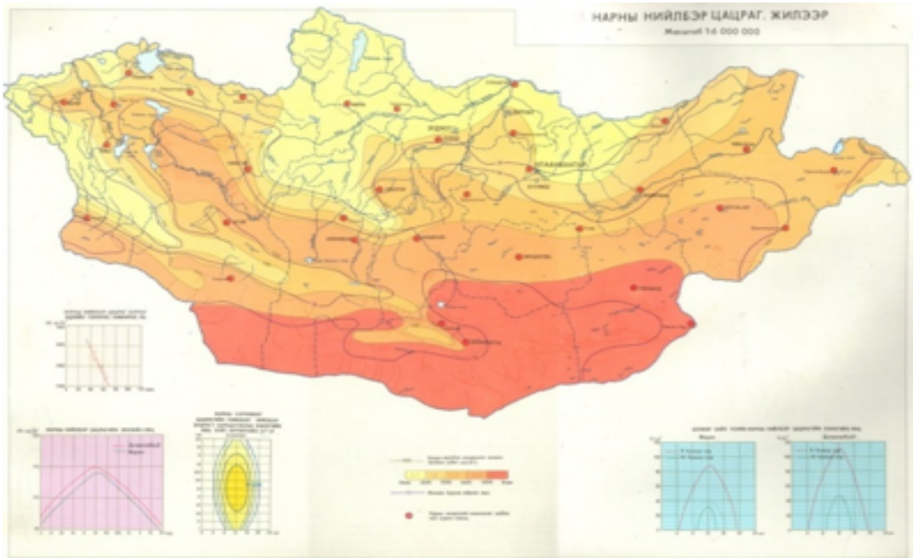

Figure 1-12. Solar energy map of Mongolia.

The majority of this solar resource area is located at Gobi Desert, in which

[4] Solar intensity is the amount of solar power (energy from the sun per unit time) per unit area reaching a location of interest.

several project proposals involving the establishment of large-scale solar energy systems, both solar photovoltaic (PV) and concentrated solar power (CSP), are being discussed, including Asian Super Grid System, an ambitious project idea, where large-scale wind and solar farms will be installed in the Gobi Desert area and can be connected via high-tension transmission lines to Korea, Japan, and China. There are some organizations and companies that have been working on this project idea, such as Japanese Renewable Energy Foundation[5] as a major player and the Mongolian private company Newcom, which recently installed the first private 50 MW wind farm in Mongolia.

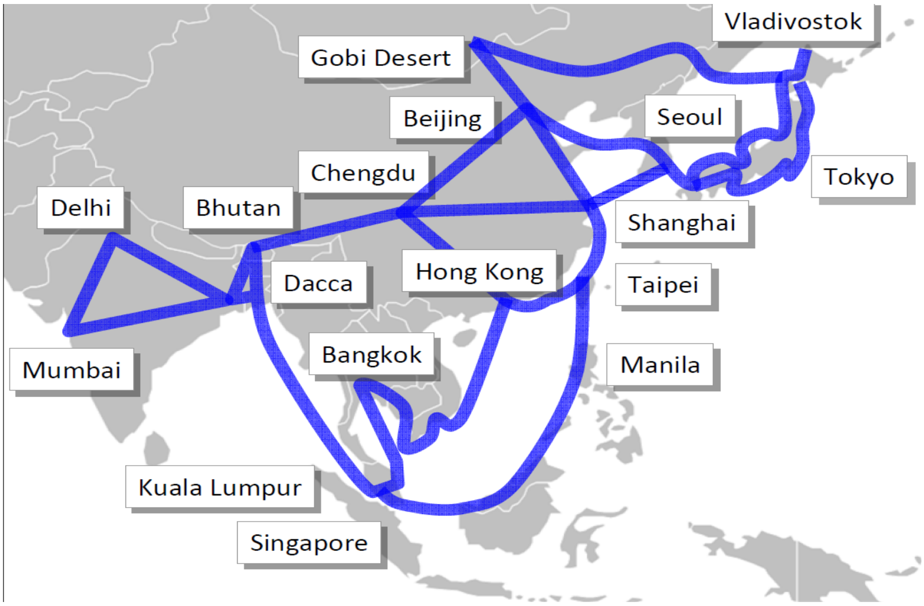

Figure 1-13. Asian Super-Grid Transmission Line.

The government of Mongolia has been implementing a project titled

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5 Based in Japan, its mission is to establish a society based on renewable energy. JREF's activities include policy research and development and development of measures and financial/business models based on the dynamics of markets and the society and on the promotion of renewable energy <www.jref.or.jp>.

“100,000 Solar Gers Program” for 10 years now, since 1999, which was designed to provide solar home system (SHS), with a capacity of 50-75 W, to almost 100,000 families in the countryside with no electricity access. Fifty percent of the cost of the PV systems was subsidized by the government and the World Bank. The program’s outcomes and impacts on the rural community are considerable and positive; the program enables them to access electricity for use with electrical devices such as lights, radios, TVs, and satellite dishes.

Stand-alone, hybrid (solar, wind, and diesel) or solar energy systems of 100-200kW projects were installed in remote soums (villages), where it was very difficult to build an electricity transmission line technically and economically.

1.6 Energy Demand and Consumption

In Mongolia, coal and oil are the main fuels for energy consumption, and coal is still the dominant and major energy source for electricity generation and heating. In the case of oil consumption, the most important industries, such as the transport and agricultural industries, depend much on oil imports; oil prices are the most important factor underlying the economic growth, and the prices of all the goods in Mongolia are dictated by them. With limited domestic oil resources, Mongolia is almost entirely dependent on imports from Russia to meet its energy consumption needs. In the case of coal consumption, the country has an abundant coal resources; the annual coal production in Mongolia is estimated at around 5 million tons. Nearly 85% of the production is used to generate electricity and heating, but 25.5 million tons were exported in 2011 (National Statistical Office of Mongolia, 2012).

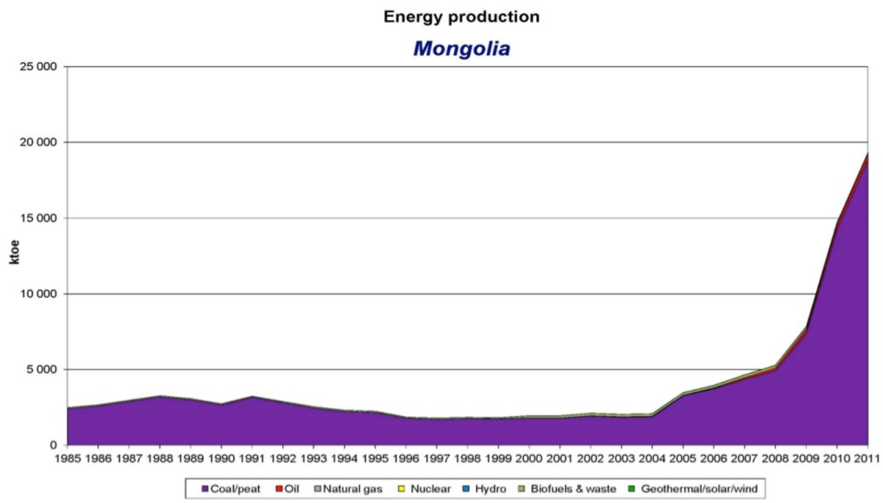

Figure 1-14. Mongolian energy production (1985-2011), IEA.

1.6.1 Electricity consumption

The Mongolian energy system consists of five small isolated regional systems and has seven coal-fired power plants, 13 relatively small-scale hydropower plants, one wind farm, a small stand-alone solar system, and diesel generators. Furthermore, the energy system imports electricity from Russia mostly for its peak demand, which accounts for ~13% of the electricity consumed in Mongolia. Due to the increase in final energy consumption in the last few years, the existing generation capacity will not able to supply the future demand, which will lead to increased electricity import unless new power plants will be operated.

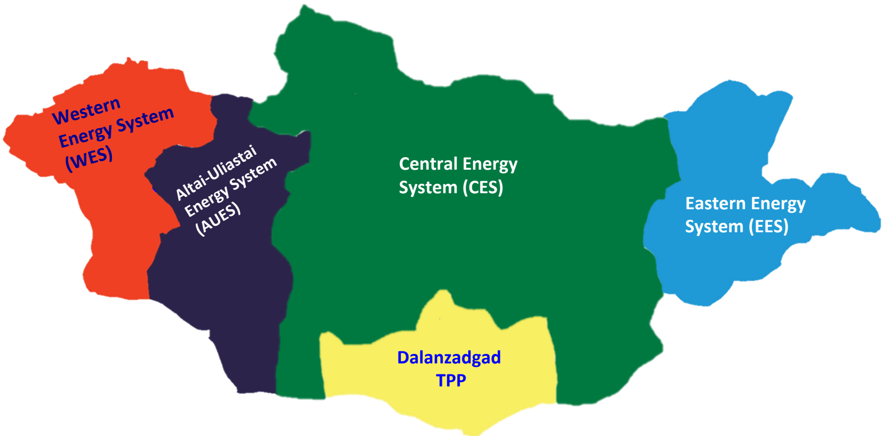

Figure 1-15. Mongolian electricity systems.

The central energy system (CES) is a relatively large energy system among the others, supplying the energy demands of 13 provinces with its five coal-fired power plants and one wind farm, and accounting for 80% of the country's total energy production. Coal-fired co-generation power plants produce electricity and hot water for district heating, with 0.2% of the production exported at a very low tariff rate to Russia at night. The percentage of losses in transport and distribution (T&D) has been decreasing gradually since its peak (23.6%) in 2001 (Energy Regulatory Committee, Mongolia, 2013).

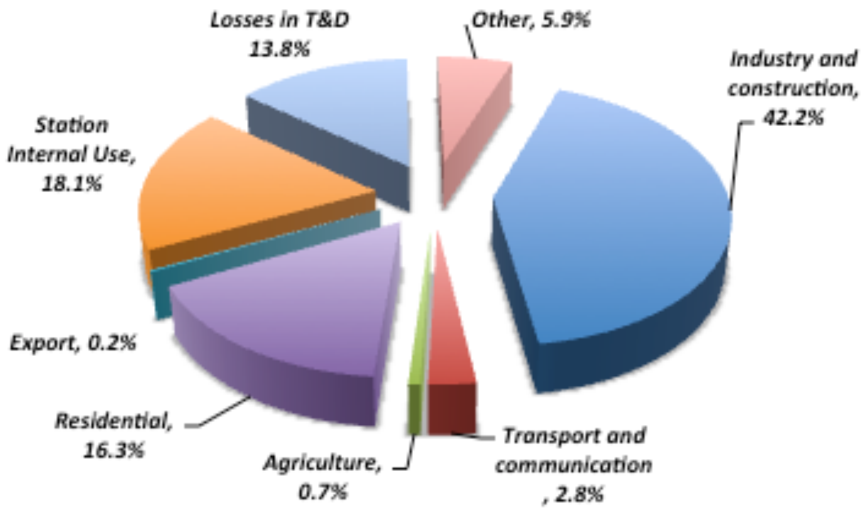

Figure 1-16. Mongolian electricity consumption by sector.

The electricity production of CES grew by 4-6% annually from 2006 to 2010, as shown in Figure 11. The distributed electricity generation also grew by 22.9%, from 2832.4 million kWh in 2006 to 3482.5 million kWh in 2010 (National Statistical Office of Mongolia, 2012).

Table 1-2. Mongolian Electricity Balance (2007-2010)

Indicators	2007	2008	2009	2010
Resources – total	3 896.1	4 198.2	4 195.4	4 575.7
Gross generation	3 700.7	4 000.6	4 038.8	4 312.8
Import	195.4	197.6	156.5	262.9
Distribution – total	3 896.1	4 198.2	4 195.4	4 575.7
Consumption	2 829.1	3 093.3	3 034.1	3 375.9
Of which: Industry and construction	1 745.6	1 9	1 883.1	2 093.8
Transport and communication	117.3	128.7	126.2	140.4
Agriculture	26.1	32.6	32.1	35.6
Household and communal housing	694.6	742.3	727.6	809.7
Other	245.5	271.5	265.1	296.2
Losses in transmission and distribution	442.4	435.9	493.9	505.4
Station internal use	614.5	653.2	649.4	672.2

Export	10.1	15.9	18.1	22.2
Electricity produced per capita (kWh)	1415.4	1504.4	1490.5	1563.6

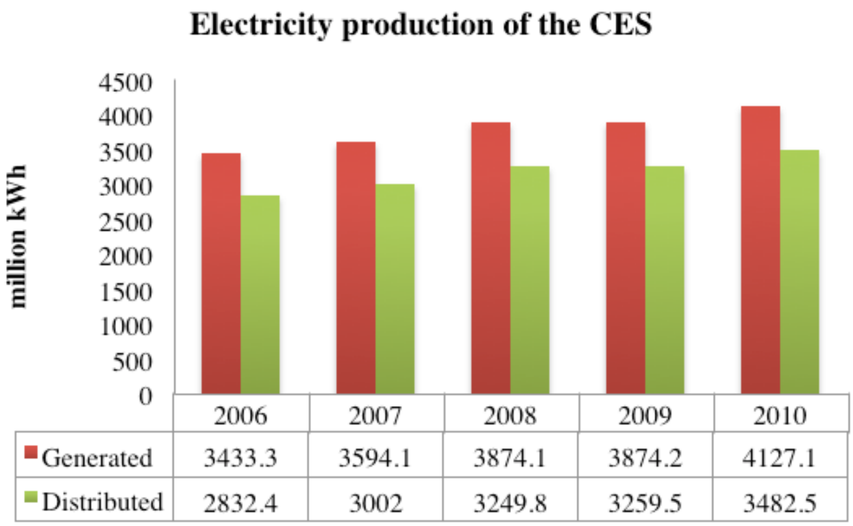

Figure 1-17. Electricity production of CES (2006-2010), ERC.

1.6.2 Heat consumption

Due to the long winter season in Mongolia, when the temperatures are usually between -20 and -30°C, having access to heat is an essential need of the country's citizens. Therefore, securing and sustaining the supply of heating energy is one of the core issues in the energy sector, which is becoming more serious as insufficient funds were invested in the construction of facilities for heating in the last two decades.

Table 1-3. Mongolian Heat Energy Balance (2007-2010)

Indicators	2007	2008	2009	2010
Gross generation	7 723.5	7 759.6	8 320.5	8 362.5
Power and thermal station’s internal use	414.8	396.6	335.3	338.4
Distributed to the economic sectors and households	7 165.0	7 237.9	7 828.5	7 820.2
Of which:				
Industry and construction	2 068.4	2 167.6	2 002.2	2 082.9
Transport and communication	285.5	278.6	264.4	281.7
Agriculture	38.3	39.7	37.8	40.5
Household and communal housing	3 372.0	3 429.8	3 573.9	3 361.8
Other	1 400.8	1 322.2	1 950.2	2 053.4
Losses in transmission and distribution	143.7	125.1	156.8	203.9

There are three main resources that generate heat energy for the heating needs in the urban areas:

- combined heat and power plants, which provide electricity, heat, and hot water to the urban centers in Ulaanbaatar and a few other cities;
- heat-only boilers, which meet the heating and hot-water needs of a small central network of several buildings; and
- individual heat stoves, which burn coal and/or wood to meet the residential heating needs in the urban areas.

The issue becomes crucial in Ulaanbaatar during the winter season as it is the coldest national capital city in the world.

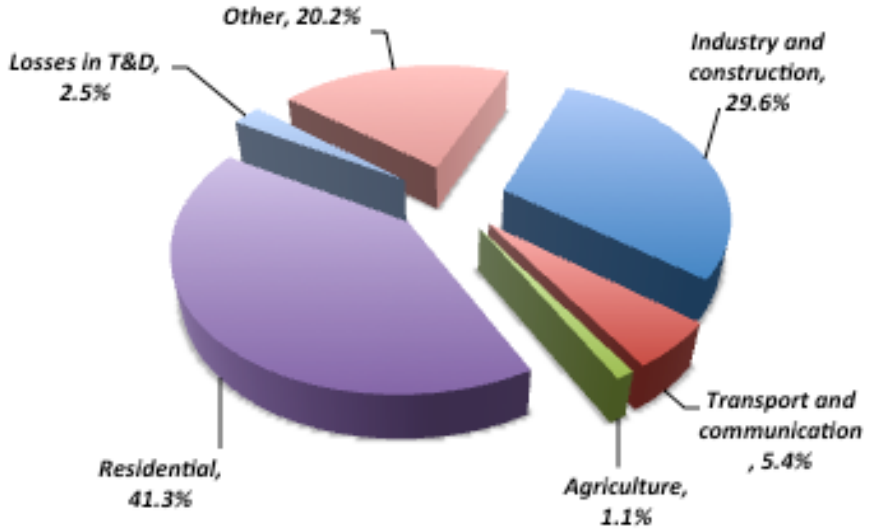

Figure 1-18. Heat consumption by sector (2006-2010), ERC.

1.6.4 Government policy, program, and incentives for the energy sector

The energy sector is one of the few sectors that can significantly contribute to the implementation of green growth in any country. There are great potentials to develop green businesses and a low-carbon economy based on the principle of green growth in the energy field. Mongolia's legal framework and government policies for the energy sector are shown below.

<u>Legal Framework</u>:

- Energy Law of Mongolia
- Renewable Energy Law of Mongolia
- Concession Law
- Development programs:

- “100,000 Solar Ger” National Program
- Integrated Power Energy System Program
- National Renewable Energy Program (NREP)
- New Construction and Midterm Coal Program
- Southern Gobi Development Program

Some of the above documents, which have been used as the underlying legal framework for the BAU, EE, and REN scenarios, are described in detail below.

Energy Law:

This is the law that regulates the production and sale of energy, the construction of energy generation facilities and other energy infrastructures for transmission and distribution, and the supply of energy to the end users, which was approved by the parliament on April 15, 2001 and was amended in 2007 and 2011. The law has some important provisions that define the responsibilities, duties, and authority of the institutes and stakeholders in the energy sector, and also descriptions of the transmission network boundaries, the approval of heating and electricity consumption, and the protection of power lines and networks.

For instance, the licenses of building facilities for energy generation, transmission, and distribution for a legal entity are different depending on the type of license, and the license period for producing and transmitting energy is 5-25 years, that for the construction of energy facilities is five years, and that for other activities is 10 years.

Integrated Power Energy System Program:

This program was ratified by the Mongolian Parliament in 2007. It includes various issues that are critical and emerging in the country's energy sector, such as building a large-scale hydropower plant that will strengthen the country's energy security and will reduce its electricity imports from Russia as well as its CO_2 emission, developing new policies and regulations supporting private sector participation in the country's energy sector, and introducing new efficient technologies that can reduce energy losses and increase the energy efficiency of the demand side. Finally, the program has the strategic goal of investing in restructuring the country's energy infrastructure to make Mongolia an energy exporter to its neighboring countries and to other countries.

The government of Mongolia has been working on updating the program of late with the assistance of Asian Development Bank (ADB), making the program more detailed and clearer with regard to its targets and projects to achieve the program goals.

National Renewable Energy Programme (NREP)

NREP has been chosen in this study as the policy to be tested in the Mongolian LEAP model. The program aims to create the conditions for ensuring ecological balance, unemployment and poverty reduction, and sustainable social and economic development by increasing the percentage of renewable energy share in the total energy supply of Mongolia, improving the energy supply structure, and widely using renewable energy for the rural areas' power supply.

According to NREP, which was approved by the Mongolian Parliament in 2005, the renewable energy contribution to the total energy system was supposed to be 3-5% by 2010 and is supposed to be 20-25% by 2020, but only 1.1% of the total electricity production in Mongolia has been produced from renewable energy resources to date, totaling 24.5 million kWh in 2011.

Another target of the program is to reduce the losses in the overall energy system by 3-5% of the current level by the year 2010, and by not less than 10% by the year 2020, by introducing advanced renewable energy technologies, intensifying energy conservation, and increasing the production, transmission, distribution, and operation efficiency.

To achieve the “20% target,” several renewable energy projects, especially those involving the construction of large-scale hydropower plants, are proposed to be completed by 2020. These are the Eg River 220 MW station, the Artsat 118 MW station on Selenge River, and the Orkhon River 110 MW station, to be built on rivers with significant hydropower resources (i.e., the Selenge, Eg, and Orkhon rivers). Also, medium-capacity (30-50 MW) wind parks are proposed to be constructed in sites with proven wind energy potential, and to be connected to the centralized power grid system, creating efficient operation conditions.

Furthermore, small-scale renewable energy systems like wind, solar, and hybrid wind plus solar energy are defined as electrification options for the villages (soums) in remote areas where it is unreasonable technically and economically to construct electric transmission lines.

In addition, pilot projects of large-scale solar PV power generation systems in the Gobi area, and energy complexes employing geothermal technology in Ulaanbaatar for reducing its air pollution, were also planned as activities that can contribute to the attainment of the target that 20-25% of the country's total energy production will be generated by renewable resources by 2020.

Main players in the market for electricity and heat energy

The market participants are five combined heat and power plants, one (state-owned) electricity transmission operator, and ten electricity distribution companies.

The Energy Regulatory Committee (ERC) introduced the single-buyer model (SBM) as a market model in September 2002 for the central electricity system. In the Mongolian case, five generating companies sell electricity at a regulated price to the single buyer, and the central regional electricity transmission company is the market operator, selling electricity to ten distribution companies.

Tested in 2005, the spot market has been effective since 2006. The National Dispatching Center was selected to act as a spot market operator. The electricity sales of the spot market were 7.0 million kWh in 2006, 6.8 million kWh in 2007, 7.6 million kWh in 2008, 4.1 million kWh in 2009, 4.9 million kWh in 2010, and 3.9 million kWh in 2011, indicating a gradual shrink.

ERC started the auction market in August 2007, where an incremental electricity demand is auctioned among the generating licensees for the best prices. Only five transactions have been recorded to date. The National

Dispatching Center operates the auction market. Despite the fact that 26 million kWh power was auctioned in 2011, only 4.5 million kWh power was sold in the market.

Table 1-4. Power and Heat Energy Generators in Mongolia

#	Power Plant	Type	Installed Capacity (MW)	Operation Start Date
	Central energy system			
1	Power Plant 2	Thermal, combined cycle	21.5	1961
2	Power Plant 3	Thermal, combined cycle	136	1968
3	Power Plant 4	Thermal, combined cycle	540	1983
4	Darkhan Power Plant	Thermal, combined cycle	48	1965
5	Erdenet Power Plant	Thermal, combined cycle	28.8	1987
6	Choibalsan Power Plant	Thermal, combined cycle	36	1967
7	“Salkhit” Wind Farm	Wind energy	50	2013
	Western energy system			
7	Durgun Hydropower Plant	Hydropower plant	12	2009
	Altai-Uliastai energy system			
8	Taishir Hydropower Plant	Hydropower plant	11	2011
9	Bogdiin Hydropower Plant	Hydropower plant	2	1998
10	Tosontsengel Hydropower Plant	Small hydro	0.36	1998
	Eastern energy system			
11	Dalanzadgad Power Plant	Thermal, combined cycle	6	1995

12	“Ukhaa Khudag”	Coal-fired	18	2011

Thermal Power Plant #4 is the biggest energy company in Mongolia, generating 2721 million kWh electricity in 2011, accounting for 70.1% of the total electricity production for that year. TPP#3, on the other hand, contributed about 14% of the electricity production and accounted for 37% of the heat energy consumed, respectively. The total electricity production of 3879 million kWh in 2011 was higher by 11% than the 3482.5 million kWh in 2010.

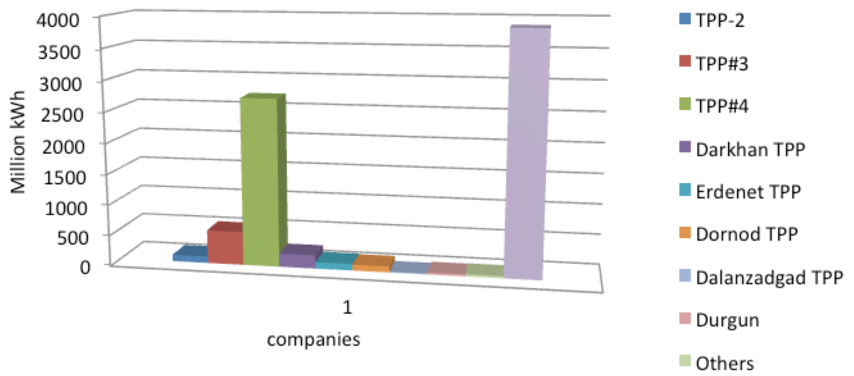

Figure 1-19. Energy companies’ share in the electricity production.

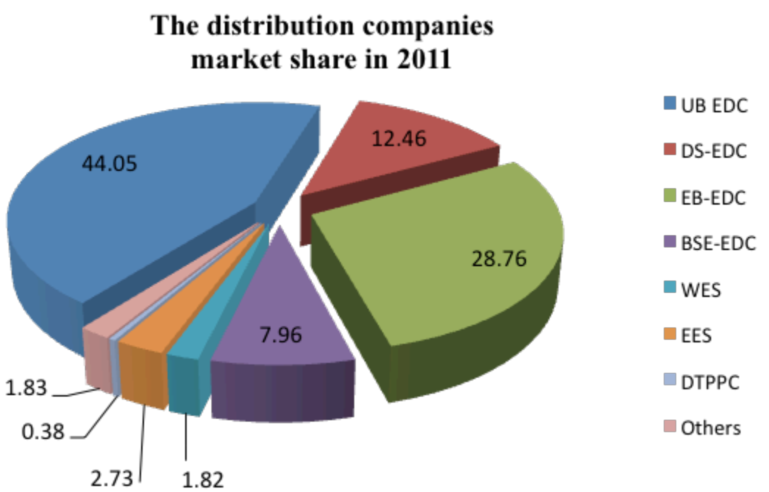

Figure 1-20. Market share of the electricity distribution companies.

The electricity distribution business of Ulaanbaatar Electricity Distribution Company (UB EDC), a stated-owned company, covers Ulaanbaatar. It distributes 44.05% of the total electricity consumed in Mongolia (Energy Regulatory Committee, Mongolia, 2013).

Tariffs for electricity and heat

The existing tariffs for electricity are too low to support the sustainable development of the power industry. To increase the participation of the private sector in the power generation industry for building power plants, the tariffs will need to cover the cost of service delivery because the private sector will not invest in non-profitable projects. According to the World Bank estimates, compared with the existing tariffs, the cost-covering tariffs for new facilities could be 3.5 times higher for electricity.

In addition, the effective participation of the private sector in the future will depend to a considerable extent on the condition of Mongolia's regulatory framework, which has several impediments to successful regulation. If regulatory reforms are not carried out, the financing gap between the available funds and the capital expenditure needs will become much wider, making it harder to fill the gap through private investment.

ERC has a tariff policy of releasing subsidized "non-realistic" tariffs, which will make it more reasonable for the generators to cover the cost by increasing the tariffs gradually on a yearly basis. For the last few years, ERC increased the tariffs five times, with the intention of reaching the USD0.8/kWh level in 2013 for the electricity prices for the customers.

ERC estimated that the cross-subsidies in industry and the residential tariffs will be removed when the tariff level reaches that of the cost-recovering tariffs.

The current average level of the subsidies on the end use price is 72% for the residential users and 58% for the industrial consumers. Other forms of subsidies are debt repayment waivers for deferrals granted by the government to various energy sector companies (Energy Regulatory Committee, Mongolia, 2013).

Table 1-4. Electricity Tariff Growth by Year

Items	2002	2005	2007	2008	2009
Electricity	4.4%	8.5%	4.4%	27.8%	17.35%

Feed-in tariff

The Mongolian FIT was the main component of the renewable energy law that was enacted by the Mongolian Parliament in 2007. In the law, tariffs for electricity production from three renewable energy resources — solar, wind, and hydro energy — have to be established, and the tariffs are categorized by size and project type. There are many different options that can be considered by a certain country for establishing its FIT. Presented below are the characteristics of the Mongolian FIT, which reflect the country’s context.

- The FIT payment is set based on the fixed price model.
- Incorporates a cost-sharing mechanism
- Payment level targeted for wind, solar, and hydropower
- The validity period of FIT, which was established in 2007, is 10 years.

- Only one wind farm project has been signed as a PPA under the FIT.
- Utility is required to purchase electricity from the RE generators.
- The generators pay a minimal connection cost.
- The generators are allowed to qualify for CERs, which are not considered part of the FIT.

Table 1-5. Mongolian FITs

Type	Types of Energy	Capacity	Tariff /cent/
On Grid	Wind energy	5 MW or less	8-9.5
	Hydro energy		4.5-6
	Solar energy		15-18
Off Grid	Wind energy		10-15
	Hydro energy	0.5 MW or less	8-10
		0.5-2 MW	5-6
		2-5 MW	4.5-5
	Solar energy		20-30

Source: Renewable Energy Law of Mongolia

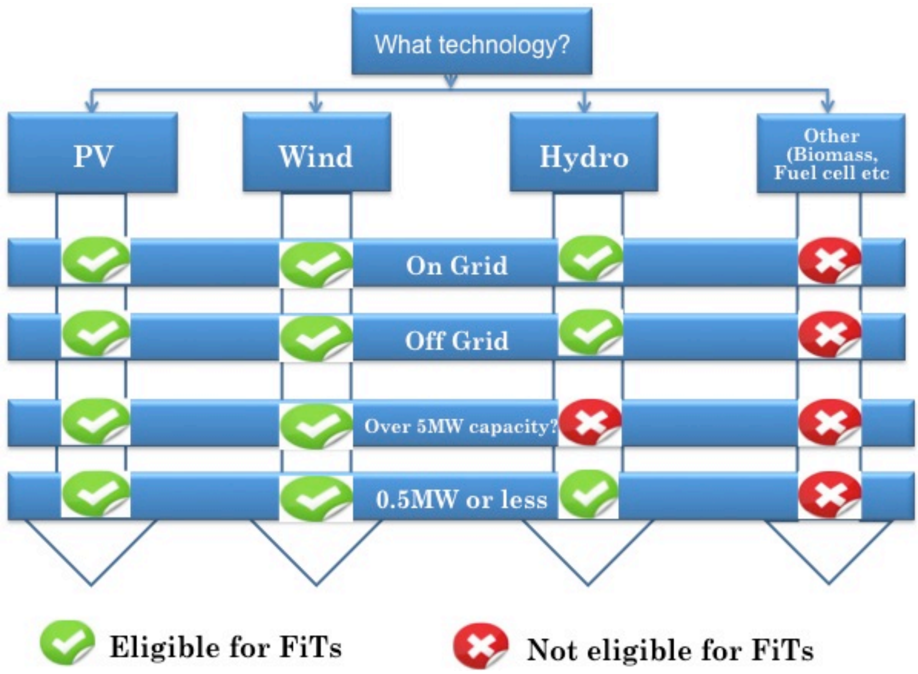

Figure 1-21. Eligibility of FIT in RE technologies.

Additional capacity for heating and power is required

The existing power and heating capacities are fully utilized with little reserve capacity in case the thermal power plants are unable to produce the amount of energy needed to meet the peak power load. The CHPs are getting older; the youngest one is CHP#4, which is 30 years old. Some of them have gone beyond their expected retirement year; CHP#2 was supposed to have retired in 2005, and CHP#3 in 2011.

These two power plants have been operating for over 30 years, and there is a risk that their operation will no longer be stable and reliable due to the poor conditions of their facilities and equipment. The TPPs are operated to supply a significant part of the heat supply in the winter season, and as such, any failure and temporary outage in TPP#2 and TPP#3 can create serious problems on the part of their users, which requires the making of a contingency situation by CES (Asian Development Bank and Ministry of Energy, Mongolia, 2013).

Existing projects in Mongolia's energy sector

The projects that have been implemented and that are being implemented in the energy sector of Mongolia were financed by only a handful of international organizations, such as WB, ADB, Germany's KfW Bank, and by countries like Japan and South Korea. In terms of the objectives and designation of the projects, basically, the WB and ADB projects aim to support energy efficiency, improvement of electricity transmission and distribution lines, and power plant development, and KfW, GTZ, and South Korea have been providing support for renewable energy development, such as of the solar PV system and small-scale hydropower plants. Table 1-6 shows the projects that are currently being implemented and sponsored by international organizations in cooperation with the Ministry of Energy of Mongolia.

Table 1-6. Existing Projects in Mongolia's Energy Sector (2013)

Title/Name	Sponsor	Financing Type	Project Duration
"Energy Efficiency-1" New Steam Turbine at Darkhan Thermal Power Plant	Kreditanstalt für Wiederaufbau (KfW)	Low-interest loan	2010-2013
Low-Carbon Energy Supply Project Using the Public-Private Partnership Model	Asian Development Bank (ADB) TA	Grant	2008-2014
Energy Efficiency Project-2	Federal Republic of Germany, BMZ	Grant	2011-2013
Demonstration Project for Improved Electricity to the Low-Income Communities in the Rural Areas	ADB/Japanese Fund for Poverty Reduction	Grant	2010-2012 (continued)
Project for the Establishment of a Heating and Hot-Tap-Water Supply System in Baruun-Urt Town	Korea International Cooperation Agency (KOICA)	Grant	2011-2012 (continued)
Rehabilitation of TPP-4 through Financing Support from KfW Bank	Federal Republic of Germany, KfW Bank	Low-interest loan	2012-2014

Source: Ministry of Energy, 2013

Chapter 2 - Literature Review

2.1 Overview

Energy planning is a commonly used method for analyzing the complex aspects of the energy system. It aims to ensure that the decisions concerning the energy demand and supply infrastructures involve all the stakeholders, consider all the possible energy supply and demand options, and are consistent with the overall goals for national sustainable development.

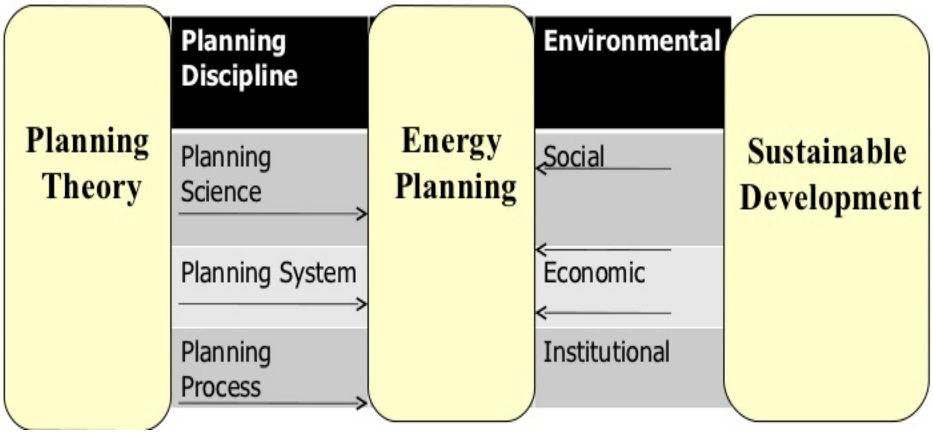

Figure 2-1. Scheme for energy planning.

Forecasting vs. backcasting

Backcasting starts with defining a desirable future and then works backwards to identify policies and programs that will connect the future to the present. The fundamental question of backcasting is "If we want to attain a certain goal, what actions must we take to get there?"

In contrast, forecasting is the process of predicting the future based on current trend analysis. It is widely used to describe likely business futures designed by extrapolating past/present trends and patterns. As these trends were observed in the past, forecasting assumes that they are also suitable for describing the future.

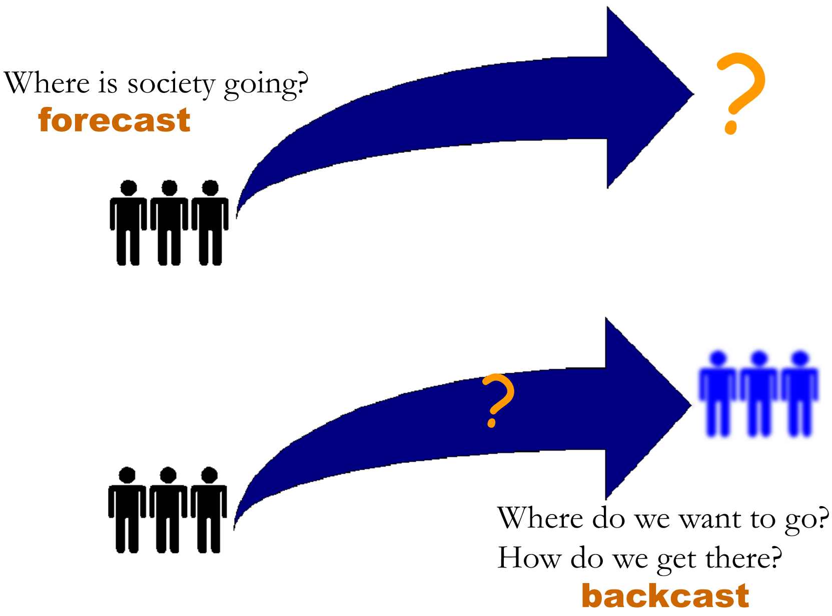

Figure 2-2. Forecasting vs. backcasting.

Source: Kemp-Benedict, 2001

2.2 Energy Models

Energy model classification

Many energy models have been developed for energy forecasting, planning, and calculation for various types of purposes in the energy field. These models vary considerably, and depending on the research purpose, selecting the right model is an important step for attaining a certain purpose or addressing a certain situation.

As mentioned above, models can be classified depending on their purpose, structure, and external or input assumption. Here are nine bases of classifying energy models:

(1) general and specific purposes of energy models;

(2) model structure: internal and external assumptions;

(3) analytical approach: top-down vs. bottom-up;

(4) underlying methodology;

(5) mathematical approach;

(6) geographic coverage: global, regional, national, local, or project;

(7) sectoral coverage;

(8) time horizon: short, medium, and long term; and

(9) data requirements.

Main characteristics and comparison of models

A model is described as a mathematical description usually in the form of a computer algorithm, a real system, or a phenomenon occurring with that system. An energy model focuses on energy issues. A general characteristic that is common to all energy models is that each model is a simplified representation of a complex real energy system and deals with quantitative and qualitative parameters related to selected energy issues (Sahir, 2007).

All energy models can be divided into two modeling approaches: the top-down and the bottom-up approaches. The top-down model is designed for the analysis and examination of broader economic variables and any economic sector, and of the socioeconomic impacts of such variables. For instance, for energy sectors, the top-down model can be used to analyze the production of energy resources (gas, oil, electricity, coal) and the energy flow and demand in monetary units. In contrast, the bottom-up model usually deals with detailed information and mathematical programming problems. It requires very comprehensive data and information as inputs to analyze the performance and planning of a certain sector. In energy sector analysis, more comprehensive data regarding the energy policies (subsidies, technology regulations) on the technology mix, fuel mix, emissions, and cost of the energy system are required. The use of the bottom-up model usually results in a more inclusive assessment and analysis of the energy technologies, policies, and fuel mix within the energy sector.

The table below lists the different characteristics and aspects of the top-down and bottom-up models for analyzing and assessing a sector.

Table 2-1. Comparison of the Top-down and Bottom-up Models

Top-down Models	Bottom-up Models
• Use an "economic approach"	• Use an "engineering approach"
• Give pessimistic estimates on the "best" performance	• Give optimistic estimates on the "best" performance
• Cannot explicitly represent technologies	• Allow for detailed descriptions of technologies
• Reflect the available technologies adopted by the market	• Reflect the technical potential
• The "most efficient" technologies are given by the production frontier (which is set by the market behavior).	• Efficient technologies can lie beyond the economic production frontier suggested by the market behavior.
• Use aggregated data for predicting purposes	• Use disaggregated data for exploring purposes
• Are based on the observed market behavior	• Are independent of the observed market behavior
• Disregard the technically most efficient technologies available, thus underestimating the potential for efficiency improvement	• Disregard the market thresholds (hidden costs and other constraints), thus overestimating the potential for efficiency improvement

• Determine the energy demand through aggregate economic indices (GNP, price elasticity), but vary in addressing the energy supply	• Represent the supply technologies in detail using disaggregated data, but vary in addressing the energy consumption
• Endogenize behavioral relationships	• Assess the costs of the technological options directly
• Assume that there are no discontinuities in historical trends	• Assume that the interactions between the energy sector and the other sectors are negligible

Source: Nicole van Beeck, 1999

2.3 Summary of Popular Models

Many energy models and tools for energy system planning are available for different customers with different purposes of model usage (e.g., policymakers, academia, businessmen), at a sufficient number of languages. Every model is designed to have one or multiple integrated approaches to energy system planning and to the assessment of the impact of the energy system on the environment and economy through the methodologies of simulation, optimization, and use of toolbox models for specific purposes. A suite of models is usually required to answer different questions, and no single model covers everything.

Below are the 10 popular energy system models that are currently being used to forecast energy supply and demand, analyze scenarios, assess the current energy system and CO_2 emission reduction, and many other purposes.

Table 2-2. Ten Popular Energy Modeling Software

№.	Name of Model	Developer	Geographic Applicability	Date Require-ment	Link for More Information
1	LEAP (Long-Range Energy Alternatives Planning System)	Stockholm Environ-ment Institute	Local, national, regional	Low-medium	http://www.energycommunity.org/default.asp?action=47
2	MARKAL	IEA/ETSAP	Local,	Medium-	http://www.iea-

	(MARket ALLocation)	(Energy Technology System	national, regional, global	high	etsap.org/web/Markal.asp
3	MESSAGE (Model of Energy Supply Strategy Alternatives and Their General Environmental Impacts)	(International Institute for Applied Systems Analysis) Austria	Local, national, regional, global	Medium-high	http://www.iiasa.ac.at/web/home/research/modelsData/MESSAGE/MESSAGE.en.html
4	MIDAS (Model Integrating Demand and Supply)	European Union	Local, national, regional, global	Low-medium	http://www.e3mlab.ntua.gr/manuals/MIDASman.pdf
5	RETScreen (Renewable Energy Technology Screening)	Natural Resources Canada	Local	Techno-logy-specific	http://www.retscreen.net/ang/home.php
6	MAED-2 (Model for the Analysis of Energy Demand)	International Atomic Energy Agency	National, regional, global	Medium-high	http://www-pub.iaea.org/MTCD/publications/PDF/CMS-18_web.pdf
7	TIMES (The Integrated MARKAL-EFOM System)	Energy Technology Systems Analysis Programme	Local, national, regional, global	Medium-high	http://www.iea-etsap.org/web/applicationGlobal.asp
8	POLES (Prospective Outlook on Long-Term Energy Systems)	IEPE (Grenoble, France)	National, regional, global	Low-medium	http://ipts.jrc.ec.europa.eu/activities/energy-and-transport/documents/POLESdescription.pdf
9	EFOM (Energy Flow Optimization Model)	European Union	Local, national, regional, global	Medium-high	http://ces.iisc.ernet.in/hpg/envis/doc98html/enbru87.html
10	Power Plan	Center for Energy and Environmental Studies, University of Groningen	Local, national, regional	Low-medium	http://www.fwn.rug.nl/ivem/soft.htm.

Chapter 3 - Methodology and Data Collection

3.1 LEAP Model

3.1.1 Overview of the LEAP model

LEAP is an integrated modeling tool that can be used to track energy consumption, production, and resource extraction in all the sectors of an economy. It can be used to account for both the energy sector and non-energy sector GHG emission sources and sinks. In addition to tracking GHGs, LEAP can also be used to analyze the emissions of local and regional air pollutants, making it well suited to studies on the climate co-benefits of local air pollution reduction (Heaps, 2012).

The LEAP model is a comprehensive energy-environment analysis tool and bottom-up-type accounting framework for forecasting various types of energy-related issues, such as energy supply and demand, CO_2 emissions, and cost-benefit accounting at the national and regional levels.

To forecast and analyze the energy system, CO_2 emissions, and costs according to the long-term energy alternative scenarios, this study used the LEAP model (2012 version), which was developed by Stockholm Environment Institute. The modeling software is being used in more than 190 countries in the world.

LEAP was designed based on the concept of long-range scenario analysis. Scenarios are self-consistent storylines of how an energy system might evolve over time. Using LEAP, policy analysts can create and then evaluate alternative scenarios by comparing their energy requirements, their social costs and benefits, and their environmental impacts (Heaps, 2012).

The model has many advantages, for which reason it was selected as the model to be used for this thesis. Below are the model's advantages.

- It is an integrated and user-friendly energy modeling tool that can be used to design models of different energy systems depending on the user's need. Also, the time needed for training in using the model for typical analysis is no longer than a week.
- LEAP can be used to account for energy production, consumption, and estimation of recourse extraction in all the sectors of an economy, and can track both the energy sector and non-energy sector GHG emission sources and sinks at the regional, national, and global levels.
- The software is widely available and has a reasonable cost. It can be downloaded by users from developing countries and by students free of charge.
- The model offers users a wide range of modeling methods for their energy demand and supply side analysis.
- Among the important features of the model are its TED technology and environmental database, which gives to users in developing countries (where data and information are not available and are unreliable) information regarding the technical characteristics, costs, and environmental effects of a range of energy technologies, and a database on the available existing technologies.
- As mentioned above, the model's 10,000 users from more than 190

countries, the national starter data on historical data on energy production and consumption, the economic/environmental/other data required for the LEAP software of more than 104 countries, and the online community of users called *COMMAND* attest to the quality and popularity of the model, which can be linked to MS Office (Excel, Word, and PowerPoint).

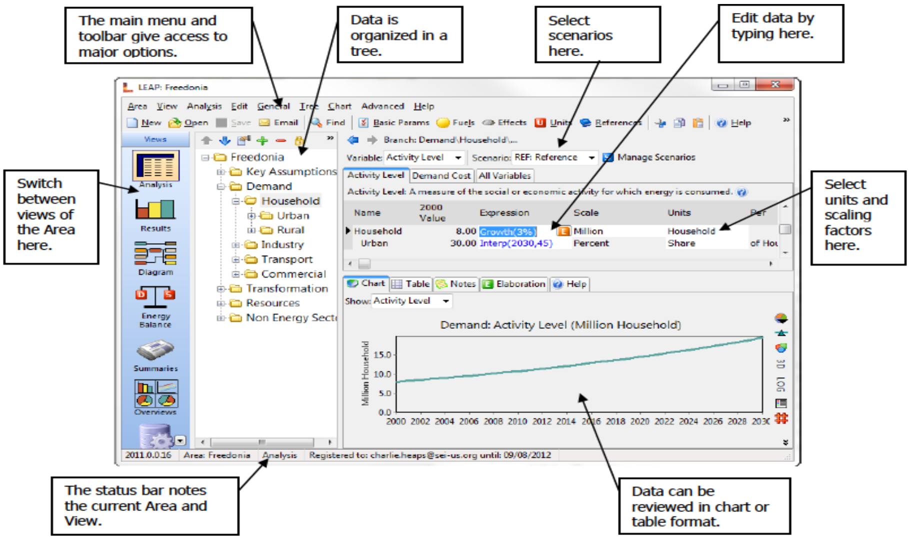

Figure 3-1. Main interface of the LEAP model.

The main interface of the LEAP software consists of eight major "views," each of which allows one to examine the different aspects of the software.

3.1.2 LEAP data requirements

As LEAP is a very general-purpose software tool that can be used to build a wide variety of energy system models, it is impossible to definitively describe its data requirements (Heaps, 2012). It does not require high-level, detailed data, though, which are often used in analyzing the bottom-up model, but it requires comprehensive knowledge on data collection and time-consuming efforts for such.

Data availability is a very important factor for the success of any study in achieving its objectives; therefore, it is crucial to select the right year as the base year — that is, one whose data are extensively available.

In the LEAP model, seven types of data are required to perform analysis, as shown in the figure below.

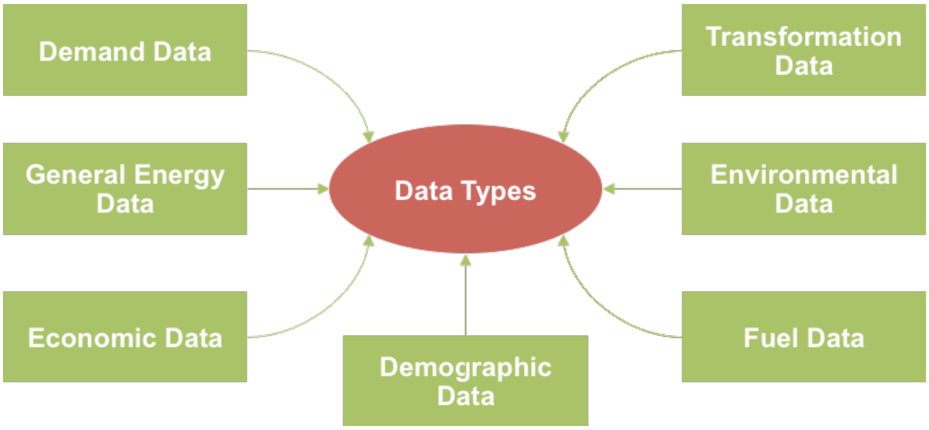

Figure 3-2. Data types for the LEAP model.

All the seven types of data that are needed to perform analyses using the LEAP model are defined below and can be found at the homepage of the LEAP software <www.energycommunity.org>.

Demographic data

In this part, the general data of a certain country (e.g., national population data, rates of urbanization, and average household sizes) are needed, which are required for the "Key Assumption" of the data tree in the model. Other useful data include the population by region, the male/female population, and the age structure of the population.

Economic data

These include the sectoral driving variables and more detailed driving variables, such as the GDP/value added, population, household size, production of energy-intensive materials (tons or $ steel), transport needs (pass-km, tonne-km), and income distribution.

General energy data

These include the characteristics of the energy supply, transport, and conversion facilities and the energy supply plans and energy resources and prices; the capital and O&M costs, performance (efficiencies, capacity factors, etc.), new-capacity online dates, costs, and characteristics; the fossil fuel reserves; and the potential for renewable resources. If these are not available in the country, they may be available from IEA's published energy statistics.

Demand data

- Activity levels: LEAP's demand analysis works by forecasting the future energy consumption as the product of two factors: the activity levels and the energy intensities. The activity levels are simply a measure of the economic activity in a sector, and the users can choose what data to use for this purpose. For example, in the household sector, the users may choose to use the number of households as the activity level; in the cement industry, the users might use tons of cement production; and in the transport sector, the users may choose to use tonne-km (for freight transport) and passenger-km (for passenger transport). The users will need to collect data describing the current, historical, and future projections of whatever data the users choose to use for their activity level variables. The users may need to consult national statistical reports or contact government or academic organizations working in specific sectors (industry, commerce, transport, households, etc.).

- Energy intensity data are often very hard to come by. If the users are preparing an aggregate analysis, they will likely be able to use their activity level data combined with the national energy consumption statistics and energy balances to calculate the historical energy intensity values by sector and by fuel. In other words, for historical data, *energy intensity = total energy consumption/activity level*. For their forward-looking scenarios, the users will instead use LEAP to calculate the total energy consumption by projecting the energy intensity and activity level. That is, *total energy consumption = energy intensity x activity level*.
- Other useful sources of energy demand data are the recent social surveys or energy consumption surveys that analyze how energy is consumed in different sectors of the economy, and reports from utilities and private companies on the sales of different energy forms (electricity, natural gas, oil products). If possible, try to get data disaggregated by sector and by consumer category.
- If the users are creating a more detailed analysis, they will likely also need information on the stocks, technical characteristics (efficiency, specific fuel consumption), costs, and environmental loadings of major energy-consuming devices in different sectors. For example, if the users want to focus on road transport energy use, they will need data describing the stocks

and sales of vehicles, their fuel economy, and some estimate of their average on-road life expectancy.

Transformation data

In general, transformation analysis requires that the users prepare a complete picture of how energy is extracted, converted, and transported in their energy system. This requires data on the flows of energy into and out of the major processes as well as information on the efficiency, costs (capital, operating and maintenance, and fuel costs), and environmental loadings associated with each major process.

• Electric sector: In general, the users will need data describing the current and historical installed capacities (MW), efficiencies, costs (capital, operating and maintenance, and fuel costs), and actual dispatch (MW-HR) of the various types of electricity generation plants in the country. The users will also need information on the seasonal load shape of their electric system and the maximum availability and dispatch priority of each different type of power plant. Capacity expansion plans, if they exist, can be very useful for establishing forecasts of how the electric system is likely to evolve in the future. In addition to collecting data on generation, the users should also collect data describing the transmission and distribution losses, including both the technical and non-technical losses. In many countries, combined heat and power (CHP) production is becoming increasingly important. The users may wish to analyze this sector separately from the dedicated electricity generation sector. For this sector, their data should include the production efficiency of both electricity and heat. In many countries, rural electrification is a key issue, so the users may wish to collect relevant data describing the rural electrification rates for the different geographic regions.

- Oil refining: If oil refining is an important sector, the users will need to collect data on the different products produced by the country's refineries, and the efficiency and capacity of the refineries.
- Extraction sectors: If extraction sectors such as coal mining or oil and gas production are important, the users will need data describing the efficiency and capacity of these sectors as well as information on the fuels produced and the energy consumed during extraction.
- Renewables: Renewable energy is becoming increasingly important in many countries and may be an important focus of any GHG mitigation analysis. Collect data describing the currently installed capacities, efficiencies, costs, and expansion plans for any relevant renewable energy, such as wind, geothermal, municipal solid waste, and solar energy.
- Biomass: If wood or other biomass fuels are important in the country, try to collect whatever data is available on the consumption and production of such fuels. Wood fuel surveys can be an important source of data for estimating the sustainability of the production of wood fuels.
- Other sectors: Other conversion sectors that may be important are charcoal making, ethanol production, and synthetic fuel production from coal.

Environmental data

- For a first-cut GHG mitigation assessment, the users may be able to rely on the basic “Tier 1” emission factors published by IPCC (and included in LEAP). As the users refine their analysis, however, they may wish to collect local emission factor estimates that reflect the fuel and technology characteristics of the devices used in their country. For example, the cars in a user’s country may have particular emission characteristics. It is particularly important to have data on the chemical composition of the fuels used in their country as these can be used to refine the emission factor estimates from different devices.

- IPCC’s online EFDB database is a key source of data on emission factors. This is available at <http://www.ipcc-nggip.iges.or.jp/EFDB/main.php>.

Fuel data

- LEAP includes a good default list of fuels and their characteristics (energy content, chemical composition) that should meet the needs of most studies. Be sure to adjust the energy, carbon, and sulfur contents in this list, however, to reflect the characteristics of the fuels used in the country. In particular, the characteristics of coal and biomass fuels vary greatly between (and even within) countries and uses. In addition to their physical characteristics, the users will also need data describing the production cost of any primary fuel produced in the country, and the import and export costs of any relevant fuel (Heaps, 2012).

3.1.3 Data collection for the Mongolian LEAP model

The Mongolian LEAP model was used in this study to forecast the future energy supply and demand based on several alternative scenarios of energy development planning that are advanced with different input components of energy resource, demand and policy, and distinctive approaches such as coal-oriented power generation, renewable-energy-based green energy system, and mixed features of energy resources.

According to the data requirements of the LEAP model, the necessary data were collected from different information resources, including Websites, statistics books, and reports of relevant trusted domestic organizations and international institutes. The National Starter Data of the LEAP model was very helpful at the stage of data collection as it had all the required general data of Mongolia collected from the database of the collaborating institutes, such as the World Bank, United Nations, International Energy Agency (IEA), and U.S. Energy Information Administration. These datasets were designed for developing-country energy planners, as a starting point for their analyses. Each dataset has been developed for a single country, and one dataset has been created for each country whose energy data are available from IEA.

Besides, despite the availability of information resources like the yearbooks of the National Statistics Office of Mongolia; the reports of the Ministry of Energy, National Dispatching Center, Petroleum Authority, and power generation companies; and other useful Websites, finding energy-intensive data from the domestic information resources was one of the limitations of this study. In some cases, data as international averages or from countries that have the same conditions or context as Mongolia were used in the analysis.

Table 3-1. Data Collection Sample

Data Type	2010 Value	Data Type	2010 Value	Data Type	2010 Value
Income	USD2065	Apartment vs. ger in UB	50% vs. 50%	Losses in distr.	Heat - 7.7%; electricity - 14%
Population	2,761 million	Construction	722.40 thou.m^2	Losses in distr.	Electricity - 3%
Household size	3.72 people	Road and bridge	0.43 km^2	Electricity import	157.5 mil. kWh
Households	742,300	Mining & quarrying	10.8 mil. tons	Electricity export	20.7 mil. kWh
GDP	5,701,460 thousand	Manufacturing	456.2 thou. tons	Exogenous capacity	947.3 MW
Income growth rate	3.5%	Transport	2.76mill. Person	Historical production	4445.9 mil. kWh
Pop growth rate	1.6%	Agriculture (crops)	315.3 thou. hectares	Coal export	16.7 mil. tons
Urban vs. rural	62.5% vs.37.5%	Losses in station own use	Heat - 5.72%; electricity - 16.6%	Electricity import cost	USD0.61/ kWh

The Mongolian LEAP dataset is divided into five sectors of energy demand: households, industry, transport, commercial & others, and agriculture, as shown in Figure 3-3. The household sector was split into two branches: urban (capital city, Ulaanbaatar, and other cities) and rural (centers of 21 provinces and soums).

The “main energy consumer,” the industry sector, has two categories: mining and quarrying, and manufacturing. The mining and quarrying sector consists of major mines such as Erdenet, Oyu-tolgoi, Tavan-tolgoi, and other mines considered the next decades’ big energy consumers. The manufacturing sector includes various types of factors pertaining to the raw materials of the mining industry, such as steel, iron, cement, and bricking, and also to resources from livestock, such as cashmere, wool, and tanning.

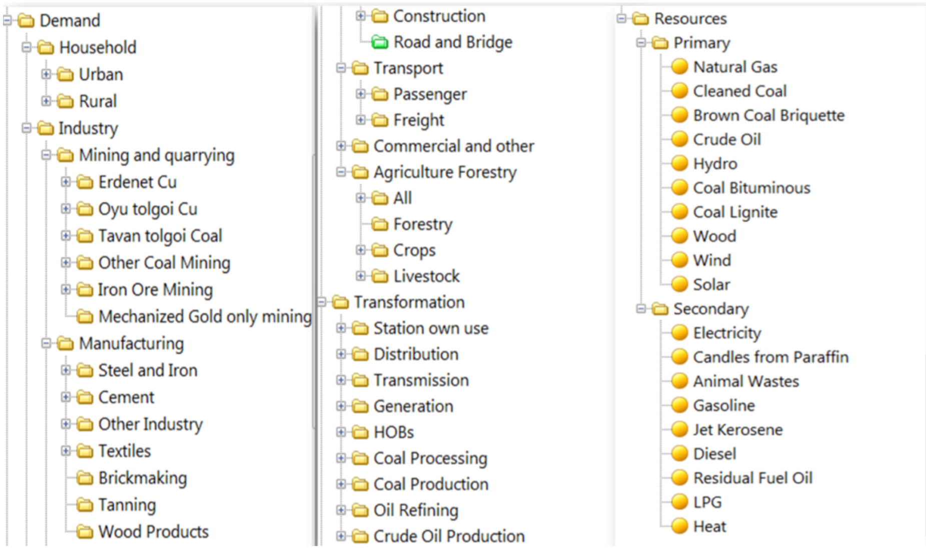

Figure 3-3. Mongolian LEAP model data branches.

In the transformation part of the dataset, all the subsectors are those that are involved in the conversion and transport of energy from the point of extraction of primary resources and imported fuels all the way to the point of final fuel consumption.

3.1.4 Building scenarios

Scenario development is different from forecasting, but the analysis presented here reevaluates how it is converging with the contemporary forecasting practice (Bunn, 199_).

To build scenarios for the future development of any sector, various issues of the social, economic, and energy sectors need to be considered beforehand, and based on such parameters or factors, different scenarios can be established, and the situations in each scenario can be analyzed. For instance, in a country's scenarios for energy development, to identify the kinds of energy trends that the country could follow in the future, the country's potential resources (e.g., energy resources), economic capability, and environmental sustainability could be considered.

Energy scenarios could be built based on the country's national strategies for long-term sustainable development and also on the results of the analysis of how the country's economy and environment will be affected in each scenario.

According to Roinioti (2012), there are four common trends in building energy scenarios, and along with these four trends, many different types of scenarios can be built.

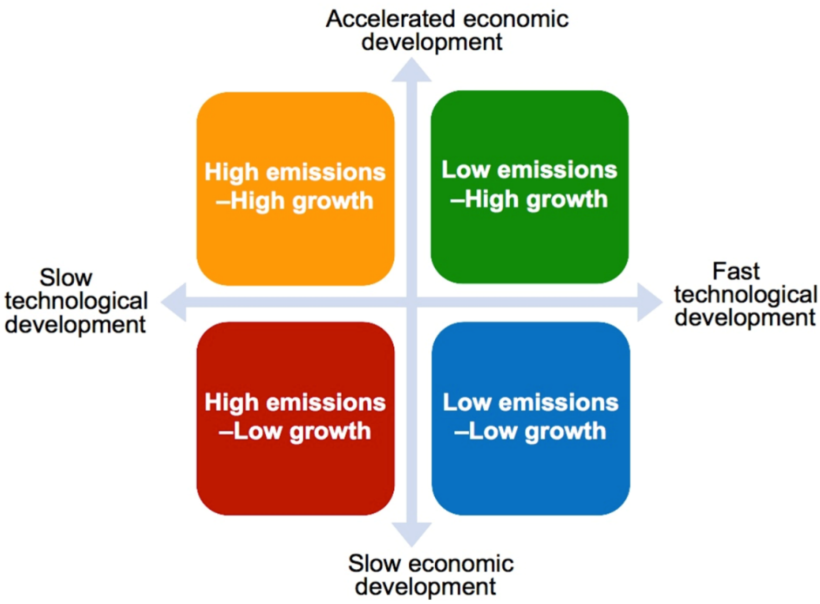

Figure 3-4. Principle of scenario creation.

In this research, three scenarios — the business-as-usual (BAU) scenario as reference, the energy efficiency (EE) scenario, and the renewable energy (REN) scenario — are assumed for the period 2010-2040 in Mongolia.

The BAU scenario reflects the impact of the existing policies and current technology levels on the future energy demand and energy choice of the country, and assumes which current trends in the development of new and renewable energy sources will continue into the future.

The EE scenario considers the potential for energy saving in both the demand and supply sides through the deployment of advanced and low-carbon technologies to increase the country's energy security.

The REN scenario aims to test the renewable energy target of Mongolia: "by 2020, 20-25% of the country's total power energy system should consist of renewable resources," which is reflected in the National Renewable Energy Program of Mongolia. The backcasting method, which is used in the REN and EE scenarios, helps determine the necessary policies, action plans, and financial and human resources that have to be taken or prepared to implement and achieve the targets.

In the BAU scenario, there are various existing policies, laws, regulations, and candidate power plant projects planned by the government of Mongolia in the energy sector. In the energy demand side, there are planned mega natural resource and infrastructure projects that are highly energy-intensive that are assumed as the base variables in the calculations of the scenario.

In the EE scenario, assumptions that can help reduce the energy demand and increase the use of energy-efficient technologies in the demand side while supporting generation technologies of renewable energy as low-carbon energy in the energy supply side to decrease the CO_2 emission and to ensure the diversification of the energy resource mix are reflected. For instance, the use of efficient and clean technologies for a building is a significant way of lowering the heat demand. In Mongolia, residential buildings use more heat energy than any other sector, and efforts to save energy for heating are also a key issue in the country. One of the assumptions in the EE scenario is efficient buildings, which can be described as buildings that have better technologies, such as better air sealing, triple-glazed low-e windows, dynamic solar control, and ultra-thin insulators for floors, windows, walls, and roofs.

Table 3-2. Principles of the Scenarios

	Business-as-Usual (BAU)	**Energy Efficiency (EE)**	**Renewable Energy (REN)**
Definitions	The government policies that had been enacted or adopted by 2013 continue unchanged, such as the plan to develop big mining projects and to build several coal-fired CHPs.	The government of Mongolia implements initiatives to reduce energy use and to conserve energy by using energy-efficient technologies. The Energy Conservation Law of Mongolia is still at the level of the Mongolian Parliament.	The government of Mongolia will pursue objectives that can help it achieve its renewable energy target of 20-25% by 2020.

Objectives	To provide a baseline that shows how the energy sector will evolve if the underlying energy trends will not be changed	To demonstrate a reasonable path towards exploring all ways of improving the country's energy efficiency that make economic sense	To test Mongolia's NREP, in which 20-25% of the total energy installed capacity will be renewable energy by 2020
Conditions	Government's long-term PPAs for new coal-fired condensing power plants at the least cost; HPP-300MW, which is already part of the government plan	Efficient lighting, reduced losses in T&D and station own use, energy-efficient buildings, diesel buses with CNG engines, and more natural-gas vehicles	Large-scale HPPs (Shuren-300 MW, Egiin-220MW, wind-250MW, and solar PV-400 MW) built, efficient lighting, reduced losses in T&D and station own use, and energy-efficient buildings

In the current government plan for the power generation industry, most of the projects in the list of preferred projects to be implemented are coal-fired CHP power plants, expect for the "Shuren" 300MW hydropower plant in Selenge River in northern Mongolia.

Table 3-3. Assumptions in All the Scenarios

Scenario/ indicator	Efficient lighting	Building energy efficiency	Losses in T&D		Diesel to CNG		Renewables		
			Electricity	Heat	Bus	Car	Solar	Hydro	Wind
BAU (current situation)	2%	District-90% Efficient-0%	14%	7.7%	Diesel-100% CNG-0%	CNG-0.3% Others-99.7%	1MW	23MW	50 MW
EE assumptions in demand	90%	District-10% Efficient-90%	8%	1.5%	Diesel-80% CNG-20%	CNG-20% Others-80%	N/A	N/A	N/A
REN assumptions in supply	N/A	N/A	N/A	N/A	N/A	N/A	400 MW	520MW	250 MW

Most of the projects that are currently at the stage of bidding and looking for financing are CHP#5, expansion of PP#4, refurbishment of PP#3, and expansion of Darkhan TPP, the 50MW Newcom wind farm, and the "Shuren" HPP.

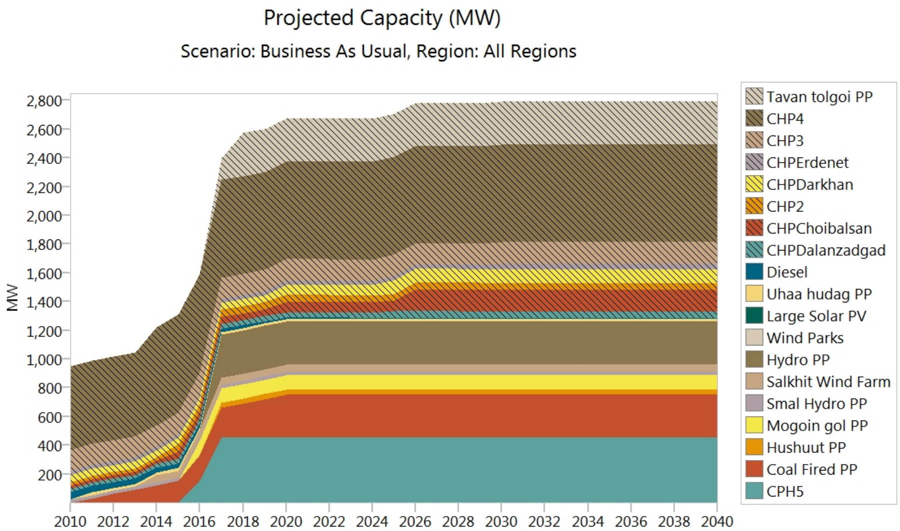

Figure 3-5. Projected capacity in the BAU scenario.

As planned in the BAU scenario, the renewable energy share in the total energy capacity could reach 13%, with a big contribution from the "Shuren" HPP and "Salkhit" wind farms, which means that Mongolia will not be able to accomplish its renewable energy target of 20-25% of its total installed capacity by 2020. The plants will be dispatched according to their specified merit orders as defined in the merit order[6] variables. Each plant will be run (if necessary) up to the limit of its maximum capacity factor in each dispatch period.

In contrast, more renewable energy projects are assumed to be

[6] The merit order is a way of ranking the available sources of energy, especially electrical generation, in ascending order of their short-run marginal costs of production.

implemented, such as the large-scale 400MW PV systems and a total of 250MW wind farms in the Gobi area, and also including two HPPs (Shure-300MW and Eg-220MW) in the REN scenario. In this case, the total installed RE sources account for 26% of the total capacity. Thus, with this scenario, Mongolia can achieve its goal. The potential to achieve the target is not the only positive aspect of implementing the REN scenario; its other benefits will be discussed in the results and analysis chapter.

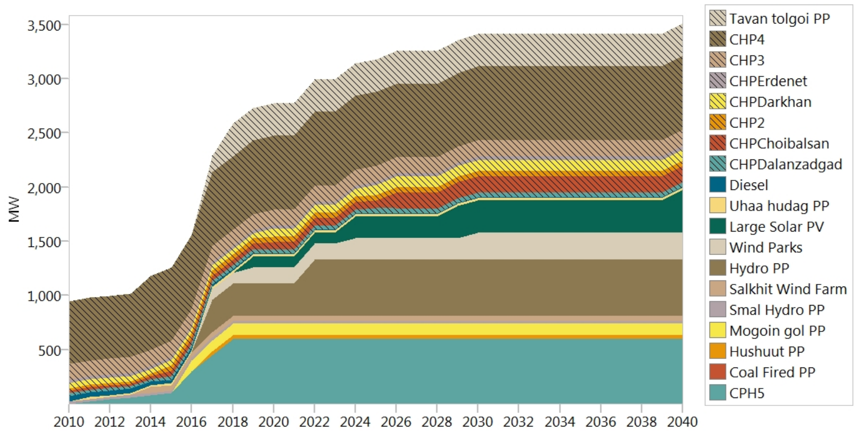

Figure 3-6. Projected capacity in the REN scenario.

The productions of the big mines (Tavan Tolgoi, Oyutolgoi, and others) mentioned above are projected to increase rapidly in the next decades, according to their development plans. For instance, the Oyu Tolgoi copper mine in South Gobi Desert, 80 km (50 mi) north of Mongolia's border with the People's Republic of China, where the mined copper is expected to be shipped, started to produce and export its copper and gold last July, and projected that it would reach its full capacity in 2018, which is 430,000 tons of copper per year, an amount equal to 3% of the global production. Also, its electricity consumption is expected to reach 300 MW when it is operated in full capacity.

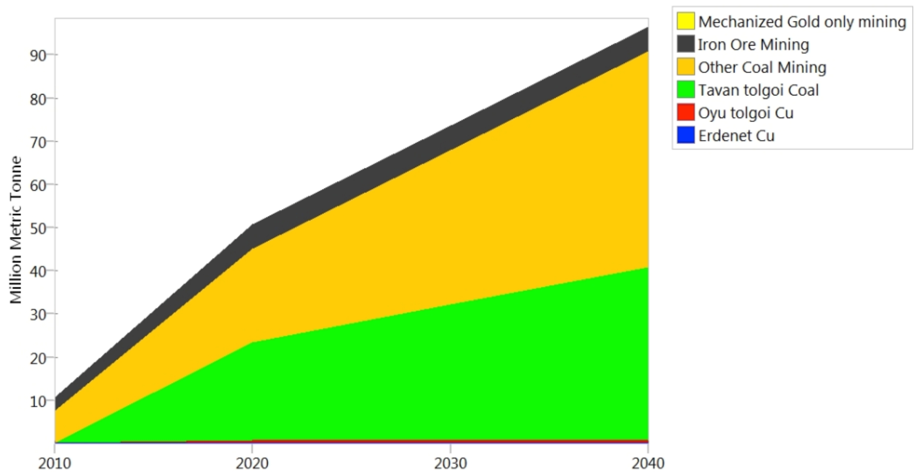

Figure 3-7. Projected mining production in Mongolia.

For the estimated mining production, it is assumed that the same amount will be produced in both the BAU and REN scenarios.

Chapter 4 – Results and Analysis

4.1 Energy Demand

It is assumed in the EE scenario that investing in efficient heating and lighting systems in household buildings and reducing station own use and the losses in energy transmission and distribution can result in 6.09 Mtoe energy savings compared to the BAU scenario.

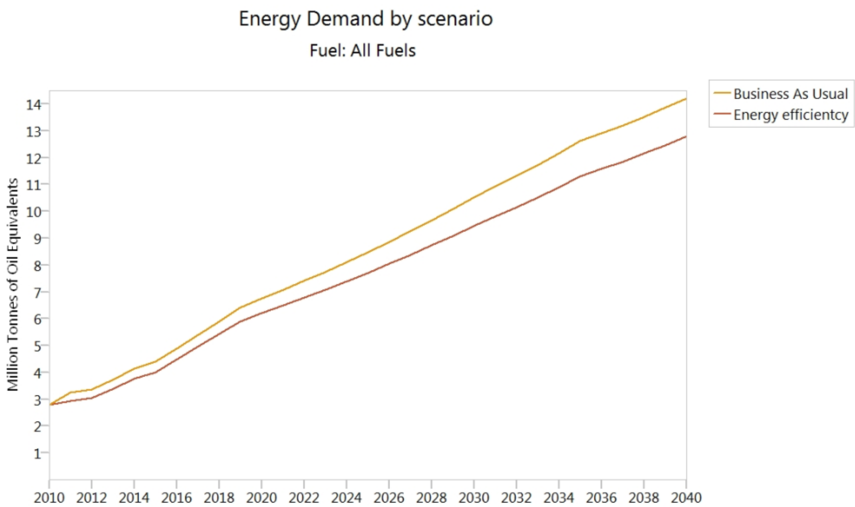

Figure 4-1. Energy demand by sector in the BAU and EE scenarios.

The total energy demand is expected to reach 14.39 Mtoe in 2040 in the BAU scenario, which is 4.53% higher than the 13.8 Mtoe in the EE scenario. (For detailed forecasting data, see Appendix A)

The industry and transport sectors are expected to be the main energy consumers in the next decades. These two sectors are expected to consume approximately 67.9% of the total energy by 2040.

Table 4-1. Energy Demand by Scenario (Unit: Mtoe)

Scenario/Year	2015	2020	2025	2030	2035	2040
Business-as-usual	4.48	6.68	8.61	10.69	12/79	14.36
Energy efficiency	4.40	6.75	8.47	10.53	12.61	14.21

By implementing activities for efficient lighting and building, the energy demand of households in the BAU scenario can be reduced in the EE scenario by 1.95 Mtoe energy. Increasing the use of an efficient heating system in households can also contribute to the reduction of the energy consumption and CO_2 emission in the household sector (Appendix E)

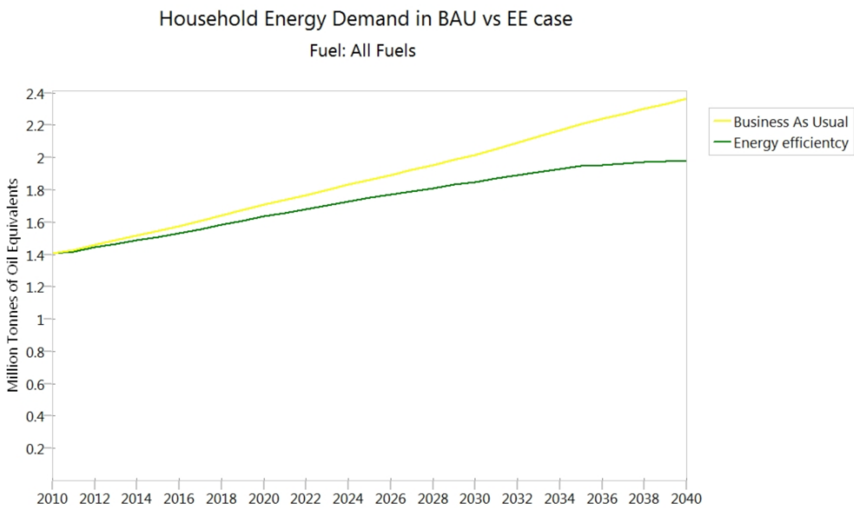

Figure 4-2. Energy demands of the BAU and EE scenarios in the household sector.

The growth in the transport sector, both passenger and freight, is expected to continue. Specifically, there has been a rising trend of buying private vehicles, which is the main factor that is expected to further increase the energy demand of the transport sector in the next decades. Figure 4-3 provides the details of the expected growth in the transport sector.

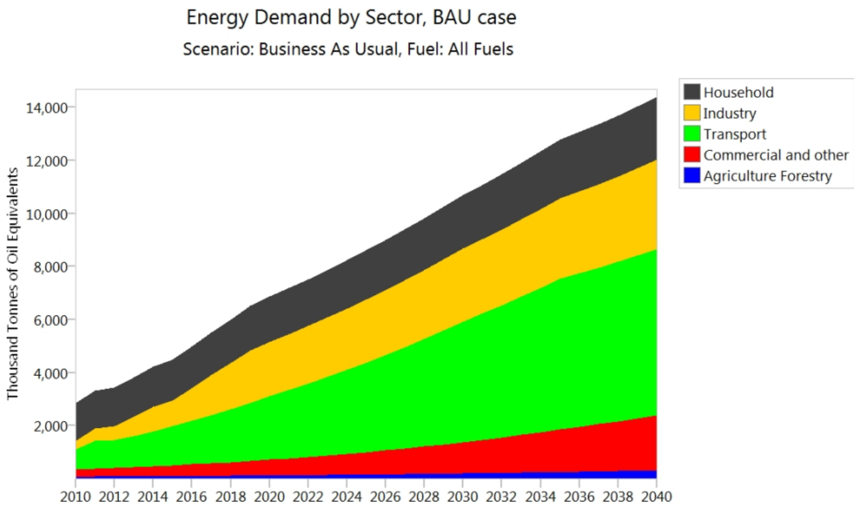

Figure 4-3. Energy demand by sector in the BAU scenario.

The electricity demand of the industrial sector will grow drastically due to the start of the operation of factories of mining and manufacturing facilities, including oil refining and iron ore. The government has a plan to establish an industrial park to produce value-added products in Mongolia. The "Tavan Tolgoi" 300MW coal-fired power plant is in the development stage; it is intended to supply Oyu Tolgoi Mine, which is now being supplied by the Inner Mongolia electricity system (Appendix D).

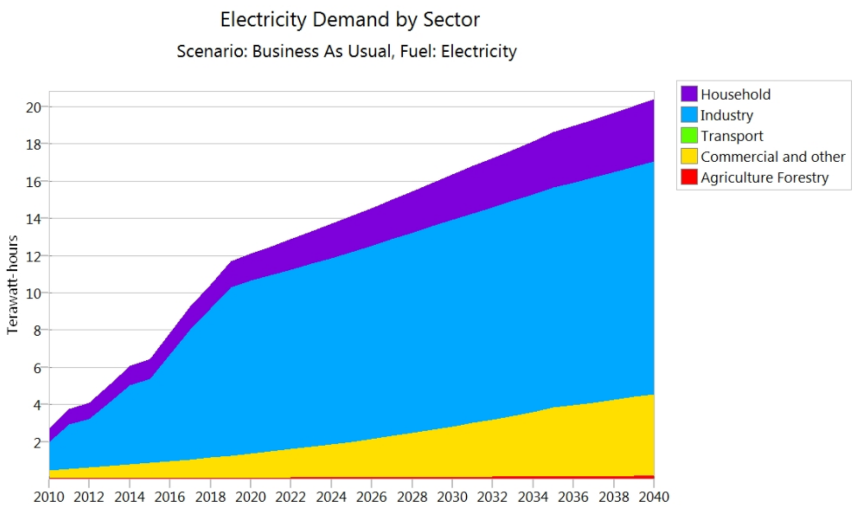

Figure 4-4. Electricity demand by sector in the BAU scenario.

Much of the electricity production will be generated by the coal-fired power plants that are built to produce only power energy. The existing TPP#3 and 4, the proposed power plants (Tavan-tolgoi-300MW, CHP5-450MW, and “Shivee Ovoo”-3600MW), and other power stations are projected as part of the government of Mongolia’s plan for the future electricity demand in the BAU scenario (Appendix H). The projects mentioned above are the energy projects that are likely to be executed in terms of the feasibility and current progress of the projects.

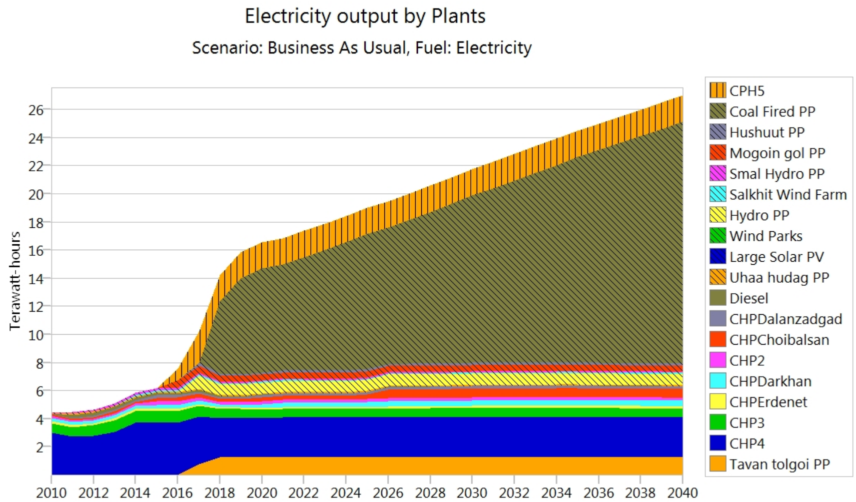

Figure 4-5. Projected electricity production of power stations in the BAU scenario.

The issues of heating shortage and the lack of facilities for extension are more serious than the electricity production. Besides, the heat consumption in the Ulaanbaatar area accounts for more than 80% of the total heat consumption. Another issue is the absence of reliable heating systems in the urban centers of the 21 aimags, where an industrial base has yet to be developed. The steam supplies could not support the ancillary heat and the electricity supplies to the local community. The heat usages of the consumers are basically classified as heating for apartment floors, and hot water is used for two purposes: as hot tap water and for space heating in the residential and industrial processes.

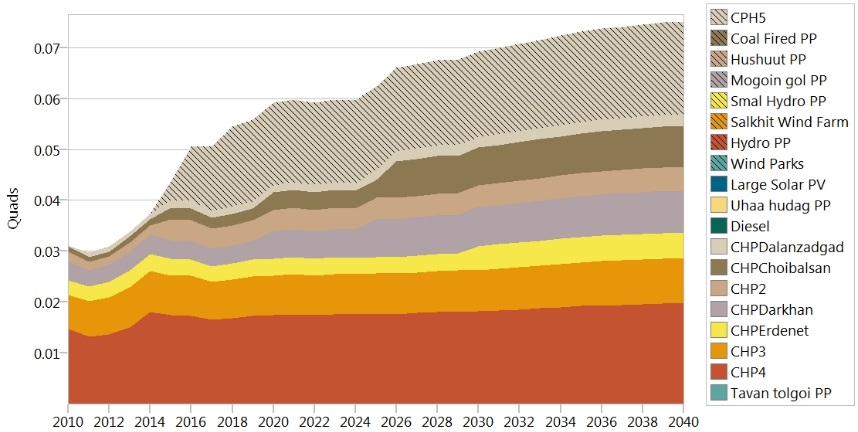

Figure 4-6. Heat production in the BAU scenario by plant.

The existing combined heat and power plants, CHP2, CHP3, CHP4, Darkhan, Erdenet, and the future CHP5, will remain major heat energy producers in CES for the next two decades. Figure 4-6 shows the projected heat production of the CHPs in the future (Appendix D).

In the EE scenario, the passenger sector is deemed to be a potential area where CO_2 emission and energy demand can be reduced. Given that CNG engine buses are expected to replace 20% of the existing diesel engine buses by 2040 from 0.3% in 2010, there would be a 10% CO_2 emission reduction compared to the 240.15 million metric tons of CO_2 in the BAU scenario. Figure 4-7 shows the CO_2 emission in the passenger sector in 2010-2040 (Appendix E, Appendix F, Appendix G).

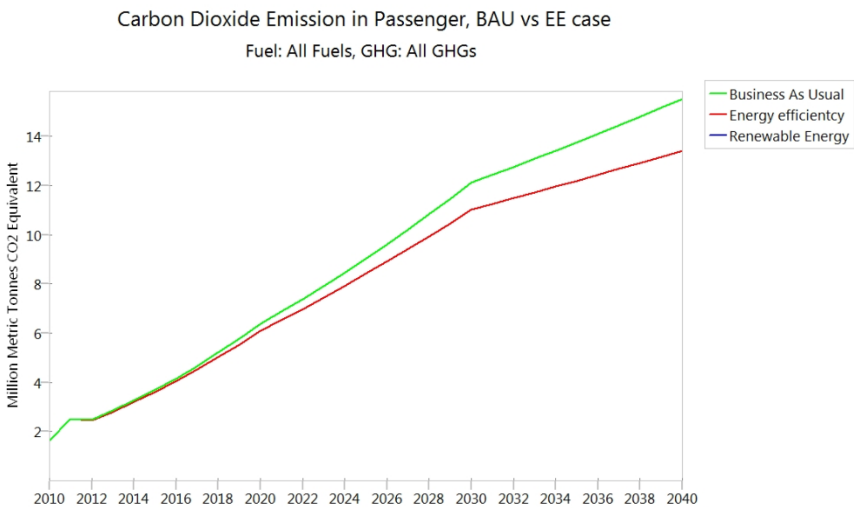

Figure 4-7. CO_2 emission in the passenger sector in the BAU and EE scenarios.

In terms of pollutant types, CO_2's non-biogenic effect will be the main pollutant among the elements, such as methane, nitrous oxide, carbon monoxide, and sulfur dioxide. The amounts of pollutant elements are compared and analyzed in Figure 4-8.

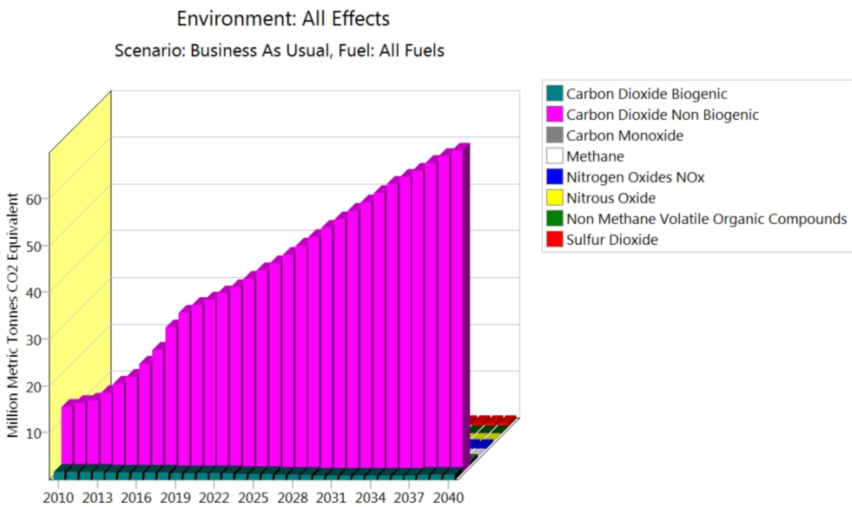

Figure 4-8. Environmental effects in the BAU scenario by pollutant.

The current CO_2 emission of energy transformation is 673.73 million metric tons, which is 18.6% higher than the 567.9 million metric tons CO_2 emission of the energy demand side in the BAU scenario. The dominant use of coal and its transformation process in the energy sector is expected to account for a large fraction of the above number in 2010-2040. In the above figure, the projected emissions of demand and transformation in the energy sector are compared.

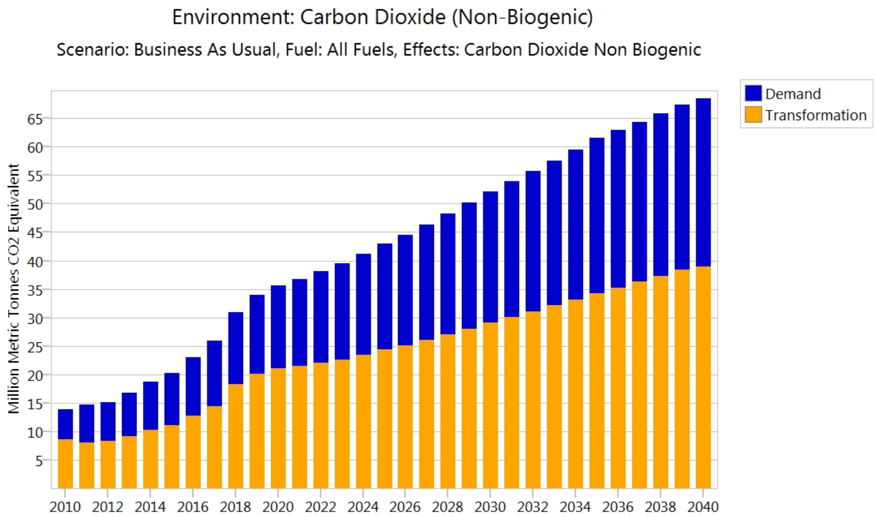

Figure 4-9. CO_2 emission of demand and transformation in the BAU scenario.

An additional USD1.48 billion is estimated to be needed to implement the REN scenario, in which large-scale renewable energy projects (hydro PP, wind farms, and solar PV systems) are assumed to be built. The additional cost is expected to be derived from the relatively high capital cost of renewable energy technologies. Financial support for the projects, however, like CDM and carbon trading, can cover the additional cost. The projected costs of the BAU and REN scenarios are shown in Figure 4-10. Apart from the financial cost comparison, there are other intangible benefits to the environment and society of more green energy projects that have to be taken into account for the scenario evaluation.

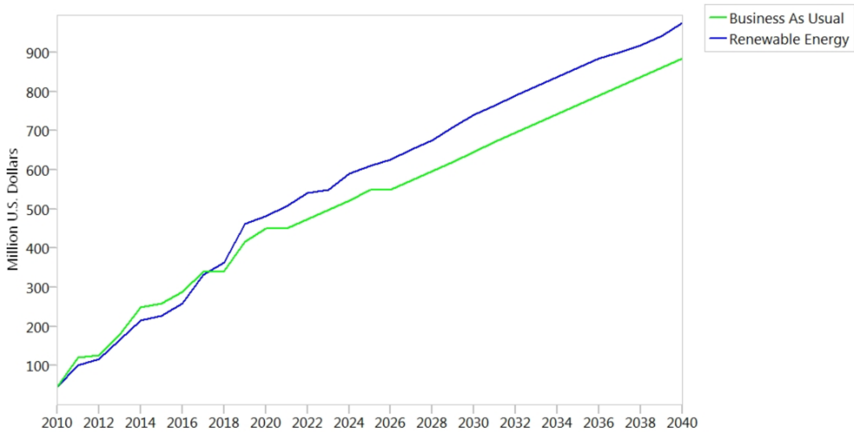

Figure 4-10. Transformation costs in the BAU and REN scenarios.

If the assumptions in the EE scenario will be implemented, the accumulated CO_2 emission will be decreased to 1273.65 million metric tons from 1321.64 million metric tons in the BAU scenario. For the REN scenario, it could reduce the emission more than the EE scenario could, with a difference of 32.05 million metric tons. The estimated CO_2 emission of REN is 1241.6 million metric tons, lower than that of the BAU scenario by 80.04 million metric tons. The CO_2 emissions of all the scenarios are forecasted in Figure 4-11 (Appendix E)

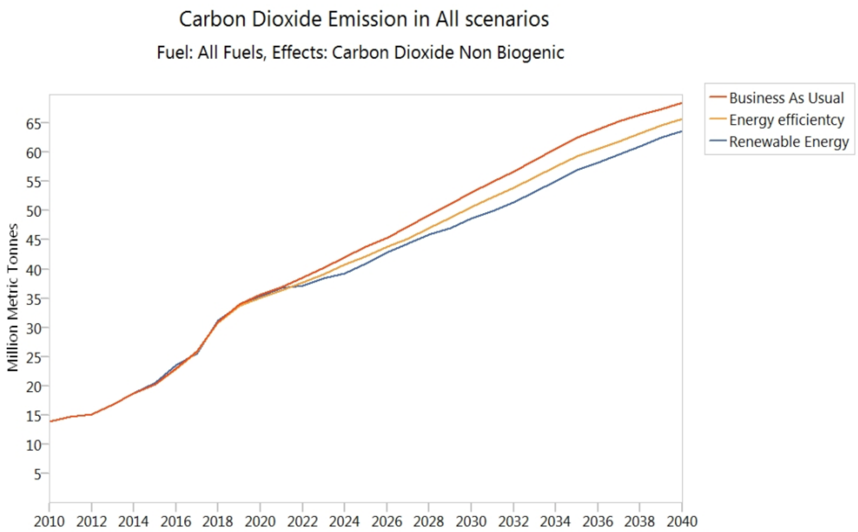

Figure 4-11. CO_2 emissions in all the scenarios.

Chapter 5 - Conclusions and Policy Implications

5.1 Conclusions

The industry and transport sectors are expected to still be the main energy consumers in the next decades. The demand of the sector will be 67.9% of the total energy demand by 2040. The development of big mine projects and the increasing number of vehicles in Mongolia are the main factors contributing to the increased demand.

In the REN scenario, the national renewable energy target — 20% of the total installed capacity by 2020 — can be achieved assuming that there will be more renewable energy deployment in the power generation industry.

Investing in improving the energy efficiency of buildings as well as of heating and lighting can save as much as 50.9 Mtoe energy. Also, reducing the losses in T&D and station internal use will help save energy.

The environmental impact issue of energy consumption (e.g., CO_2 emission) can be mitigated significantly in the combined EE-REN scenario. The CO_2 emission level in the combined scenario — 59.6 million tons of CO_2 — is 13.1% lower than that in the BAU scenario (68.51 million tons of CO_2).

Another promising sector where CO_2 emission and energy use can be reduced is the transport sector. Assuming that 20% of the existing buses will shift from a diesel engine to a CNG engine, and that up to 20% of all vehicles will use CNG (the current penetration rate of CNG cars is only 0.3%), by 2040, the EE scenario is expected to show a 10% higher CO_2 emission reduction compared to the BAU scenario.

Furthermore, while there already exist fuel-efficient vehicles, including hybrid, plug-in hybrid, and electric vehicles, the deployment of these vehicle technologies will face barriers like the lack of infrastructure development for fuel-charging stations, and insufficient incentives.

5.2 Policy Implications

Mongolia's abundant coal reserves make the Mongolian energy sector more dependent on fossil fuel, which accounts for about 70% of the primary energy consumption of the country, and 98.1% of the total power generation is being produced in coal-fired CHPs.

Not surprisingly, coal will be chosen as the main fuel for meeting the country's increasing demand from the perspective of energy security, economic benefits, and technical possibilities, but the impact of coal-fired CHPs on the environment is becoming more serious than ever. There is a possibility of applying carbon capture & storage (CCS), a technology that can significantly reduce the CO_2 emissions of coal-fired power plants, in the projected coal-fired power plants, but high cost and lack of deployment worldwide might constrain the efforts for CO_2 reduction in the power generation sector in Mongolia for the next few years.

The deployment of renewable energy (especially HPP, wind, and solar energy) can reduce the reliance on coal for energy generation in the face of the declining trend of the costs of renewable technologies.

Due to the intermittency of renewable energy, energy storage technologies (ESTs) are needed to fill the energy shortfall in the energy system.

Heat supply is important in Mongolia. Therefore, there is a need to increase the usage of other technologies that produce heat energy, such as heat pumps and boilers, if renewables are to replace the CHPs.

The government of Mongolia needs to revise or update the existing main policy and legal frameworks (e.g., Law on Energy, Law on Renewable Energy, Law on Mongolian Energy, etc.) to support the participation of the private sector in the energy sector.

Based on the energy plans, an energy sector investment structure with a clear mechanism that can describe the size and source of funds for projects must be established. In addition, a monitoring and evaluation system that can assess the performance of the targeted policy and programs based on the energy sector indicators needs to be established. More investment and actions are also needed to reduce the energy demand and to increase the energy efficiency in the sectors with great potentials, such as in achieving energy efficiency in buildings (heating system, building envelope, and lighting), district heating, and in reducing the electricity production, transmission, and distribution losses.

5.3 Future Research

In this thesis, the analyses of the three scenarios mentioned focused on the future energy demand and supply, and on the environmental effects (CO_2 emission) of those scenarios rather than on their costs. The data collection process was time-consuming and was a challenging part of the thesis due to the lack of information or data regarding Mongolia. Below are some important suggestions for the future research that can help make this thesis more comprehensive.

- Calculate and analyze the economic and social costs of the assumptions made in all the scenarios to determine if such assumptions can be implemented. Apart from the effects of energy technologies on energy security, their cost-effectiveness is also a critical factor for the energy planning policymaking of developing countries like Mongolia.
- Build more scenarios in the other sectors to expose the potentials to reduce the energy demand and the CO_2 emission, and also to increase energy efficiency, specifically in the sectors where more energy has been consumed and that are forecasted to have the same demand in the future, such as the mining and manufacturing industries (electricity demand), the vehicle passenger transport sector (oil demand), and the residential housing sector (heating demand for ger district heating and cooking). Also, increasing the electricity import can be another CO_2 reduction solution, but it will increase the level of energy security risk.
- Analyzing the possibility of reducing the CO_2 emission caused by energy-related activities was one of the purposes of this study, taking into account the fact that the CCS technology can radically reduce the CO_2 emissions of coal-fired power plants and industries in a county like Mongolia, where the use of coal dominates the power generation industry. The CCS technology can be introduced along with the construction of all the projected new coal-fired power plants, but the cost of additional fuel and storage as well as other system costs are valued at 30-60% of the total investment for the power plant, depending on certain conditions (McKinsey & Company, 2014).

Chapter 6 **References**

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Appendix A

Demand: Energy Demand Final Units
Scenario: Business As Usual, Fuel: All Fuels
Branch: Demand
Units: Million Tonnes of Oil Equivalents

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Household	1.41	1.46	1.52	1.58	1.64	1.71	1.77	1.83	1.89	1.95	2.02	2.09	2.17	2.24	2.3	2.37
Industry	0.33	0.53	0.91	1.24	1.74	2.04	2.17	2.31	2.45	2.6	2.76	2.86	2.97	3.09	3.21	3.36
Transport	0.76	1.05	1.32	1.63	1.99	2.39	2.76	3.16	3.59	4.05	4.55	4.99	5.45	5.8	6.02	6.27
Commercial and other	0.27	0.32	0.38	0.45	0.52	0.6	0.69	0.8	0.91	1.04	1.18	1.34	1.52	1.7	1.88	2.08
Agriculture Forestry	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.16	0.17	0.19	0.21	0.23	0.26	0.28	0.31

Demand: Energy Demand Final Units
Scenario: Energy efficiency, Fuel: All Fuels
Branch: Demand
Units: Million Tonnes of Oil Equivalents

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Household	1.41	1.46	1.52	1.58	1.64	1.7	1.76	1.81	1.85	1.9	1.94	1.99	2.04	2.08	2.1	2.13
Industry	0.33	0.53	0.91	1.24	1.74	2.04	2.17	2.31	2.45	2.6	2.76	2.86	2.97	3.09	3.21	3.36
Transport	0.76	1.05	1.31	1.61	1.96	2.35	2.7	3.07	3.47	3.9	4.37	4.77	5.19	5.5	5.7	5.92
Commercial and other	0.27	0.32	0.38	0.45	0.52	0.6	0.69	0.8	0.91	1.04	1.18	1.34	1.52	1.7	1.88	2.08
Agriculture Forestry	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.16	0.17	0.19	0.21	0.23	0.26	0.28	0.31

Appendix B

Demand: Energy Demand Final Units Scenario: Business As Usual Branch: Demand Units: Million Tonnes of Oil Equivalents																
	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Animal Wastes	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.14	0.14	0.14
Brown Coal Briquette	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Candles from Paraffin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coal Bituminous	0.16	0.24	0.46	0.64	0.93	1.09	1.15	1.2	1.26	1.32	1.38	1.4	1.42	1.43	1.44	1.44
Coal Lignite	0.53	0.56	0.58	0.6	0.63	0.66	0.69	0.72	0.75	0.78	0.81	0.86	0.9	0.95	0.99	1.04
Diesel	0.36	0.43	0.49	0.56	0.65	0.74	0.86	0.98	1.13	1.29	1.47	1.66	1.87	2.12	2.4	2.72
Electricity	0.24	0.35	0.52	0.67	0.9	1.04	1.11	1.18	1.25	1.33	1.41	1.48	1.56	1.63	1.69	1.76
Gasoline	0.47	0.72	0.94	1.2	1.5	1.83	2.13	2.44	2.78	3.14	3.53	3.84	4.16	4.36	4.41	4.47
Heat	0.54	0.62	0.69	0.78	0.86	0.96	1.06	1.17	1.29	1.42	1.56	1.71	1.86	2.02	2.17	2.35
Jet Kerosene	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.15	0.16	0.16	0.17
LPG	0	0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.09	0.09	0.1	0.1
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	0.37	0.35	0.34	0.32	0.31	0.3	0.28	0.26	0.24	0.22	0.2	0.19	0.19	0.19	0.2	0.2

Appendix C

Demand: Energy Demand Final Units
Scenario: Energy efficiency
Branch: Demand
Units: Million Tonnes of Oil Equivalents

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Animal Wastes	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.14	0.14	0.14
Brown Coal Briquette	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Candles from Paraffin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coal Bituminous	0.16	0.24	0.46	0.64	0.93	1.09	1.15	1.2	1.26	1.32	1.38	1.4	1.42	1.43	1.44	1.44
Coal Lignite	0.53	0.56	0.58	0.6	0.63	0.66	0.69	0.72	0.75	0.78	0.81	0.86	0.9	0.95	0.99	1.04
Diesel	0.36	0.43	0.49	0.56	0.64	0.74	0.85	0.98	1.12	1.28	1.47	1.65	1.86	2.11	2.39	2.72
Electricity	0.24	0.35	0.52	0.67	0.9	1.04	1.1	1.17	1.24	1.32	1.39	1.47	1.54	1.61	1.67	1.73
Gasoline	0.47	0.71	0.93	1.18	1.46	1.79	2.06	2.36	2.67	3	3.35	3.62	3.9	4.06	4.1	4.13
Heat	0.54	0.62	0.7	0.78	0.87	0.96	1.05	1.16	1.27	1.38	1.5	1.62	1.75	1.88	2	2.13
Jet Kerosene	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.15	0.16	0.16	0.17
LPG	0	0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.09	0.09	0.1	0.1
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0.01	0.01
Solar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	0.37	0.35	0.34	0.32	0.31	0.3	0.28	0.26	0.24	0.22	0.2	0.19	0.19	0.19	0.2	0.2

Appendix D

Demand: Energy Demand Final Units
Fuel: Electricity
Branch: Demand\Household
Units: Terawatt-hours

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Business As Usual	0.75	0.88	1.01	1.15	1.3	1.47	1.64	1.82	2.02	2.22	2.44	2.64	2.85	3.04	3.18	3.34
Energy efficiency	0.75	0.87	1	1.13	1.27	1.42	1.57	1.73	1.9	2.08	2.26	2.44	2.64	2.8	2.92	3.05
Renewable Energy	0.75	0.88	1.01	1.15	1.3	1.47	1.64	1.82	2.02	2.22	2.44	2.64	2.85	3.04	3.18	3.34

Demand: Energy Demand Final Units
Scenario: Business As Usual, Fuel: Electricity
Branch: Demand
Units: Terawatt-hours

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Household	0.75	0.88	1.01	1.15	1.3	1.47	1.64	1.82	2.02	2.22	2.44	2.64	2.85	3.04	3.18	3.34
Industry	1.52	2.6	4.27	5.74	8.02	9.28	9.65	10.01	10.38	10.75	11.13	11.4	11.68	11.96	12.23	12.52
Transport	0	0	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Commercial and other	0.44	0.58	0.73	0.9	1.09	1.3	1.54	1.79	2.07	2.38	2.72	3.09	3.5	3.84	4.12	4.41
Agriculture Forestry	0.04	0.04	0.04	0.05	0.05	0.06	0.06	0.07	0.08	0.09	0.09	0.1	0.11	0.13	0.14	0.15

Demand: Energy Demand Final Units. Fuel: Heat
Branch: Demand\Household
Units: Million Gigajoules

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Business As Usual	14.71	16.77	18.8	20.91	23.08	25.35	27.63	30.05	32.48	35.03	37.65	39.91	42.28	44.03	45.11	46.2
Energy efficiency	14.71	16.85	18.93	21.05	23.15	25.29	27.34	29.4	31.34	33.24	35.01	36.33	37.55	38.03	37.74	37.3
Renewable Energy	14.71	13.89	15.56	17.27	18.99	20.8	22.61	24.55	26.49	28.54	30.65	32.77	35	36.6	37.49	38.4

Appendix E

Demand: Energy Demand Final Units
Fuel: All Fuels
Branch: Demand\Transport\Passenger
Units: Million Tonnes of Oil Equivalents

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Business As Usual	0.48	0.73	0.96	1.23	1.53	1.88	2.18	2.5	2.85	3.22	3.61	3.93	4.26	4.46	4.52	4.57
Energy efficiency	0.48	0.73	0.95	1.21	1.5	1.83	2.11	2.42	2.73	3.07	3.43	3.71	4	4.17	4.2	4.23
Renewable Energy	0.48	0.73	0.96	1.23	1.53	1.88	2.18	2.5	2.85	3.22	3.61	3.93	4.26	4.46	4.52	4.57

Environment: Carbon Dioxide (Non-Biogenic)
Fuel: All Fuels, Effects: Carbon Dioxide Non Biogenic
Branch: All
Units: Million Metric Tonnes CO2 Equivalent

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Business As Usual	13.91	15.13	18.76	23.04	30.89	35.65	38.55	41.98	45.37	49.17	53.17	56.76	60.57	63.97	66.38	68.51
Energy efficiency	13.91	15.1	18.7	22.93	30.72	35.13	37.65	40.71	43.82	47.01	50.62	53.96	57.48	60.57	63.2	65.74
Renewable Energy	13.91	15.13	18.72	23.53	31.13	35.38	37.23	39.24	42.8	45.88	48.6	51.4	55.02	58.28	60.97	63.63

Environment: Carbon Dioxide (Non-Biogenic)
Fuel: All Fuels, Effects: Carbon Dioxide Non Biogenic
Branch: Demand
Units: Million Metric Tonnes CO2 Equivalent

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Business As Usual	5.38	6.78	8.55	10.31	12.63	14.6	16.1	17.69	19.38	21.18	23.1	24.66	26.32	27.62	28.55	29.56
Energy efficiency	5.38	6.77	8.53	10.25	12.54	14.46	15.9	17.44	19.05	20.76	22.57	24.03	25.57	26.78	27.63	28.56
Renewable Energy	5.38	6.78	8.55	10.31	12.63	14.6	16.1	17.69	19.38	21.18	23.1	24.66	26.32	27.62	28.55	29.56

Appendix F

Environment: Carbon Dioxide (Non-Biogenic) Scenario: Business As Usual, Fuel: All Fuels, Effects: Carbon Dioxide Non Biogenic Branch: Transformation\Generation\Processes Units: Million Metric Tonnes CO2 Equivalent																
	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
CPH5	0	0	0	1.09	2.48	2.45	2.5	2.49	2.5	2.51	2.51	2.51	2.51	2.51	2.5	2.5
Coal Fired PP	0	0	0	0	5.67	8.17	8.91	10.09	10.72	11.94	13.16	14.35	15.56	16.74	17.88	19.03
Hushuut PP	0	0	0	0	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Mogoin gol PP	0	0	0	0.52	0.4	0.39	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Uhaa hudag PP	0	0.08	0.09	0.09	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Diesel	0.05	0.21	0.19	0.15	0.08	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
CHPDalanzadgad	0.05	0.23	0.26	0.38	0.29	0.29	0.29	0.29	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
CHPChoibalsan	0.21	0.23	0.26	0.52	0.39	0.58	0.59	0.59	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
CHP2	0.42	0.35	0.4	0.93	0.7	0.7	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
CHPDarkhan	0.69	0.62	0.7	0.71	0.53	0.79	0.81	0.81	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
CHPErdenet	0.41	0.43	0.49	0.49	0.37	0.37	0.37	0.37	0.37	0.38	0.52	0.52	0.52	0.52	0.52	0.52
CHP3	1.49	1.8	2.03	2.04	1.54	1.52	1.55	1.55	1.55	1.56	1.56	1.56	1.56	1.56	1.56	1.55
CHP4	4.13	4.39	5.79	5.82	4.4	4.35	4.43	4.42	4.44	4.45	4.46	4.46	4.46	4.46	4.44	4.43
Tavan tolgoi PP	0	0	0	0	1.19	1.17	1.19	1.19	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2

Appendix G

Environment: Carbon Dioxide (Non-Biogenic) Scenario: Renewable Energy, Fuel: All Fuels, Effects: Carbon Dioxide Non Biogenic Branch: Transformation\Generation\Processes Units: Million Metric Tonnes CO2 Equivalent																
	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
CPH5	0	0	0	2.09	3.05	3.15	3.16	3.19	3.21	3.29	3.31	3.38	3.45	3.51	3.55	3.57
Coal Fired PP	0	0	0	0	3.02	4.22	4.55	4.83	5.32	6.17	6.63	7.45	8.3	9.19	9.92	10.5
Hushuut PP	0	0	0	0	0.18	0.18	0.18	0.18	0.18	0.19	0.19	0.19	0.2	0.2	0.2	0.2
Mogoin gol PP	0	0	0	0.5	0.49	0.5	0.5	0.51	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.57
Uhaa hudag PP	0	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.1	0.1	0.1	0.1	0.1	0.1
Diesel	0.05	0.21	0.19	0.14	0.1	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03
CHPDalanzadgad	0.05	0.23	0.25	0.37	0.36	0.37	0.37	0.37	0.5	0.51	0.52	0.53	0.54	0.55	0.55	0.56
CHPChoibalsan	0.21	0.23	0.26	0.49	0.48	0.75	0.75	0.76	1.56	1.6	1.61	1.65	1.68	1.71	1.73	1.74
CHP2	0.42	0.35	0.4	0.89	0.87	0.89	0.9	0.9	0.91	0.93	0.94	0.96	0.98	0.99	1.01	1.01
CHPDarkhan	0.69	0.62	0.7	0.67	0.66	1.02	1.02	1.03	1.38	1.42	1.43	1.46	1.49	1.51	1.53	1.54
CHPErdenet	0.41	0.43	0.49	0.47	0.46	0.47	0.47	0.48	0.48	0.49	0.69	0.7	0.72	0.73	0.74	0.74
CHP3	1.49	1.8	2.02	1.95	1.9	1.96	1.96	1.98	1.99	2.04	2.06	2.1	2.15	2.18	2.21	2.22
CHP4	4.13	4.39	5.77	5.56	5.41	5.6	5.61	5.66	5.7	5.83	5.88	6	6.13	6.22	6.3	6.33
Tavan tolgoi PP	0	0	0	0	1.46	1.51	1.51	1.53	1.54	1.57	1.59	1.62	1.65	1.68	1.7	1.71

Appendix H

Transformation: Outputs
Scenario: Business As Usual, Fuel: Electricity
Branch: Transformation\Generation\Processes
Units: Terawatt-hour

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
CPH5	0	0	0	0.82	1.87	1.85	1.88	1.88	1.88	1.89	1.89	1.89	1.89	1.89	1.89	1.88
Coal Fired PP	0	0	0	0	5.13	7.39	8.06	9.13	9.7	10.8	11.91	12.98	14.08	15.15	16.17	17.21
Hushuut PP	0	0	0	0	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Mogoin gol PP	0	0	0	0.55	0.42	0.41	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Smal Hydro PP	0.08	0.11	0.13	0.13	0.1	0.09	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Salkhit Wind Farm	0	0	0.11	0.11	0.09	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Hydro PP	0	0	0	0	0.78	0.77	0.78	0.78	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.78
Wind Parks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large Solar PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uhaa hudag PP	0	0.09	0.1	0.1	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Diesel	0.05	0.2	0.19	0.14	0.07	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
CHPDalanzadgad	0.02	0.1	0.11	0.17	0.13	0.13	0.13	0.13	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
CHPChoibalsan	0.11	0.12	0.13	0.26	0.2	0.3	0.3	0.3	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
CHP2	0.12	0.1	0.12	0.27	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
CHPDarkhan	0.26	0.23	0.26	0.26	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
CHPErdenet	0.13	0.14	0.16	0.16	0.12	0.12	0.12	0.12	0.12	0.12	0.17	0.17	0.17	0.17	0.17	0.17
CHP3	0.67	0.72	0.81	0.81	0.61	0.61	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
CHP4	3	2.81	3.72	3.73	2.82	2.79	2.84	2.84	2.85	2.85	2.86	2.86	2.86	2.86	2.85	2.84
Tavan tolgoi PP	0	0	0	0	1.25	1.23	1.25	1.25	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.25

Appendix I

Transformation: Outputs
Scenario: Renewable Energy, Fuel: Electricity
Branch: Transformation\Generation\Processes
Units: Terawatt-hours

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
CPH5	0	0	0	1.57	2.3	2.38	2.38	2.4	2.42	2.48	2.5	2.55	2.6	2.64	2.67	2.69
Coal Fired PP	0	0	0	0	2.73	3.82	4.12	4.37	4.81	5.58	6	6.74	7.51	8.31	8.97	9.49
Hushuut PP	0	0	0	0	0.18	0.19	0.19	0.19	0.19	0.2	0.2	0.2	0.21	0.21	0.21	0.21
Mogoin gol PP	0	0	0	0.52	0.51	0.53	0.53	0.53	0.54	0.55	0.55	0.57	0.58	0.59	0.59	0.6
Smal Hydro PP	0.08	0.11	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14
Salkhit Wind Farm	0	0	0.17	0.16	0.16	0.17	0.17	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.19	0.19
Hydro PP	0	0	0	0	0.96	0.99	1.72	1.73	1.75	1.79	1.8	1.84	1.88	1.91	1.93	1.94
Wind Parks	0	0	0	0	0.32	0.5	0.5	0.67	0.67	0.69	0.87	0.88	0.9	0.92	0.93	0.93
Large Solar PV	0	0	0	0	0	0.33	0.33	0.67	0.67	0.69	1.04	1.06	1.08	1.1	1.11	1.49
Uhaa hudag PP	0	0.09	0.1	0.09	0.09	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.11	0.11	0.11
Diesel	0.05	0.2	0.19	0.14	0.09	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03
CHPDalanzadgad	0.02	0.1	0.11	0.17	0.16	0.17	0.17	0.17	0.23	0.23	0.23	0.24	0.24	0.25	0.25	0.25
CHPChoibalsan	0.11	0.12	0.13	0.25	0.25	0.38	0.38	0.38	0.8	0.81	0.82	0.84	0.86	0.87	0.88	0.88
CHP2	0.12	0.1	0.12	0.26	0.26	0.26	0.26	0.27	0.27	0.28	0.28	0.28	0.29	0.29	0.3	0.3
CHPDarkhan	0.26	0.23	0.26	0.25	0.25	0.38	0.38	0.38	0.52	0.53	0.53	0.54	0.56	0.56	0.57	0.57
CHPErdenet	0.13	0.14	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.22	0.23	0.23	0.23	0.24	0.24
CHP3	0.67	0.72	0.81	0.78	0.76	0.78	0.78	0.79	0.8	0.81	0.82	0.84	0.86	0.87	0.88	0.88
CHP4	3	2.81	3.7	3.57	3.47	3.59	3.6	3.63	3.65	3.74	3.77	3.85	3.93	3.99	4.04	4.06
Tavan tolgoi PP	0	0	0	0	1.53	1.58	1.59	1.6	1.61	1.65	1.66	1.7	1.74	1.76	1.78	1.79

장기 에너지 대체 계획 시스템(LEAP) 모델을 사용한 몽고의 에너지 수요와 공급에 대한 장기 예측

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초록

제대로 관리될 경우 풍부한 천연자원으로 인해 독립적, 지속적이며 청정한 에너지 개발의 가능성이 크기 때문에, 에너지 수요 및 공급에 대한 장기 예측은 몽고에서 매우 중요한 주제 중의 하나이다. 본 학위 논문에서는, 몽고의 에너지 분야에 대한 현재 상황과 경제 및 환경에서의 역할 및 공헌에 대한 개요, 그리고 해당 분야의 포괄적인 평가까지도 제시하고 있다. 가장 중요한 점은, 몽고에서의 향후 에너지 수요 및 공급을 예측하고, 경제적 발전, 환경적 지속성 및 에너지 안보를 지속할 수 있는 가능한 시나리오들을 구축 및 비교하기 위하여 장기 에너지 대체 계획 시스템(LEAP) 모델을 사용하였다는 점이다.

본 학위 논문에서는, 2040 년까지 몽고에서의 장기 에너지 개발에 대한 세 가지 시나리오가 LEAP 모델을 통하여 구축되었으며, 2010 년이 기준 년으로 설정되어 있다. 에너지 수요 및 공급의 예측은 평상시 대로(BAU)의 사례에 따라 기존의 국가 에너지 계획 및 동향을 기준으로 한 것이며, 수력, 풍력 및 태양 에너지와 같이 몽고에서 사용 가능한 재생성 에너지 자원들을 기준으로 한 구성은 재생성 에너지(REN) 시나리오에서 제시된 대로이며, 에너지 효율(EE) 시나리오에서 가정 및 분석된 경제적 관점에 따라 에너지 효율이 향상되는 것으로 하였다. 각 시나리오는 상이한 특성을 보이며 명확히 구분되는 개발 경로를 나타낼 수 있으며, 이는 몽고의 에너지 분야로 적용될 수 있을 것이다.

학번 2012-22599

키워드: LEAP, 에너지 계획, 시나리오, 몽도, BAU, EE 및 REN

M.S. Thesis in Engineering

The Long-Term Forecasting of the Mongolian Energy Demand and Supply Using the Long-Range Energy Alternatives Planning System (LEAP) Model

장기 에너지 대체 계획 시스템(LEAP) 모델을 사용한 몽고의 에너지 수요와 공급에 대한 장기 예측

February 2014

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The Long-Term Forecasting of the Mongolian Energy Demand and Supply Using the Long-Range Energy Alternatives Planning System (LEAP) Model

지도교수 허은녕

이 논문을 공학석사학위 논문으로 제출함

2014 년 02 월

서울대학교 대학원

협동과정 기술경영경제정책전공

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Jambaa Lkhagva 의 석사학위 논문을 인준함

2014 년 02 월

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The Long-Term Forecasting of the Mongolian Energy Demand and Supply Using the Long-Range Energy Alternatives Planning System (LEAP) Model

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Abstract

The long-term forecasting of energy supply and demand is one of the most important topics in relation to Mongolia due to the country's abundant natural resources, which offer great opportunities for achieving independent, sustainable, and green energy development if managed properly. In this thesis, an overview of the current situation of Mongolia's energy sector and its role and contribution in the country's economy and environment, and a comprehensive assessment of the sector, are provided. Most importantly, the long-range energy alternatives planning system (LEAP) model was used to forecast the future energy supply and demand and to build and compare possible scenarios that could sustain economic development, environmental sustainability, and energy security in the country.

In this thesis, three scenarios for long-term energy development in Mongolia by 2040 were built using the LEAP model, and 2010 was set as the base year. The forecasting of the energy demand and supply was shown as a business-as-usual (BAU) scenario, based on the existing national energy plans and trends, and a configuration based on the renewable energy resources available in Mongolia, such as hydro, wind, and solar energy, were suggested as the renewable energy (REN) scenario while improving the energy efficiency in every way that makes economic sense was assumed and analyzed in the energy efficiency (EE) scenario. Each scenario can represent a distinctive development pathway with different characteristics, which can be applied to Mongolia's energy sector.

Student No. 2012-22599

Keywords: *LEAP, energy planning, scenario, Mongolia, BAU, EE, and RE*

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Chapter 1 - Introduction

1.1 Purpose of the Study

> The word "energy" incidentally equates with the Greek word for "challenge." I think there is much to learn in thinking of our federal energy problem in that light. Further, it is important for us to think of energy in terms of a gift of life.
>
> \- Thomas Carr

Energy is one of the factors underlying the social and economic development of any country. Due to the environmental impact of energy production activities, the governmental policies on the issues of energy security and energy planning have been drastically shifting to more sustainable, efficient, cleaner, and safer energy production.

Regardless of the amount of wealth and power of any country, the transition from a fossil-fuel-based energy system to a green energy system entails various economic, social, and technical challenges and problems that require effective, committed, and clear planning and interventions, and solutions to the problem of resources.

As World Energy Council[1] (WEC) defined the three energy goals as accessibility, availability, and acceptability, national development plans for long-term design investments in the energy sector should be assessed on whether they could accomplish all the aforementioned goals and meet the

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[1] World Energy Council is the world's principal network of energy leaders and practitioners. It has been headquartered in London since its founding in 1923. <http://www.worldenergy.org>

requirements of the three fundamental dimensions and keep an appropriate balance among them.

Driven by an economy based on natural resources and infrastructure development, the Mongolian energy demand is expected to increase substantially over the next few decades, particularly in the southern part of the country, where there are many mega natural resource projects being implemented and planned to be started in the coming years. The development of mega projects involving coal, copper, gold, iron ore, and uranium mining can dramatically increase the energy demand in the following decades but can also play a vital role in facilitating economic and social development.

The energy security issue is the first priority among the energy concerns associated with Mongolia's energy sector development as due to the country's high dependence on fossil fuel (98% of its oil is being imported from Russia, whose future pricing and long-term availability are always uncertain) and aging energy facilities, especially those of the power generation sector, such issue is more serious than the others in the country. In addition to the above issue, the environmental impact of energy industry production and its significant contribution to the country's CO_2 emission are raising more concerns.

Investment in the energy sector requires a huge amount of money and long-term planning to get a return on investment, which is complex, capital-intensive, and largely irreversible. A simple example of this is the fact that the energy sector cost investment efficiency can increase through overinvestment, which is frequently caused by overestimating the energy demand; in contrast, inadequate investment, which is often caused by underestimating the energy demand, can result in an imbalance between the demand and supply of energy, which can affect the economy adversely.

Considering the foregoing, any policy decision and investment planning on energy sector development has to be done while keeping in mind that the existing energy consumption and the forecasted future energy demand can fulfill all the investment requirements. It is critical and challenging, however, to make such policy decisions in a country that has no national energy sector development plan, which must be formulated based on the precisely forecasted long-term energy demand, which is influenced by various factors, such as the demographic changes, natural-resource development, and infrastructure.

Coal for power generation and oil for transportation are the primary fuels being used by the Mongolian energy industry. The fact that such fuels' prices are in a state of uncertainty has been stunting the growth of the Mongolian economy, which has been heavily dependent on the export and import of fossil fuels in areas that had been full of volatility and uncertainty over the last decades. Moreover, the abundant renewable energy sources in Mongolia can enable the country to diversify its energy resource mix, which is the fundamental principle of energy security for the long term.

Thus, the development of a scenario for a long-term energy planning system that can benefit both the environment and the people is crucial in Mongolia.

In this context, this research aimed to forecast the future energy demand of Mongolia and to identify alternative supply options that include different energy resource combinations and policy implications by building scenario. All the assumptions made in this study were analyzed in terms of energy demand and CO_2 to determine the benefits of such assumptions to Mongolia's energy sector and environment.

1.2 Research Motivation

Energy dependence issue

One hundred and 11% of the oil and electricity consumed in Mongolia, respectively, are imported from Russia, China, and other countries (Ministry of Energy, Mongolia, 2012). The reason that Mongolia is dependent for its energy needs on other countries is not the lack of resources in the country but the Mongolian government's lack of political will to address such issue, and the lack of accurate planning by the government for the energy sector. Mongolia has great potential to supply 100% of its current energy demand at all the scenarios built in this thesis in terms of energy resources. It has significant coal resources (approximately 173 billion tons), and according to the National Renewable Energy Programme of Mongolia (NREP), it has 6.2 GW renewable-energy potential; a high wind density (400-600 W/m^2), which covers almost 10% of the total land area, with an estimated potential of 1100 GW; applicable solar energy resources for both solar power and heating amounting to 5.5-6.0 kW/m^2 per day in the Gobi area for the 270 sunny days in a year; and 74,000 tU in reasonably assured resources plus inferred resources.

Coal-fired CHPs produce 98.1% of the power generated, causing an increase in CO_2 emission

Although Mongolia has sufficient amounts of primary energy resources to supply a sustainable energy system over the next decades, the environmental and ecological issues caused by the use of the conventional energy system should be taken into account in the energy policy formulation and planning, in line with the global trends of the use of environment-friendly energy systems.

As it has a small energy market, Mongolia is not a large greenhouse gas (GHG) emitter; its contribution to the global GHG emission is not as considerable as those of its neighbor countries China and Russia, but its total GHG emission generally increased in line with the global trend for the past eight years, growing steadily at 3.62% from a total of 7.9 million metric tons in 2005, down from the record high of 11.37 million metric tons in 1991 (Madrigal, 2008).

Looking for and developing renewable energy sources and improving energy efficiency are significant ways of mitigating the problems

The availability of renewable energy sources in Mongolia and the country's relatively small energy market can enable the country's energy sector to become more eco-friendly, green, and efficient. The diversification of energy resources is an important issue in energy planning for the long term. This will result in significant energy security and economic benefits.

1.3 Research Questions

- What are the most suitable solutions to sustainable economic growth and green energy, and what are the results of their implementation?
- What are the institutional and legislative implications of the successful

implementation of such solutions, and the essential changes needed from the government of Mongolia?

1.4 Mongolia's Geographic, Economic, and Government Policies

Geographic policies

Mongolia is situated in central Asia and is bordered on the north by Russia and on the south by China. It is located at approximately 106.5 degrees east longitude and 47.6 degrees north latitude, and its land area is approximately 1.567 million km^2.

The population of Mongolia is estimated to be 2.8 million (2010). Its capital is Ulaanbaatar, with a population of more than 1.2 million.

Mongolia has a continental climate. In general, the winter season is cold and dry whereas the summer season is warm, with occasional precipitation. The climatic conditions vary across the country and with elevation. There are large variations in the seasonal and diurnal temperatures. In Ulaanbaatar, January (the coldest month of the year) has an average temperature of -26^{o}C, with an average low of -32^{o}C and an average high of -19^{o}C. In July (the warmest month of the year), the average temperature is 17^{o}C, with an average low of 11^{o}C and an average high of 22^{o}C.

Population

The population growth (annual %) in Mongolia was last reported at 1.62% in 2010, according to a World Bank report released in 2011. Two thirds of the Mongolian population is below 30 years old, and two fifths of the population is 14 years old or below. Much of the population growth of Mongolia has been absorbed by the urban areas, but a significant part of the urban population still lives in gers/national dwellings/habitations in the town peripheries. While the average population density of the country is just over 1 person per sq. km, the population density of Omnogov' aimag is only 0.2 per sq. km.

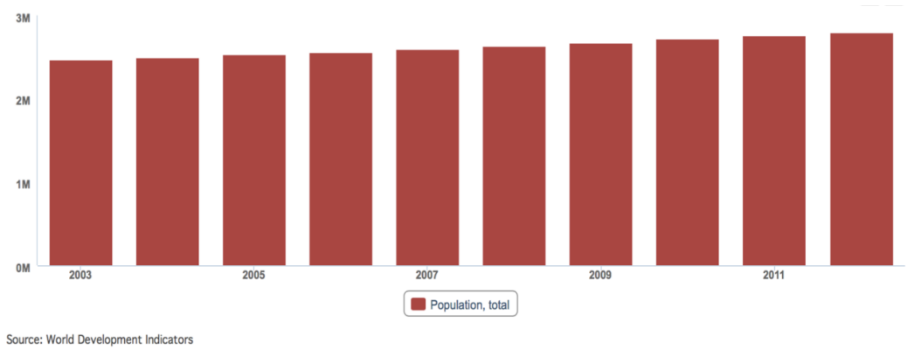

Figure 1-1. Population of Mongolia (2003-2011).

Economy and energy

Historically, the Mongolian economy and its activities have been based on agriculture and herding; Mongolia’s extensive mineral deposits, however, have attracted foreign investors. The country holds copper, gold, coal, molybdenum, fluorspar, uranium, tin, and tungsten deposits, which account for a large part of its foreign direct investment (FDI) and government revenue

(Forbes, 2011).

As shown in Figure 1-2, mining and agriculture are the main industries of Mongolia and have large shares in the country's GDP. In 2011, mining production accounted for 22% of the total GDP, and agricultural production, 13%.

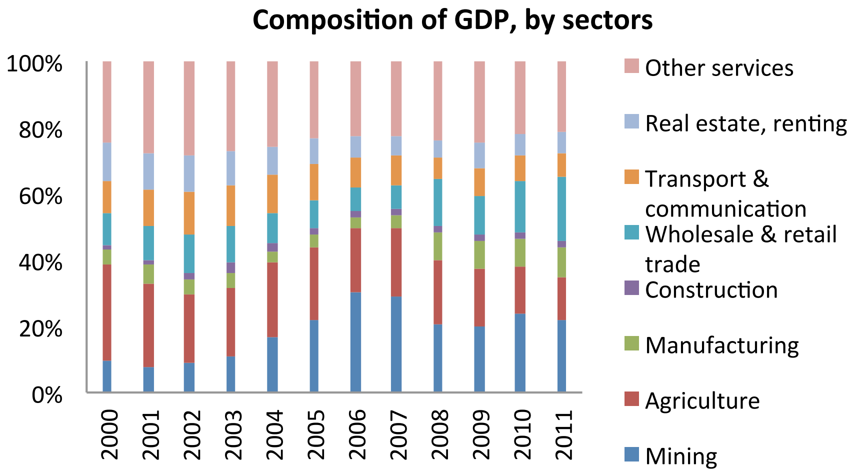

Figure 1-2. Mongolian GDP composition by sector

The total foreign trade turnover was USD11.4 billion in 2011. The main exports are mineral products, and the main imports are mineral products, machinery, equipment, vehicles, and food products. The Mongolian exports experienced significant growth in value and in volumes in the last few years. The coal exports went from virtually zero in 2000 to over 21 million tons in 2011 (National Statistical Office of Mongolia, 2012).

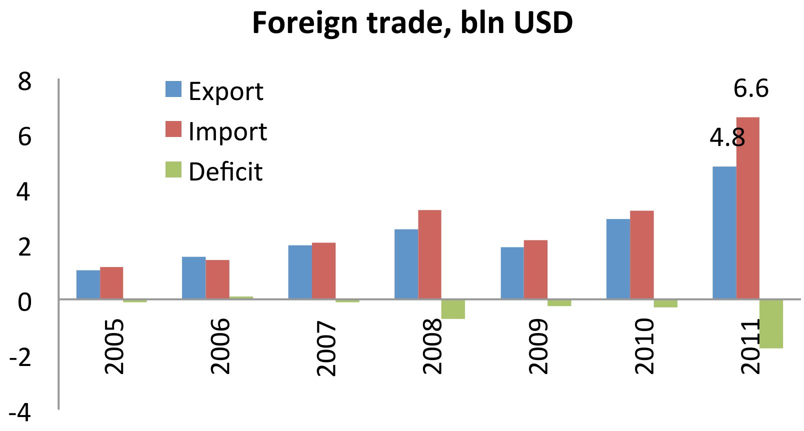

Figure 1-3. Foreign trade balance of Mongolia (2005-2011)

Traditionally, the great majority of Mongolia's exports are intended for China (85% in 2010, up from 64% in 2008), and the dominance of this market is illustrated in Figure III-2 below. The remaining 15% of the exports go to the EU member states (27 countries) and Russia.

Source: National Statistical Office of Mongolia

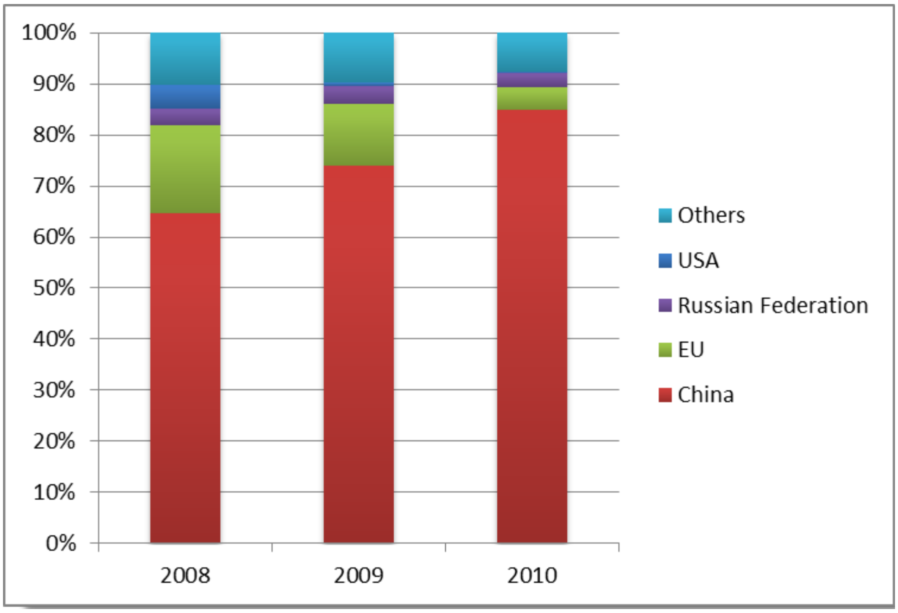

Figure 1-4. Mongolia's exports y country or region (2008-2012)

Even if the industries and agriculture that have significant contributions to the GDP are not yet mature or labor- or resource-intensive, most of them depend on conventional, mature technologies. Therefore, much government support is needed for such industries to sustain their production and to be able to compete in the market.

There are several official documents that have been approved by the Mongolian parliament for the infrastructure development plan, including the Millennium-Development-Goals-(MDG)-based Comprehensive National Development Strategy of Mongolia, the Action Plan of the Government of Mongolia for 2012-2016, the Action Strategy and Formation Plan of National Development, and the Plan for the Establishment of the Innovation Committee.

The Mongolian energy sector is one of the strategic sectors in the country, with the changes in the electricity and oil prices dictating the prices of all the commodities in the country.

Environment and energy

According to the World Bank data, the per-capita energy consumption and the GHG emission from energy production (Figure 1-4) in Mongolia are constantly increasing due to the country's rapid resource-based economic development. This situation has elicited warnings that clean, green energy systems, which have environment-friendly and efficient energy production technologies, are fundamental elements that must be considered to solve the country's environmental issues. Mongolia has no obligation to reduce its CO_2 emission under the Kyoto Protocol, but voluntarily efforts and initiatives to reduce CO_2 emission have been intensely promoted in the country in the last few decades due to the increasing air pollution in Ulaanbaatar.

Therefore, the government of Mongolia has been trying to support a more eco-friendly energy system. It established a policy that aims to shift from the use of highly polluting fossil fuel to low carbon energy resources like hydro, solar, and wind energy. A particular target has been set in the National Renewable Energy Program: 20% of the country's energy base has to come from renewable-energy production by 2020-2025. In addition, the feed-in tariff (FIT) was inserted in the Mongolian Law on Renewable Energy as an incentive to support the provision of additional capacity in the medium term.

Another environmental issue in the energy sector is water usage for power generation. Coal-fired generators are intensive water users, and while the regional imbalances can be improved through water infrastructure development, the long-term impact on the whole water balance in the country is usually studied during the feasibility study stage of specific power plant development projects.

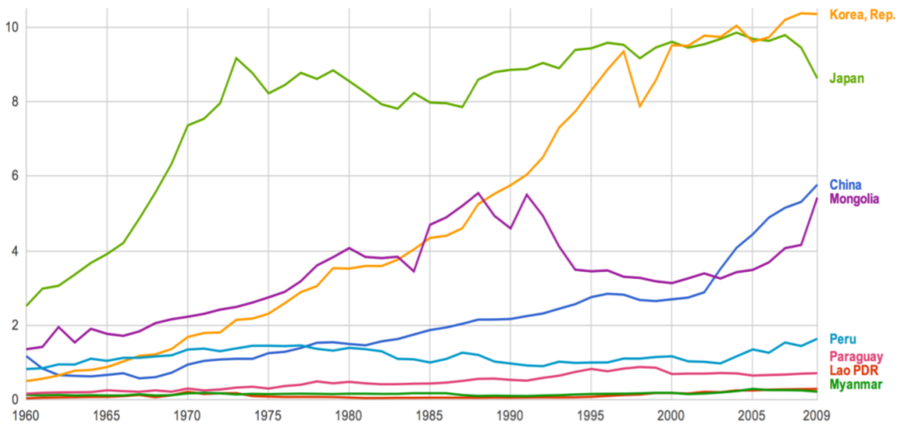

Figure 1-5. Country comparison in terms of per-capita energy consumption and CO_2.

Existing policy and strategies for sustainable energy

"A green economy will not materialize through incremental changes. A shift towards green growth requires a fundamental system change, restructuring both the visible (physical infrastructure) as well as the invisible aspects of the economy (market prices, fiscal policies, institutions, governance, and lifestyles) (UN report "Low Carbon Green Growth Roadmap for Asia and the Pacific," 2012).

For developing countries like Mongolia, the lack of technical and financial resources could serve as a barrier to the pursuit of green growth or development, but on the other hand, the country's less integrated market with global and beginning-stage market structuring can offer great opportunities for the country to create policies and a business environment based more on environment-friendly technologies while supporting its economy and lifting its population out of poverty as system change for green growth requires changing the "invisible" structure of the economy, including the market prices, fiscal policy, financial systems, institutional arrangements, regulations, and lifestyles (UN report).[2]

Since 1990, Mongolia has well transitioned from a centrally planned economy to a market economy, and the government of Mongolia incorporated the fundamental principles of sustainable development in its subsequent development policy documents.

The comprehensive national development policy has synergized the perspective, goals, and targets that have been stated and formulated in 304

[2] UNESCAP's report "Low Carbon Green Growth Roadmap for Asia and the Pacific" <http://www.unescap.org/esd/environment/lcgg/documents/Roadmap_FINAL_15_6_12.pdf>

policy documents developed and approved in the last 15 years ("Mongolia's Sustainable Development Agenda" report).

The following are the main basic policy framework documents on Mongolia's sustainable development strategy:

Mongolia's Sustainable Development Program for the 21st Century

This was adopted through a resolution of the government of Mongolia on May 27, 1998. This program was further incorporated with other policies, programs, and strategies into a policy paper called "MDG-based Comprehensive National Development Strategy of 2007-2021" and was adopted by the State Great Khural of Mongolia[3] and is now in effect.

Millennium-Development-Goals-based Comprehensive National Development Policy (2007-2021)

This puts emphasis on good governance, export-oriented economic development (Mongolia should focus on its advantages, like mining), rural development, poverty reduction, and human development issues. Mongolia has developed the Transportation Sector Development Strategy and has submitted it to State Great Khural for approval. In addition, the Ministry of Road, Transport, Construction, and Urban Development has developed the Road Sector Master Plan "Transit Mongolia" for implementation in 2008-2020, and a 15-year investment plan.

Government Action Plan for 2012-2016

This is the main official document that shows that the government is

[3] The highest organ of state power and the supreme legislative power is vested only upon the State Great Khural <http://www.parliament.mn/en>.

willing to implement all the policies and activities reflected on the action plan. This document contains several objectives that have been set for the adaptation and promotion of the green development concepts in the national strategies on sustainable development programs and plans.

The new government’s policy and strategy on green development

One of the main objectives of the Mongolian “Reform” government is to identify and develop its national strategy on green growth. To achieve this goal, the government started to change its intuitional structure that was designed to develop and implement the national strategy and action plans on green growth. It restructured the existing Ministry of Nature, Environment, and Tourism into the Ministry of Environment and Green Development (MEGD), which was established according to the law on government structure promulgated on August 16, 2012, with the status of core ministry. The new ministry has six departments, one being the Department of Green Development Policy and Planning, which is designed to develop strategies for and policies on green growth.

The new ministry recently prepared a draft form of the National Green Development Strategy of Mongolia, and it is being discussed at the level of the government-commissioned working group and international consultant groups (e.g., UNDP) to include the plausible pathways, priority measures, realistic targets, and needs for developing the necessary capacities at various levels to shift to a green economy.

1.5 Mongolian Energy Sector

Mongolia has abundant energy resources that could meet its energy demand in the next decades. Coal is the most dominant energy resource for electricity and heating in the country, and the existing energy supply system has thus been built on this capacity of the resource.

Coal export is one of most important revenue streams of the country. The huge demand for coal in the Asian countries, especially in China, can enable Mongolia to export its coal to the Asian markets for the next few decades.

Solar, wind, and hydropower are renewable energy resources that can play important roles in the energy system. The potential capacity of each of these resources is huge compared to the existing capacity of the country's energy system. Due to the high initial investment and other technology-inadequate factors, however, the renewable energy sources could not compete with the cheap domestic, subsidized coal power plants. Mongolia has legal documents on renewable energy promotion and deployment and has successfully implemented several renewable energy projects, mainly in rural area electrification, with assistance from international aid organizations. Also, the first 50MW wind farm project, the first project that used FIT since its establishment in 2007, has been implemented by the private sector.

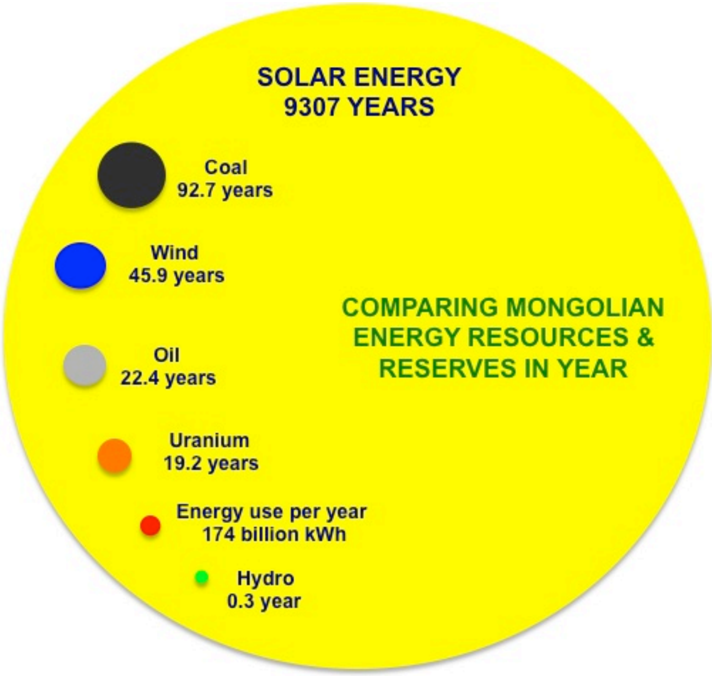

Figure 1-6. Comparison of Mongolia's energy resources and reserves.

The natural gas resource is not in the list of the country's energy sources, and importing the resource would be very costly due to Mongolia's geographic location as a landlocked country and the high energy security risk due to the country's dependence on its neighboring countries' gas supply capacity. Besides the energy sources mentioned above, there are other energy sources available for use in the energy system, such as uranium, geothermal energy, and coalbed methane gas.

1.5.1 Fossil fuels

A. Coal

Mongolia has abundant coal resources around the country, especially in the Gobi area in the south, with a total estimated resource of approximately 173 billion tons found within 15 coal basins. Bituminous coal is found in the south Gobi and western basins. Most of the resources in the central, northern, and western regions are subbituminous or lignite. The coal deposits in Mongolia are typically suitable for open cast mining because of their geological conditions.

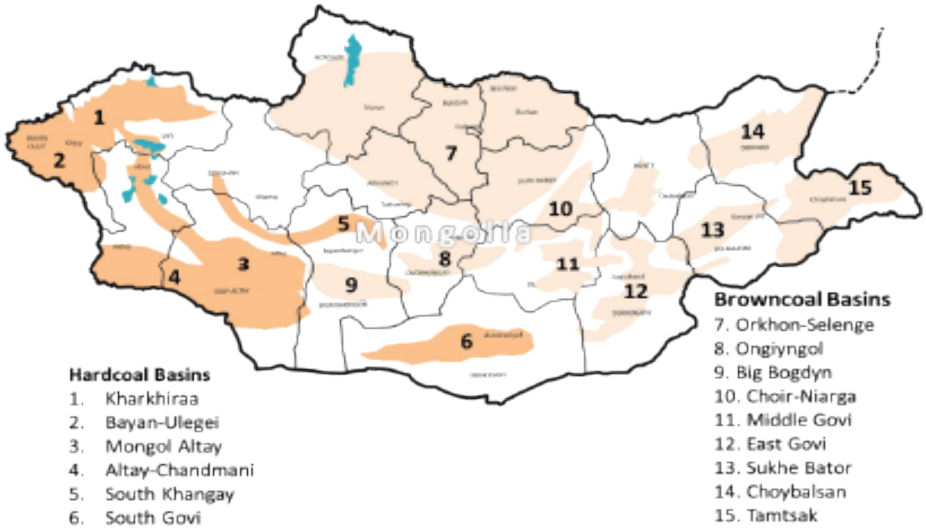

Figure 1-7. Locations of the coal deposits in Mongolia.

The coal resources were found in a total of 85 deposits, and in over 370 identified occurrences and findings, the coal reserves were measured as about 22 billion tons. Thanks to the increasing exploration activities, the amount of coal reserves is even increasing yearly. The share of high-calorific-value thermal and coking coal is estimated at 7-8 billion tons. The proven reserves are at 12 billion tons, including 2 billion tons of coking coal and 10 billion tons of thermal coal (ADB, 2013). The importance of coal in Mongolia is high, and its contribution to the economy and energy system is becoming even more significant.

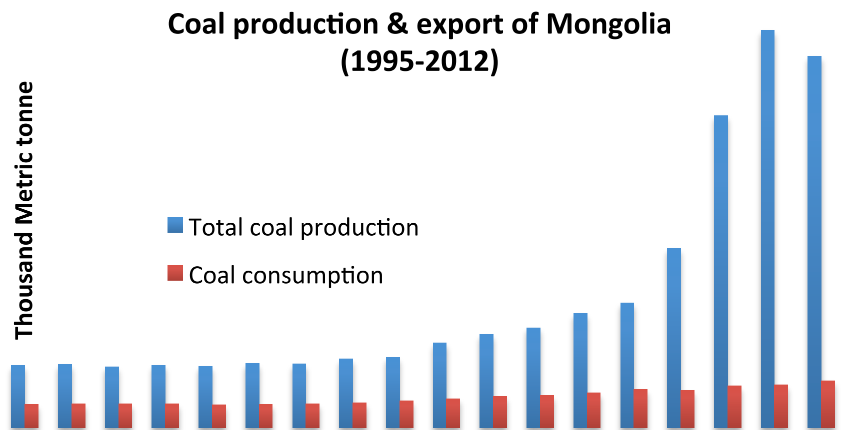

Figure 1-8. Mongolian coal production and export (1995-2012).

Today, coal provides primary energy for 65% of Mongolia's total energy use, and for over 90% of the country's power and heat generation. Coal represents 40-50% of Mongolia's export revenues (47% in 2011), and according to the Mongolian Economic Research Institute, over 10% of the budget revenues and 80% of the FDI. Mongolia's domestic coal consumption is about 5-6 million tons, but the number is likely to increase due to the CHP development projects. Millions of tons of cheap coal, which is shown in Figure 1-7, is being exported to China, the biggest raw material market in the world, every year.

B. Oil

Mongolia's oil reserve in east Gobi was estimated by a Soviet geologist for the first time to be 6.2 million tons. A total 10.58 million barrels of oil have been produced, 9.89 million barrels of which have been exported to China for refining as there is no refining factory in Mongolia. Mongolia officially became an oil-producing country in 2010, with a combined total of

272 million tons of proved reserves (Petroleum Authority of Mongolia, 2012).

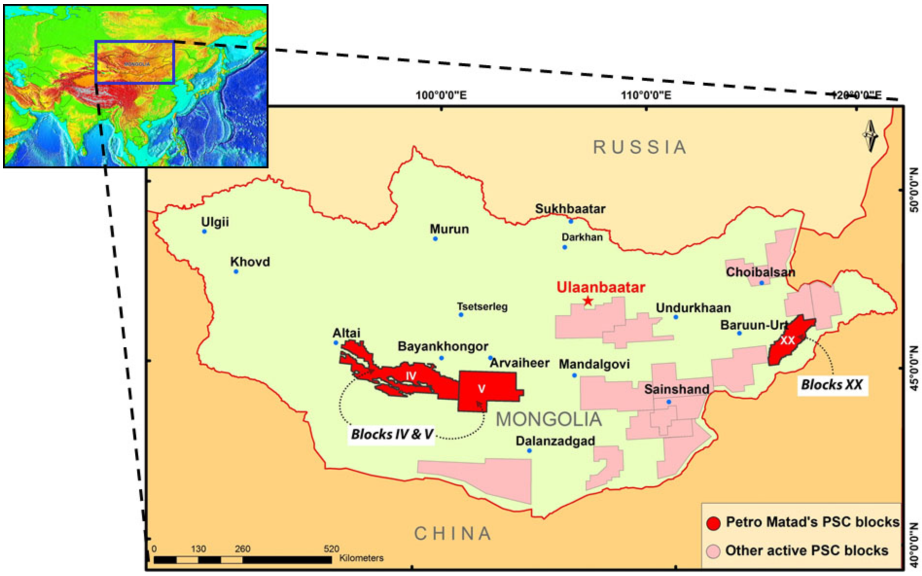

Figure 1-9. Oil blocks in Mongolia.

Today, there are 14 companies conducting oil-related businesses on 18 blocks with a product sharing contract, but only two of them, both Chinese companies, are actively participating in oil production in Mongolia, and the production increased 11 times over the last five years.

Zuunbayan and Tamsag are also the only two basins that produce crude oil in Mongolia. Both are located in the southeast Gobi Desert. Zuunbayan engaged in crude oil production from 1953 to 1969 and resumed it in 2007. Tamsag started to produce crude oil in 1998, and its production significantly increased in the last five years, with approximately 2.07 million barrels recovered by 2011. In that year, Mongolia's crude oil production reached 2.60 million barrels, and the annual growth was around 10% (Petroleum Authority of Mongolia, 2012).

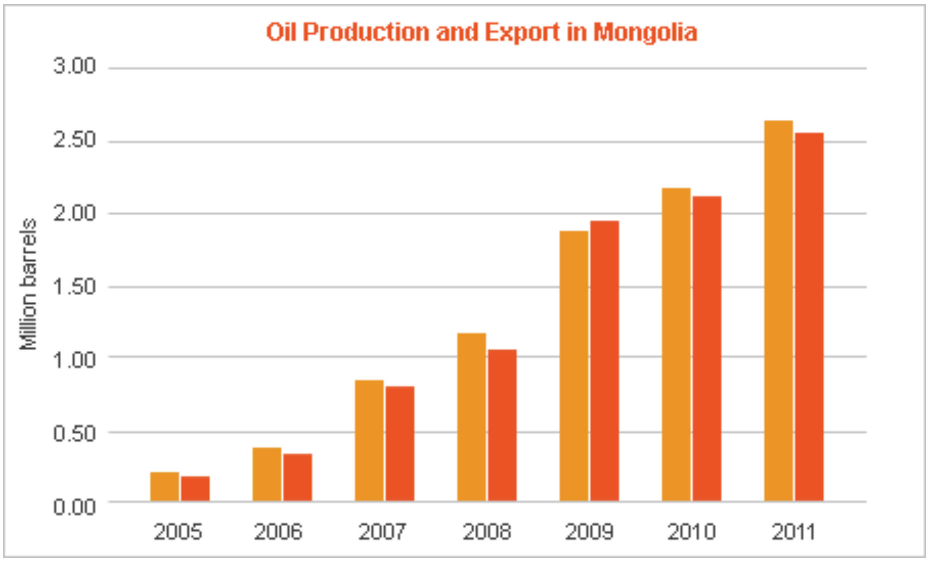

Figure 1-10. Oil production and export in Mongolia

Mongolia's potential oil reserve has not yet been discovered fully and remains unknown. Some experts from the U.S. estimate that its recoverable oil reserves can reach from 4 to 6 billion barrels. Nevertheless, more detailed studies and analyses have to be done on the presence of source and quality reservoir rocks, and more seismic data acquisition and geological analyses should be conducted to assess and determine the country's actual potential reserves.

1.5.2 Renewables

Mongolia also has significant potential renewable energy resources that could replace fossil fuels as the country's main energy source. According to the U.S. National Renewable Energy Laboratory (Elliott et al., 2001) and the Mongolian National Renewable Energy Center (NREC), Mongolia's potential renewable energy generation capacity is estimated at 2.6 million MW.

There are various types of barriers, however, to renewable energy development in Mongolia, such as the high initial cost, the lack of a legal framework and policy for promotion, and technical conformity issues. In the last decade, the renewable energy usage in Mongolia was focused on electrification in the country's rural areas, for which several renewable energy projects were implemented by the government of Mongolia with international financial support to supply the people in the remote areas with electricity using renewable energy resources such as solar, wind, and hydro energy.

A. Hydro energy

Hydropower is another important primary energy resource that could be a big contributor to the reduction of the electricity imported from Russia. Therefore, the significance of this resource to midterm energy system security in Mongolia is considerable.

Mongolia has an estimated 3,800 small rivers with a total length of 6,500 km, which theoretically have a potential of about 6.2 GW. The major big rivers are in the northern and western parts of the country, which are mountainous areas. A total of 13 small-scale hydro plants are being operated in Mongolia, with a capacity range of 150 kW to 12.0 MW (Ministry of Energy, 2005).

Table 1-1. Small HPPs in operation in Mongolia

Location	Capacity	Operation Start Year
Kharkhorin	525 KW	1959
Ondorkhangai	200 KW	1989
Guulin	480 KW	1998
Mankhan	150 KW	2003
Monkhairkhan	150 KW	2003
Bogdiin	2.0 MW	2005
Tosontsengel	375 KW	2006

Uench	930 KW	2006
Erdenebulgan	200 KW	2006
Zavkhanmandal	110 KW	2009
Tsetsen-Uul	110 KW	2009
Dorgon	12 MW	2009
Taishir	11 MW	2009

The National Renewable Energy Program that was approved by the Mongolian Parliament in 2005 includes the construction of several big-scale hydropower plants, such as the Orkhon 100 MW, Egiin 220 MW, and Artsat 118 MW hydropower projects until 2020.

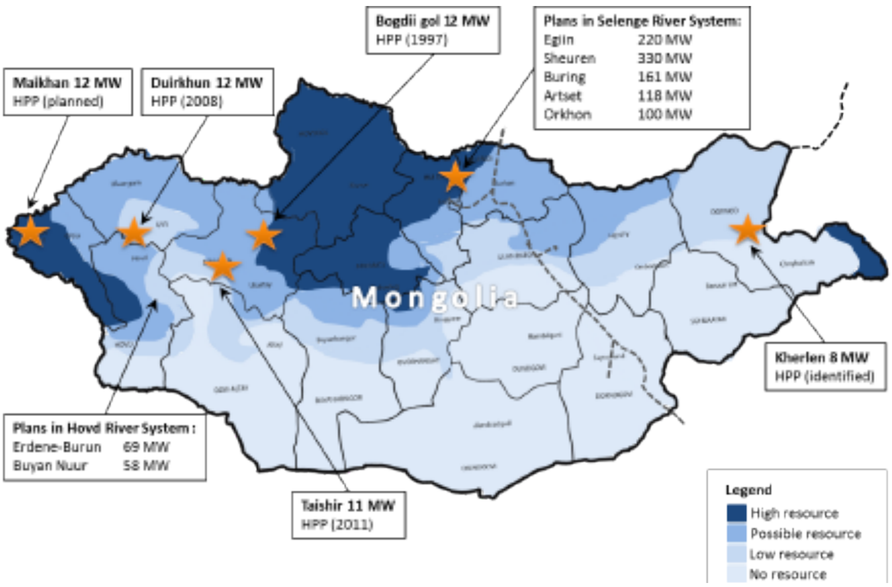

Figure 1-11. Sites of large-scale HPPs in Mongolia.

The necessity of constructing large-scale hydropower plants has become more important of late due to the electricity shortage in the central energy system. The Shuren 330 MW hydropower plant project is the option most considered to be built first among the candidate projects. The government of Mongolia has been working with international organizations and with Russia as a neighboring country to ensure the successful implementation of this project by 2020. The building of HPP in the central energy system will bring some important benefits and contributions to the energy system. For instance, it will be a good opportunity for and support to CES's normal operational system adjustment, including increased independence, while enabling the initial wind park project in the Gobi Desert area.

B. Solar energy

Mongolia has substantial solar potential for both solar power and solar heating as it has around 270 sunshine days in a year (2600-2900 sunshine hours per year) with a solar intensity[4] rate of 5.5-6.0 kWh/m^2 per day in approximately 71% of the country's total land area (Ministry of Energy, 2005).

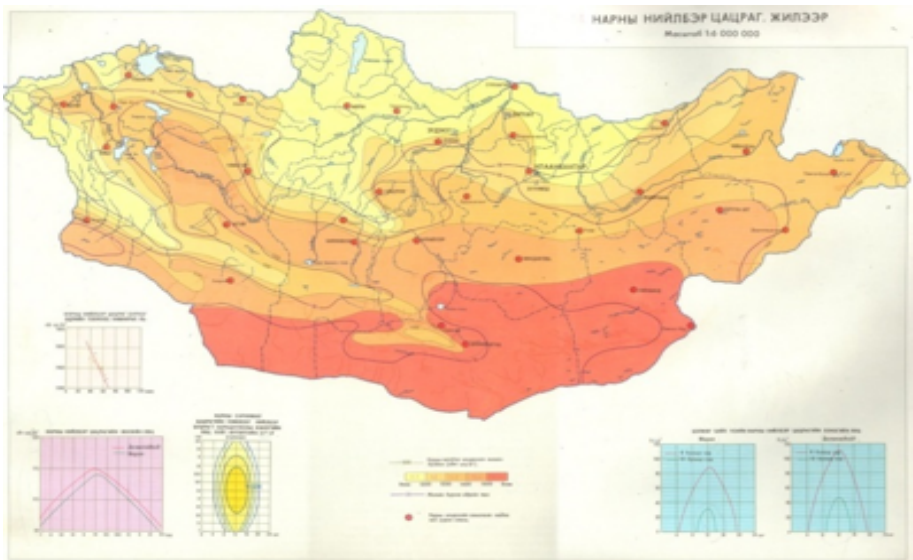

Figure 1-12. Solar energy map of Mongolia.

The majority of this solar resource area is located at Gobi Desert, in which

[4] Solar intensity is the amount of solar power (energy from the sun per unit time) per unit area reaching a location of interest.

several project proposals involving the establishment of large-scale solar energy systems, both solar photovoltaic (PV) and concentrated solar power (CSP), are being discussed, including Asian Super Grid System, an ambitious project idea, where large-scale wind and solar farms will be installed in the Gobi Desert area and can be connected via high-tension transmission lines to Korea, Japan, and China. There are some organizations and companies that have been working on this project idea, such as Japanese Renewable Energy Foundation[5] as a major player and the Mongolian private company Newcom, which recently installed the first private 50 MW wind farm in Mongolia.

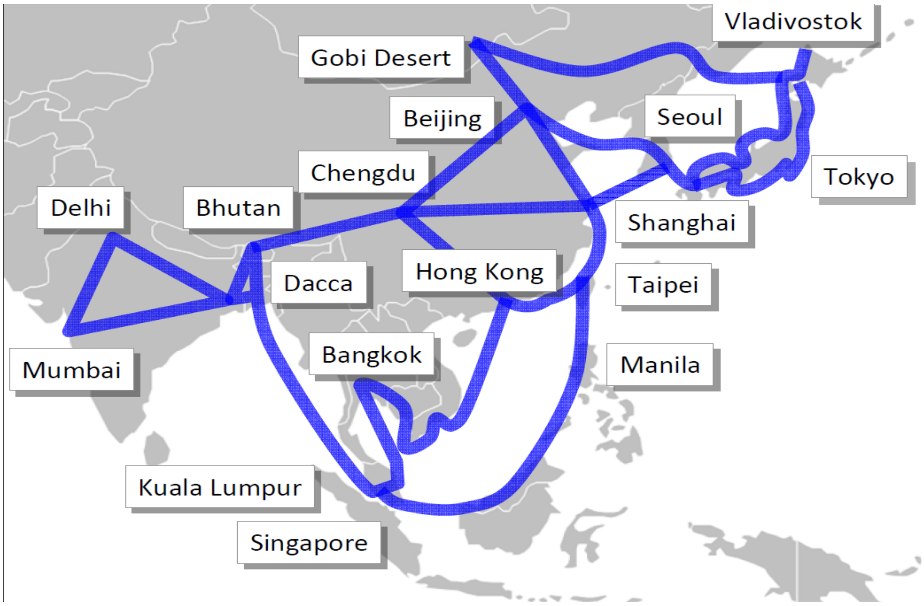

Figure 1-13. Asian Super-Grid Transmission Line.

The government of Mongolia has been implementing a project titled

[5] Based in Japan, its mission is to establish a society based on renewable energy. JREF's activities include policy research and development and development of measures and financial/business models based on the dynamics of markets and the society and on the promotion of renewable energy <www.jref.or.jp>.

“100,000 Solar Gers Program” for 10 years now, since 1999, which was designed to provide solar home system (SHS), with a capacity of 50-75 W, to almost 100,000 families in the countryside with no electricity access. Fifty percent of the cost of the PV systems was subsidized by the government and the World Bank. The program’s outcomes and impacts on the rural community are considerable and positive; the program enables them to access electricity for use with electrical devices such as lights, radios, TVs, and satellite dishes.

Stand-alone, hybrid (solar, wind, and diesel) or solar energy systems of 100-200kW projects were installed in remote soums (villages), where it was very difficult to build an electricity transmission line technically and economically.

1.6 Energy Demand and Consumption

In Mongolia, coal and oil are the main fuels for energy consumption, and coal is still the dominant and major energy source for electricity generation and heating. In the case of oil consumption, the most important industries, such as the transport and agricultural industries, depend much on oil imports; oil prices are the most important factor underlying the economic growth, and the prices of all the goods in Mongolia are dictated by them. With limited domestic oil resources, Mongolia is almost entirely dependent on imports from Russia to meet its energy consumption needs. In the case of coal consumption, the country has an abundant coal resources; the annual coal production in Mongolia is estimated at around 5 million tons. Nearly 85% of the production is used to generate electricity and heating, but 25.5 million tons were exported in 2011 (National Statistical Office of Mongolia, 2012).

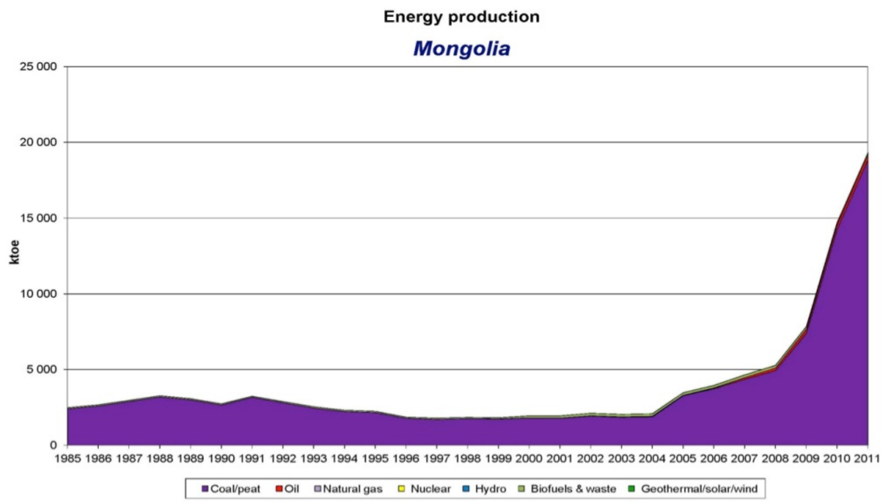

Figure 1-14. Mongolian energy production (1985-2011), IEA.

1.6.1 Electricity consumption

The Mongolian energy system consists of five small isolated regional systems and has seven coal-fired power plants, 13 relatively small-scale hydropower plants, one wind farm, a small stand-alone solar system, and diesel generators. Furthermore, the energy system imports electricity from Russia mostly for its peak demand, which accounts for ~13% of the electricity consumed in Mongolia. Due to the increase in final energy consumption in the last few years, the existing generation capacity will not able to supply the future demand, which will lead to increased electricity import unless new power plants will be operated.

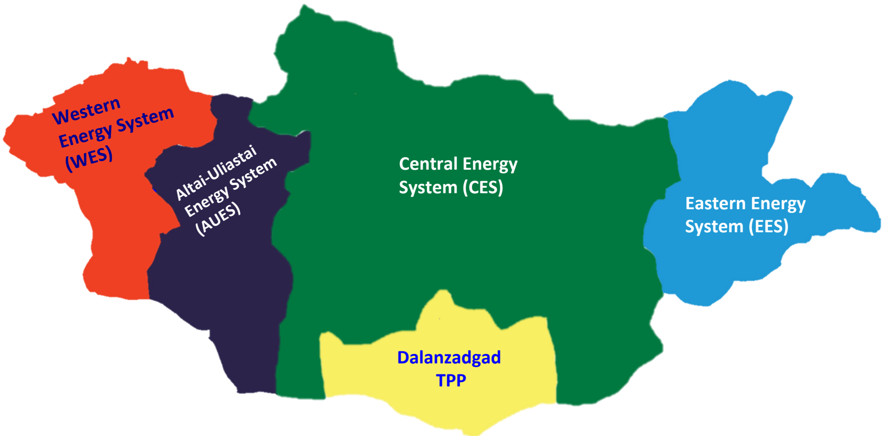

Figure 1-15. Mongolian electricity systems.

The central energy system (CES) is a relatively large energy system among the others, supplying the energy demands of 13 provinces with its five coal-fired power plants and one wind farm, and accounting for 80% of the country's total energy production. Coal-fired co-generation power plants produce electricity and hot water for district heating, with 0.2% of the production exported at a very low tariff rate to Russia at night. The percentage of losses in transport and distribution (T&D) has been decreasing gradually since its peak (23.6%) in 2001 (Energy Regulatory Committee, Mongolia, 2013).

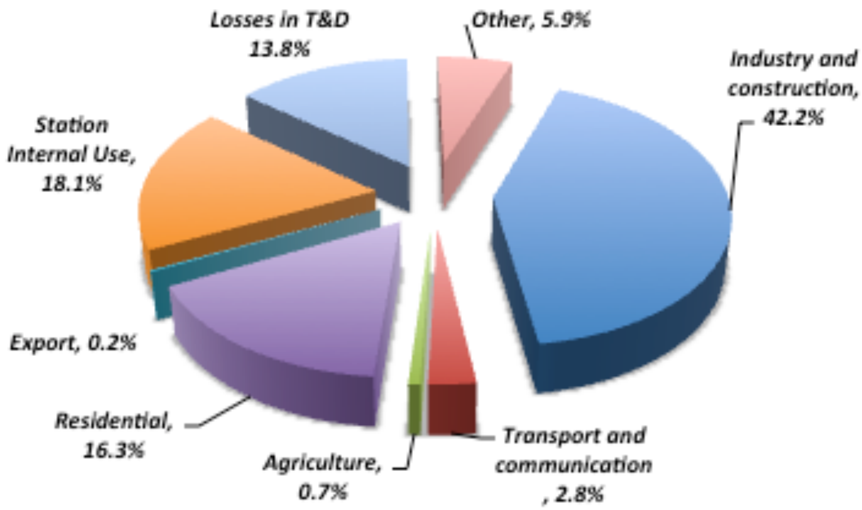

Figure 1-16. Mongolian electricity consumption by sector.

The electricity production of CES grew by 4-6% annually from 2006 to 2010, as shown in Figure 11. The distributed electricity generation also grew by 22.9%, from 2832.4 million kWh in 2006 to 3482.5 million kWh in 2010 (National Statistical Office of Mongolia, 2012).

Table 1-2. Mongolian Electricity Balance (2007-2010)

Indicators	2007	2008	2009	2010
Resources – total	3 896.1	4 198.2	4 195.4	4 575.7
Gross generation	3 700.7	4 000.6	4 038.8	4 312.8
Import	195.4	197.6	156.5	262.9
Distribution – total	3 896.1	4 198.2	4 195.4	4 575.7
Consumption	2 829.1	3 093.3	3 034.1	3 375.9
Of which: Industry and construction	1 745.6	1 9	1 883.1	2 093.8
Transport and communication	117.3	128.7	126.2	140.4
Agriculture	26.1	32.6	32.1	35.6
Household and communal housing	694.6	742.3	727.6	809.7
Other	245.5	271.5	265.1	296.2
Losses in transmission and distribution	442.4	435.9	493.9	505.4
Station internal use	614.5	653.2	649.4	672.2

Export	10.1	15.9	18.1	22.2
Electricity produced per capita (kWh)	1415.4	1504.4	1490.5	1563.6

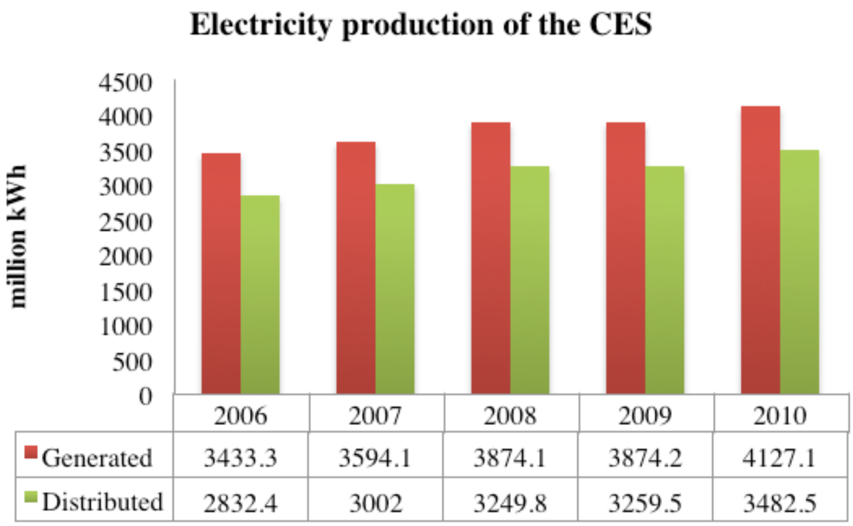

Figure 1-17. Electricity production of CES (2006-2010), ERC.

1.6.2 Heat consumption

Due to the long winter season in Mongolia, when the temperatures are usually between -20 and -30°C, having access to heat is an essential need of the country's citizens. Therefore, securing and sustaining the supply of heating energy is one of the core issues in the energy sector, which is becoming more serious as insufficient funds were invested in the construction of facilities for heating in the last two decades.

Table 1-3. Mongolian Heat Energy Balance (2007-2010)

Indicators	2007	2008	2009	2010
Gross generation	7 723.5	7 759.6	8 320.5	8 362.5
Power and thermal station's internal use	414.8	396.6	335.3	338.4
Distributed to the economic sectors and households	7 165.0	7 237.9	7 828.5	7 820.2
Of which:				
Industry and construction	2 068.4	2 167.6	2 002.2	2 082.9
Transport and communication	285.5	278.6	264.4	281.7
Agriculture	38.3	39.7	37.8	40.5
Household and communal housing	3 372.0	3 429.8	3 573.9	3 361.8
Other	1 400.8	1 322.2	1 950.2	2 053.4
Losses in transmission and distribution	143.7	125.1	156.8	203.9

There are three main resources that generate heat energy for the heating needs in the urban areas:

- combined heat and power plants, which provide electricity, heat, and hot water to the urban centers in Ulaanbaatar and a few other cities;
- heat-only boilers, which meet the heating and hot-water needs of a small central network of several buildings; and
- individual heat stoves, which burn coal and/or wood to meet the residential heating needs in the urban areas.

The issue becomes crucial in Ulaanbaatar during the winter season as it is the coldest national capital city in the world.

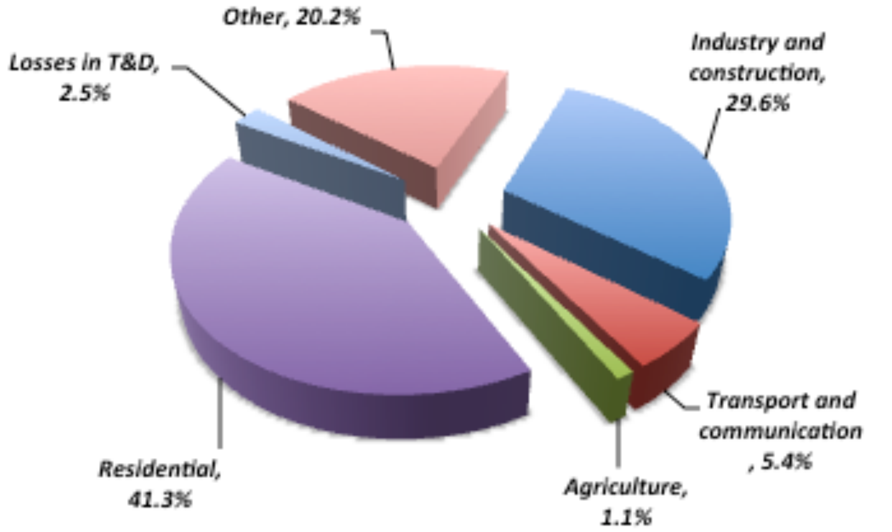

Figure 1-18. Heat consumption by sector (2006-2010), ERC.

1.6.4 Government policy, program, and incentives for the energy sector

The energy sector is one of the few sectors that can significantly contribute to the implementation of green growth in any country. There are great potentials to develop green businesses and a low-carbon economy based on the principle of green growth in the energy field. Mongolia's legal framework and government policies for the energy sector are shown below.

Legal Framework:

- Energy Law of Mongolia
- Renewable Energy Law of Mongolia
- Concession Law
- Development programs:

- “100,000 Solar Ger” National Program
- Integrated Power Energy System Program
- National Renewable Energy Program (NREP)
- New Construction and Midterm Coal Program
- Southern Gobi Development Program

Some of the above documents, which have been used as the underlying legal framework for the BAU, EE, and REN scenarios, are described in detail below.

Energy Law:

This is the law that regulates the production and sale of energy, the construction of energy generation facilities and other energy infrastructures for transmission and distribution, and the supply of energy to the end users, which was approved by the parliament on April 15, 2001 and was amended in 2007 and 2011. The law has some important provisions that define the responsibilities, duties, and authority of the institutes and stakeholders in the energy sector, and also descriptions of the transmission network boundaries, the approval of heating and electricity consumption, and the protection of power lines and networks.

For instance, the licenses of building facilities for energy generation, transmission, and distribution for a legal entity are different depending on the type of license, and the license period for producing and transmitting energy is 5-25 years, that for the construction of energy facilities is five years, and that for other activities is 10 years.

Integrated Power Energy System Program:

This program was ratified by the Mongolian Parliament in 2007. It includes various issues that are critical and emerging in the country's energy sector, such as building a large-scale hydropower plant that will strengthen the country's energy security and will reduce its electricity imports from Russia as well as its CO_2 emission, developing new policies and regulations supporting private sector participation in the country's energy sector, and introducing new efficient technologies that can reduce energy losses and increase the energy efficiency of the demand side. Finally, the program has the strategic goal of investing in restructuring the country's energy infrastructure to make Mongolia an energy exporter to its neighboring countries and to other countries.

The government of Mongolia has been working on updating the program of late with the assistance of Asian Development Bank (ADB), making the program more detailed and clearer with regard to its targets and projects to achieve the program goals.

National Renewable Energy Programme (NREP)

NREP has been chosen in this study as the policy to be tested in the Mongolian LEAP model. The program aims to create the conditions for ensuring ecological balance, unemployment and poverty reduction, and sustainable social and economic development by increasing the percentage of renewable energy share in the total energy supply of Mongolia, improving the energy supply structure, and widely using renewable energy for the rural areas' power supply.

According to NREP, which was approved by the Mongolian Parliament in 2005, the renewable energy contribution to the total energy system was supposed to be 3-5% by 2010 and is supposed to be 20-25% by 2020, but only 1.1% of the total electricity production in Mongolia has been produced from renewable energy resources to date, totaling 24.5 million kWh in 2011.

Another target of the program is to reduce the losses in the overall energy system by 3-5% of the current level by the year 2010, and by not less than 10% by the year 2020, by introducing advanced renewable energy technologies, intensifying energy conservation, and increasing the production, transmission, distribution, and operation efficiency.

To achieve the "20% target," several renewable energy projects, especially those involving the construction of large-scale hydropower plants, are proposed to be completed by 2020. These are the Eg River 220 MW station, the Artsat 118 MW station on Selenge River, and the Orkhon River 110 MW station, to be built on rivers with significant hydropower resources (i.e., the Selenge, Eg, and Orkhon rivers). Also, medium-capacity (30-50 MW) wind parks are proposed to be constructed in sites with proven wind energy potential, and to be connected to the centralized power grid system, creating efficient operation conditions.

Furthermore, small-scale renewable energy systems like wind, solar, and hybrid wind plus solar energy are defined as electrification options for the villages (soums) in remote areas where it is unreasonable technically and economically to construct electric transmission lines.

In addition, pilot projects of large-scale solar PV power generation systems in the Gobi area, and energy complexes employing geothermal technology in Ulaanbaatar for reducing its air pollution, were also planned as activities that can contribute to the attainment of the target that 20-25% of the country's total energy production will be generated by renewable resources by 2020.

Main players in the market for electricity and heat energy

The market participants are five combined heat and power plants, one (state-owned) electricity transmission operator, and ten electricity distribution companies.

The Energy Regulatory Committee (ERC) introduced the single-buyer model (SBM) as a market model in September 2002 for the central electricity system. In the Mongolian case, five generating companies sell electricity at a regulated price to the single buyer, and the central regional electricity transmission company is the market operator, selling electricity to ten distribution companies.

Tested in 2005, the spot market has been effective since 2006. The National Dispatching Center was selected to act as a spot market operator. The electricity sales of the spot market were 7.0 million kWh in 2006, 6.8 million kWh in 2007, 7.6 million kWh in 2008, 4.1 million kWh in 2009, 4.9 million kWh in 2010, and 3.9 million kWh in 2011, indicating a gradual shrink.

ERC started the auction market in August 2007, where an incremental electricity demand is auctioned among the generating licensees for the best prices. Only five transactions have been recorded to date. The National

Dispatching Center operates the auction market. Despite the fact that 26 million kWh power was auctioned in 2011, only 4.5 million kWh power was sold in the market.

Table 1-4. Power and Heat Energy Generators in Mongolia

#	Power Plant	Type	Installed Capacity (MW)	Operation Start Date
	Central energy system			
1	Power Plant 2	Thermal, combined cycle	21.5	1961
2	Power Plant 3	Thermal, combined cycle	136	1968
3	Power Plant 4	Thermal, combined cycle	540	1983
4	Darkhan Power Plant	Thermal, combined cycle	48	1965
5	Erdenet Power Plant	Thermal, combined cycle	28.8	1987
6	Choibalsan Power Plant	Thermal, combined cycle	36	1967
7	"Salkhit" Wind Farm	Wind energy	50	2013
	Western energy system			
7	Durgun Hydropower Plant	Hydropower plant	12	2009
	Altai-Uliastai energy system			
8	Taishir Hydropower Plant	Hydropower plant	11	2011
9	Bogdiin Hydropower Plant	Hydropower plant	2	1998
10	Tosontsengel Hydropower Plant	Small hydro	0.36	1998
	Eastern energy system			
11	Dalanzadgad Power Plant	Thermal, combined cycle	6	1995

12	"Ukhaa Khudag"	Coal-fired	18	2011

Thermal Power Plant #4 is the biggest energy company in Mongolia, generating 2721 million kWh electricity in 2011, accounting for 70.1% of the total electricity production for that year. TPP#3, on the other hand, contributed about 14% of the electricity production and accounted for 37% of the heat energy consumed, respectively. The total electricity production of 3879 million kWh in 2011 was higher by 11% than the 3482.5 million kWh in 2010.

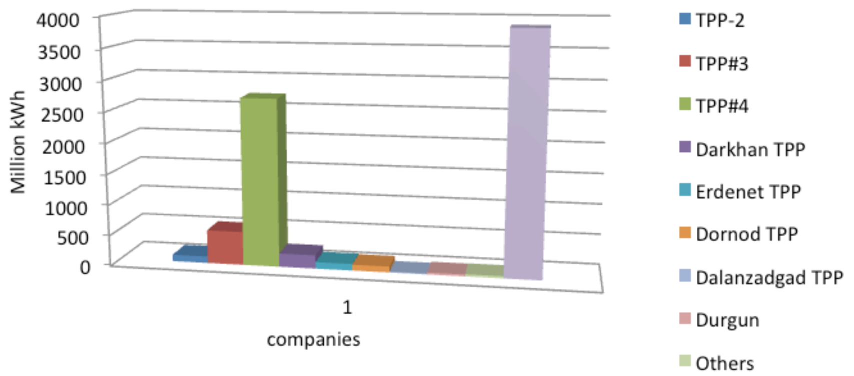

Figure 1-19. Energy companies' share in the electricity production.

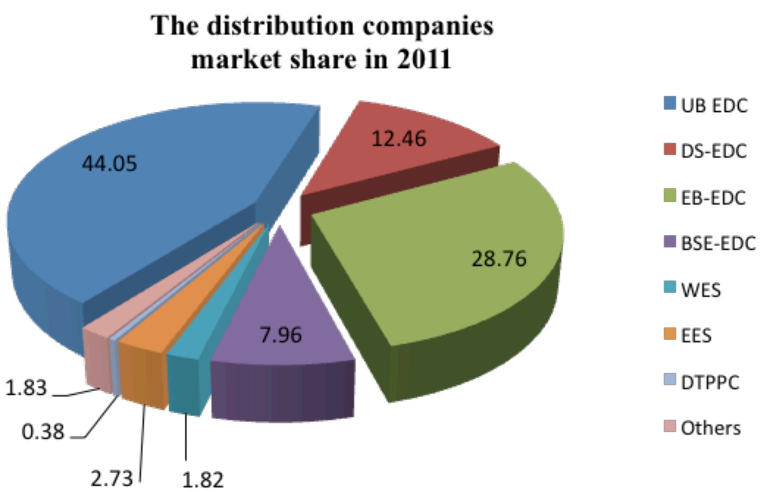

Figure 1-20. Market share of the electricity distribution companies.

The electricity distribution business of Ulaanbaatar Electricity Distribution Company (UB EDC), a stated-owned company, covers Ulaanbaatar. It distributes 44.05% of the total electricity consumed in Mongolia (Energy Regulatory Committee, Mongolia, 2013).

Tariffs for electricity and heat

The existing tariffs for electricity are too low to support the sustainable development of the power industry. To increase the participation of the private sector in the power generation industry for building power plants, the tariffs will need to cover the cost of service delivery because the private sector will not invest in non-profitable projects. According to the World Bank estimates, compared with the existing tariffs, the cost-covering tariffs for new facilities could be 3.5 times higher for electricity.

In addition, the effective participation of the private sector in the future will depend to a considerable extent on the condition of Mongolia's regulatory framework, which has several impediments to successful regulation. If regulatory reforms are not carried out, the financing gap between the available funds and the capital expenditure needs will become much wider, making it harder to fill the gap through private investment.

ERC has a tariff policy of releasing subsidized "non-realistic" tariffs, which will make it more reasonable for the generators to cover the cost by increasing the tariffs gradually on a yearly basis. For the last few years, ERC increased the tariffs five times, with the intention of reaching the USD0.8/kWh level in 2013 for the electricity prices for the customers.

ERC estimated that the cross-subsidies in industry and the residential tariffs will be removed when the tariff level reaches that of the cost-recovering tariffs.

The current average level of the subsidies on the end use price is 72% for the residential users and 58% for the industrial consumers. Other forms of subsidies are debt repayment waivers for deferrals granted by the government to various energy sector companies (Energy Regulatory Committee, Mongolia, 2013).

Table 1-4. Electricity Tariff Growth by Year

Items	2002	2005	2007	2008	2009
Electricity	4.4%	8.5%	4.4%	27.8%	17.35%

Feed-in tariff

The Mongolian FIT was the main component of the renewable energy law that was enacted by the Mongolian Parliament in 2007. In the law, tariffs for electricity production from three renewable energy resources — solar, wind, and hydro energy — have to be established, and the tariffs are categorized by size and project type. There are many different options that can be considered by a certain country for establishing its FIT. Presented below are the characteristics of the Mongolian FIT, which reflect the country's context.

- The FIT payment is set based on the fixed price model.
- Incorporates a cost-sharing mechanism
- Payment level targeted for wind, solar, and hydropower
- The validity period of FIT, which was established in 2007, is 10 years.

- Only one wind farm project has been signed as a PPA under the FIT.
- Utility is required to purchase electricity from the RE generators.
- The generators pay a minimal connection cost.
- The generators are allowed to qualify for CERs, which are not considered part of the FIT.

Table 1-5. Mongolian FITs

Type	Types of Energy	Capacity	Tariff /cent/
On Grid	Wind energy	5 MW or less	8-9.5
	Hydro energy		4.5-6
	Solar energy		15-18
Off Grid	Wind energy		10-15
	Hydro energy	0.5 MW or less	8-10
		0.5-2 MW	5-6
		2-5 MW	4.5-5
	Solar energy		20-30

Source: Renewable Energy Law of Mongolia

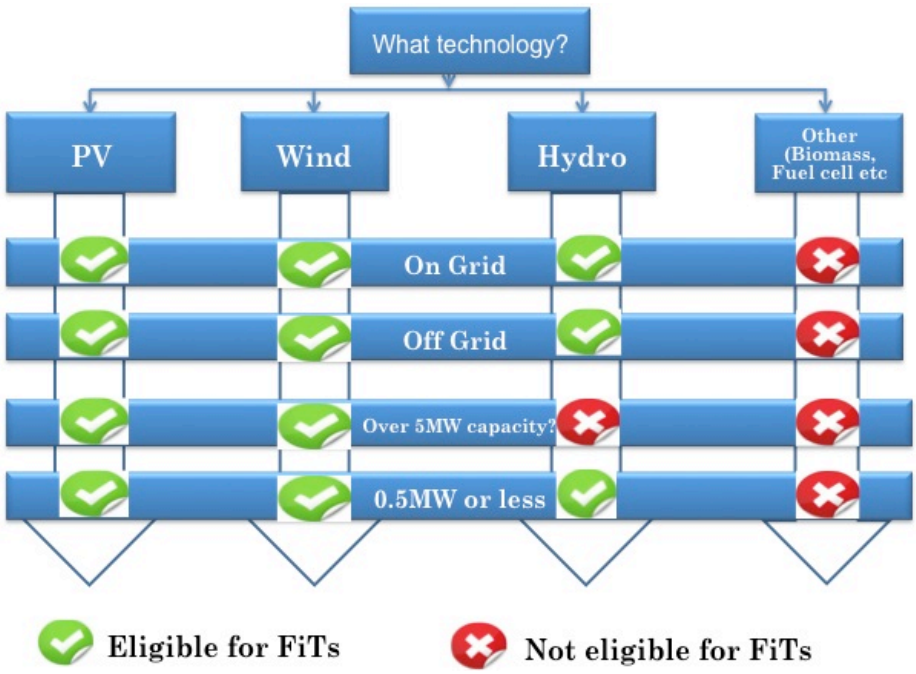

Figure 1-21. Eligibility of FIT in RE technologies.

Additional capacity for heating and power is required

The existing power and heating capacities are fully utilized with little reserve capacity in case the thermal power plants are unable to produce the amount of energy needed to meet the peak power load. The CHPs are getting older; the youngest one is CHP#4, which is 30 years old. Some of them have gone beyond their expected retirement year; CHP#2 was supposed to have retired in 2005, and CHP#3 in 2011.

These two power plants have been operating for over 30 years, and there is a risk that their operation will no longer be stable and reliable due to the poor conditions of their facilities and equipment. The TPPs are operated to supply a significant part of the heat supply in the winter season, and as such, any failure and temporary outage in TPP#2 and TPP#3 can create serious problems on the part of their users, which requires the making of a contingency situation by CES (Asian Development Bank and Ministry of Energy, Mongolia, 2013).

Existing projects in Mongolia's energy sector

The projects that have been implemented and that are being implemented in the energy sector of Mongolia were financed by only a handful of international organizations, such as WB, ADB, Germany's KfW Bank, and by countries like Japan and South Korea. In terms of the objectives and designation of the projects, basically, the WB and ADB projects aim to support energy efficiency, improvement of electricity transmission and distribution lines, and power plant development, and KfW, GTZ, and South Korea have been providing support for renewable energy development, such as of the solar PV system and small-scale hydropower plants. Table 1-6 shows the projects that are currently being implemented and sponsored by international organizations in cooperation with the Ministry of Energy of Mongolia.

Table 1-6. Existing Projects in Mongolia's Energy Sector (2013)

Title/Name	Sponsor	Financing Type	Project Duration
"Energy Efficiency-1" New Steam Turbine at Darkhan Thermal Power Plant	Kreditanstalt für Wiederaufbau (KfW)	Low-interest loan	2010-2013
Low-Carbon Energy Supply Project Using the Public-Private Partnership Model	Asian Development Bank (ADB) TA	Grant	2008-2014
Energy Efficiency Project-2	Federal Republic of Germany, BMZ	Grant	2011-2013
Demonstration Project for Improved Electricity to the Low-Income Communities in the Rural Areas	ADB/Japanese Fund for Poverty Reduction	Grant	2010-2012 (continued)
Project for the Establishment of a Heating and Hot-Tap-Water Supply System in Baruun-Urt Town	Korea International Cooperation Agency (KOICA)	Grant	2011-2012 (continued)
Rehabilitation of TPP-4 through Financing Support from KfW Bank	Federal Republic of Germany, KfW Bank	Low-interest loan	2012-2014

Source: Ministry of Energy, 2013

Chapter 2 - Literature Review

2.1 Overview

Energy planning is a commonly used method for analyzing the complex aspects of the energy system. It aims to ensure that the decisions concerning the energy demand and supply infrastructures involve all the stakeholders, consider all the possible energy supply and demand options, and are consistent with the overall goals for national sustainable development.

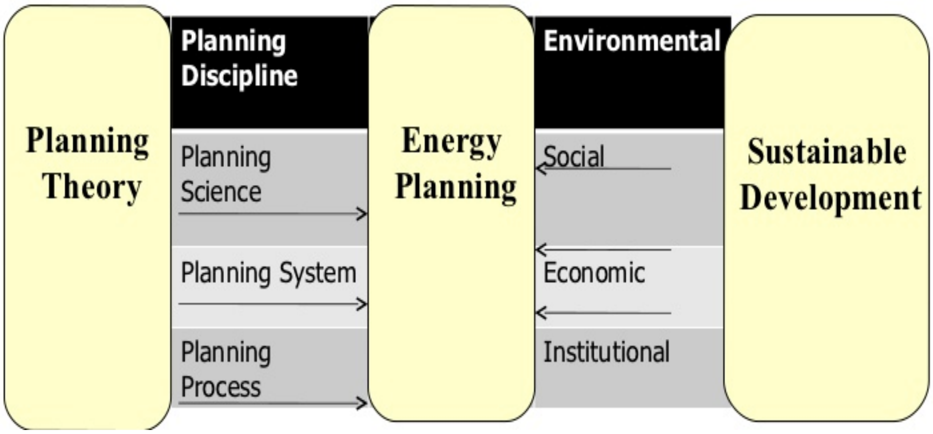

Figure 2-1. Scheme for energy planning.

Forecasting vs. backcasting

Backcasting starts with defining a desirable future and then works backwards to identify policies and programs that will connect the future to the present. The fundamental question of backcasting is “If we want to attain a certain goal, what actions must we take to get there?”

In contrast, forecasting is the process of predicting the future based on current trend analysis. It is widely used to describe likely business futures designed by extrapolating past/present trends and patterns. As these trends were observed in the past, forecasting assumes that they are also suitable for describing the future.

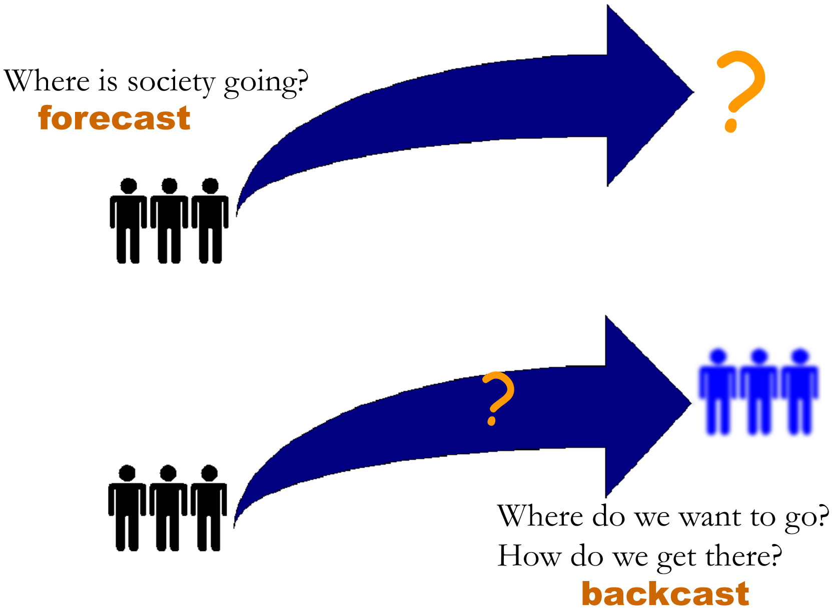

Figure 2-2. Forecasting vs. backcasting.

Source: Kemp-Benedict, 2001

2.2 Energy Models

Energy model classification

Many energy models have been developed for energy forecasting, planning, and calculation for various types of purposes in the energy field. These models vary considerably, and depending on the research purpose, selecting the right model is an important step for attaining a certain purpose or addressing a certain situation.

As mentioned above, models can be classified depending on their purpose, structure, and external or input assumption. Here are nine bases of classifying energy models:

(1) general and specific purposes of energy models;

(2) model structure: internal and external assumptions;

(3) analytical approach: top-down vs. bottom-up;

(4) underlying methodology;

(5) mathematical approach;

(6) geographic coverage: global, regional, national, local, or project;

(7) sectoral coverage;

(8) time horizon: short, medium, and long term; and

(9) data requirements.

Main characteristics and comparison of models

A model is described as a mathematical description usually in the form of a computer algorithm, a real system, or a phenomenon occurring with that system. An energy model focuses on energy issues. A general characteristic that is common to all energy models is that each model is a simplified representation of a complex real energy system and deals with quantitative and qualitative parameters related to selected energy issues (Sahir, 2007).

All energy models can be divided into two modeling approaches: the top-down and the bottom-up approaches. The top-down model is designed for the analysis and examination of broader economic variables and any economic sector, and of the socioeconomic impacts of such variables. For instance, for energy sectors, the top-down model can be used to analyze the production of energy resources (gas, oil, electricity, coal) and the energy flow and demand in monetary units. In contrast, the bottom-up model usually deals with detailed information and mathematical programming problems. It requires very comprehensive data and information as inputs to analyze the performance and planning of a certain sector. In energy sector analysis, more comprehensive data regarding the energy policies (subsidies, technology regulations) on the technology mix, fuel mix, emissions, and cost of the energy system are required. The use of the bottom-up model usually results in a more inclusive assessment and analysis of the energy technologies, policies, and fuel mix within the energy sector.

The table below lists the different characteristics and aspects of the top-down and bottom-up models for analyzing and assessing a sector.

Table 2-1. Comparison of the Top-down and Bottom-up Models

Top-down Models	Bottom-up Models
• Use an "economic approach"	• Use an "engineering approach"
• Give pessimistic estimates on the "best" performance	• Give optimistic estimates on the "best" performance
• Cannot explicitly represent technologies	• Allow for detailed descriptions of technologies
• Reflect the available technologies adopted by the market	• Reflect the technical potential
• The "most efficient" technologies are given by the production frontier (which is set by the market behavior).	• Efficient technologies can lie beyond the economic production frontier suggested by the market behavior.
• Use aggregated data for predicting purposes	• Use disaggregated data for exploring purposes
• Are based on the observed market behavior	• Are independent of the observed market behavior
• Disregard the technically most efficient technologies available, thus underestimating the potential for efficiency improvement	• Disregard the market thresholds (hidden costs and other constraints), thus overestimating the potential for efficiency improvement

• Determine the energy demand through aggregate economic indices (GNP, price elasticity), but vary in addressing the energy supply	• Represent the supply technologies in detail using disaggregated data, but vary in addressing the energy consumption
• Endogenize behavioral relationships	• Assess the costs of the technological options directly
• Assume that there are no discontinuities in historical trends	• Assume that the interactions between the energy sector and the other sectors are negligible

Source: Nicole van Beeck, 1999

2.3 Summary of Popular Models

Many energy models and tools for energy system planning are available for different customers with different purposes of model usage (e.g., policymakers, academia, businessmen), at a sufficient number of languages. Every model is designed to have one or multiple integrated approaches to energy system planning and to the assessment of the impact of the energy system on the environment and economy through the methodologies of simulation, optimization, and use of toolbox models for specific purposes. A suite of models is usually required to answer different questions, and no single model covers everything.

Below are the 10 popular energy system models that are currently being used to forecast energy supply and demand, analyze scenarios, assess the current energy system and CO_2 emission reduction, and many other purposes.

Table 2-2. Ten Popular Energy Modeling Software

№.	Name of Model	Developer	Geographic Applicability	Date Requirement	Link for More Information
1	LEAP (Long-Range Energy Alternatives Planning System)	Stockholm Environment Institute	Local, national, regional	Low-medium	http://www.energycommunity.org/default.asp?action=47
2	MARKAL	IEA/ETSAP	Local,	Medium-	http://www.iea-

	(MARket ALLocation)	(Energy Technology System	national, regional, global	high	etsap.org/web/Markal.asp
3	MESSAGE (Model of Energy Supply Strategy Alternatives and Their General Environmental Impacts)	(International Institute for Applied Systems Analysis) Austria	Local, national, regional, global	Medium-high	http://www.iiasa.ac.at/web/home/research/modelsData/MESSAGE/MESSAGE.en.html
4	MIDAS (Model Integrating Demand and Supply)	European Union	Local, national, regional, global	Low-medium	http://www.e3mlab.ntua.gr/manuals/MIDASman.pdf
5	RETScreen (Renewable Energy Technology Screening)	Natural Resources Canada	Local	Techno-logy-specific	http://www.retscreen.net/ang/home.php
6	MAED-2 (Model for the Analysis of Energy Demand)	International Atomic Energy Agency	National, regional, global	Medium-high	http://www-pub.iaea.org/MTCD/publications/PDF/CMS-18_web.pdf
7	TIMES (The Integrated MARKAL-EFOM System)	Energy Technology Systems Analysis Programme	Local, national, regional, global	Medium-high	http://www.iea-etsap.org/web/applicationGlobal.asp
8	POLES (Prospective Outlook on Long-Term Energy Systems)	IEPE (Grenoble, France)	National, regional, global	Low-medium	http://ipts.jrc.ec.europa.eu/activities/energy-and-transport/documents/POLESdescription.pdf
9	EFOM (Energy Flow Optimization Model)	European Union	Local, national, regional, global	Medium-high	http://ces.iisc.ernet.in/hpg/envis/doc98html/enbru87.html
10	Power Plan	Center for Energy and Environmental Studies, University of Groningen	Local, national, regional	Low-medium	http://www.fwn.rug.nl/ivem/soft.htm.

Chapter 3 - Methodology and Data Collection

3.1 LEAP Model

3.1.1 Overview of the LEAP model

LEAP is an integrated modeling tool that can be used to track energy consumption, production, and resource extraction in all the sectors of an economy. It can be used to account for both the energy sector and non-energy sector GHG emission sources and sinks. In addition to tracking GHGs, LEAP can also be used to analyze the emissions of local and regional air pollutants, making it well suited to studies on the climate co-benefits of local air pollution reduction (Heaps, 2012).

The LEAP model is a comprehensive energy-environment analysis tool and bottom-up-type accounting framework for forecasting various types of energy-related issues, such as energy supply and demand, CO_2 emissions, and cost-benefit accounting at the national and regional levels.

To forecast and analyze the energy system, CO_2 emissions, and costs according to the long-term energy alternative scenarios, this study used the LEAP model (2012 version), which was developed by Stockholm Environment Institute. The modeling software is being used in more than 190 countries in the world.

LEAP was designed based on the concept of long-range scenario analysis. Scenarios are self-consistent storylines of how an energy system might evolve over time. Using LEAP, policy analysts can create and then evaluate alternative scenarios by comparing their energy requirements, their social costs and benefits, and their environmental impacts (Heaps, 2012).

The model has many advantages, for which reason it was selected as the model to be used for this thesis. Below are the model's advantages.

- It is an integrated and user-friendly energy modeling tool that can be used to design models of different energy systems depending on the user's need. Also, the time needed for training in using the model for typical analysis is no longer than a week.
- LEAP can be used to account for energy production, consumption, and estimation of recourse extraction in all the sectors of an economy, and can track both the energy sector and non-energy sector GHG emission sources and sinks at the regional, national, and global levels.
- The software is widely available and has a reasonable cost. It can be downloaded by users from developing countries and by students free of charge.
- The model offers users a wide range of modeling methods for their energy demand and supply side analysis.
- Among the important features of the model are its TED technology and environmental database, which gives to users in developing countries (where data and information are not available and are unreliable) information regarding the technical characteristics, costs, and environmental effects of a range of energy technologies, and a database on the available existing technologies.
- As mentioned above, the model's 10,000 users from more than 190

countries, the national starter data on historical data on energy production and consumption, the economic/environmental/other data required for the LEAP software of more than 104 countries, and the online community of users called *COMMAND* attest to the quality and popularity of the model, which can be linked to MS Office (Excel, Word, and PowerPoint).

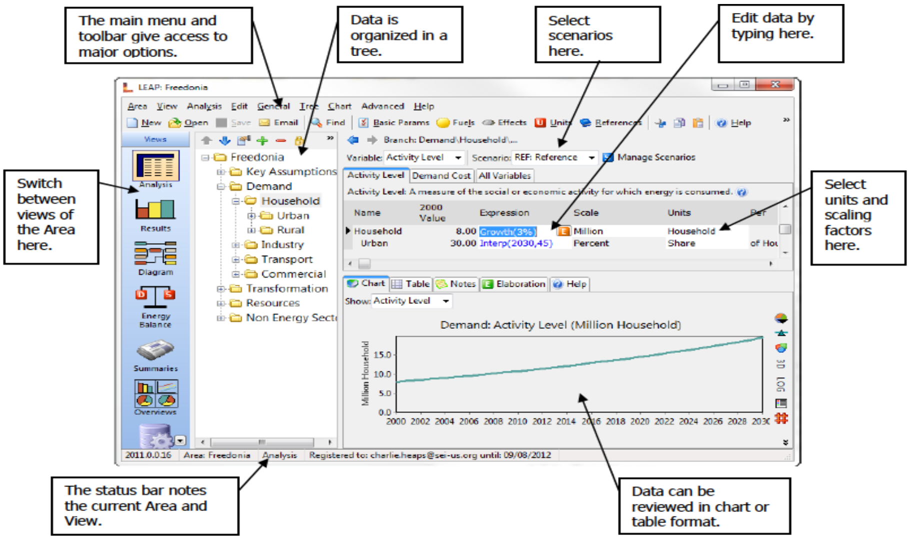

Figure 3-1. Main interface of the LEAP model.

The main interface of the LEAP software consists of eight major "views," each of which allows one to examine the different aspects of the software.

3.1.2 LEAP data requirements

As LEAP is a very general-purpose software tool that can be used to build a wide variety of energy system models, it is impossible to definitively describe its data requirements (Heaps, 2012). It does not require high-level, detailed data, though, which are often used in analyzing the bottom-up model, but it requires comprehensive knowledge on data collection and time-consuming efforts for such.

Data availability is a very important factor for the success of any study in achieving its objectives; therefore, it is crucial to select the right year as the base year — that is, one whose data are extensively available.

In the LEAP model, seven types of data are required to perform analysis, as shown in the figure below.

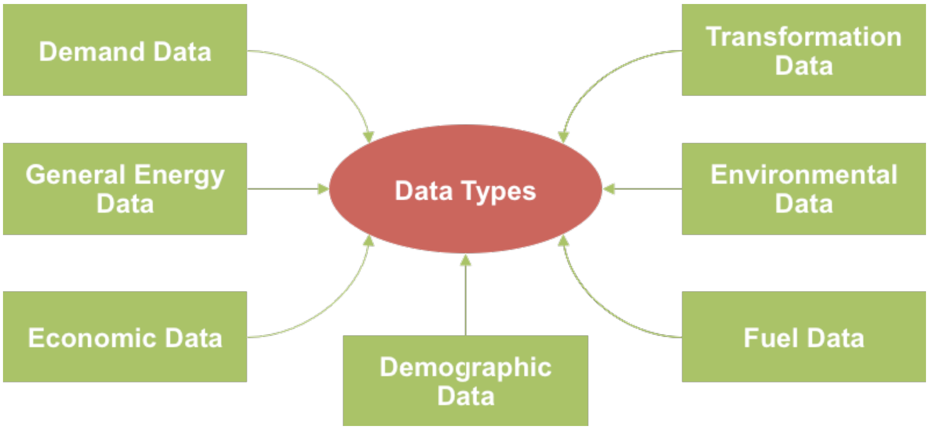

Figure 3-2. Data types for the LEAP model.

All the seven types of data that are needed to perform analyses using the LEAP model are defined below and can be found at the homepage of the LEAP software <www.energycommunity.org>.

Demographic data

In this part, the general data of a certain country (e.g., national population data, rates of urbanization, and average household sizes) are needed, which are required for the "Key Assumption" of the data tree in the model. Other useful data include the population by region, the male/female population, and the age structure of the population.

Economic data

These include the sectoral driving variables and more detailed driving variables, such as the GDP/value added, population, household size, production of energy-intensive materials (tons or $ steel), transport needs (pass-km, tonne-km), and income distribution.

General energy data

These include the characteristics of the energy supply, transport, and conversion facilities and the energy supply plans and energy resources and prices; the capital and O&M costs, performance (efficiencies, capacity factors, etc.), new-capacity online dates, costs, and characteristics; the fossil fuel reserves; and the potential for renewable resources. If these are not available in the country, they may be available from IEA's published energy statistics.

Demand data

- Activity levels: LEAP's demand analysis works by forecasting the future energy consumption as the product of two factors: the activity levels and the energy intensities. The activity levels are simply a measure of the economic activity in a sector, and the users can choose what data to use for this purpose. For example, in the household sector, the users may choose to use the number of households as the activity level; in the cement industry, the users might use tons of cement production; and in the transport sector, the users may choose to use tonne-km (for freight transport) and passenger-km (for passenger transport). The users will need to collect data describing the current, historical, and future projections of whatever data the users choose to use for their activity level variables. The users may need to consult national statistical reports or contact government or academic organizations working in specific sectors (industry, commerce, transport, households, etc.).

- Energy intensity data are often very hard to come by. If the users are preparing an aggregate analysis, they will likely be able to use their activity level data combined with the national energy consumption statistics and energy balances to calculate the historical energy intensity values by sector and by fuel. In other words, for historical data, *energy intensity = total energy consumption/activity level*. For their forward-looking scenarios, the users will instead use LEAP to calculate the total energy consumption by projecting the energy intensity and activity level. That is, *total energy consumption = energy intensity x activity level*.
- Other useful sources of energy demand data are the recent social surveys or energy consumption surveys that analyze how energy is consumed in different sectors of the economy, and reports from utilities and private companies on the sales of different energy forms (electricity, natural gas, oil products). If possible, try to get data disaggregated by sector and by consumer category.
- If the users are creating a more detailed analysis, they will likely also need information on the stocks, technical characteristics (efficiency, specific fuel consumption), costs, and environmental loadings of major energy-consuming devices in different sectors. For example, if the users want to focus on road transport energy use, they will need data describing the stocks

and sales of vehicles, their fuel economy, and some estimate of their average on-road life expectancy.

Transformation data

In general, transformation analysis requires that the users prepare a complete picture of how energy is extracted, converted, and transported in their energy system. This requires data on the flows of energy into and out of the major processes as well as information on the efficiency, costs (capital, operating and maintenance, and fuel costs), and environmental loadings associated with each major process.

- Electric sector: In general, the users will need data describing the current and historical installed capacities (MW), efficiencies, costs (capital, operating and maintenance, and fuel costs), and actual dispatch (MW-HR) of the various types of electricity generation plants in the country. The users will also need information on the seasonal load shape of their electric system and the maximum availability and dispatch priority of each different type of power plant. Capacity expansion plans, if they exist, can be very useful for establishing forecasts of how the electric system is likely to evolve in the future. In addition to collecting data on generation, the users should also collect data describing the transmission and distribution losses, including both the technical and non-technical losses. In many countries, combined heat and power (CHP) production is becoming increasingly important. The users may wish to analyze this sector separately from the dedicated electricity generation sector. For this sector, their data should include the production efficiency of both electricity and heat. In many countries, rural electrification is a key issue, so the users may wish to collect relevant data describing the rural electrification rates for the different geographic regions.

- Oil refining: If oil refining is an important sector, the users will need to collect data on the different products produced by the country's refineries, and the efficiency and capacity of the refineries.
- Extraction sectors: If extraction sectors such as coal mining or oil and gas production are important, the users will need data describing the efficiency and capacity of these sectors as well as information on the fuels produced and the energy consumed during extraction.
- Renewables: Renewable energy is becoming increasingly important in many countries and may be an important focus of any GHG mitigation analysis. Collect data describing the currently installed capacities, efficiencies, costs, and expansion plans for any relevant renewable energy, such as wind, geothermal, municipal solid waste, and solar energy.
- Biomass: If wood or other biomass fuels are important in the country, try to collect whatever data is available on the consumption and production of such fuels. Wood fuel surveys can be an important source of data for estimating the sustainability of the production of wood fuels.
- Other sectors: Other conversion sectors that may be important are charcoal making, ethanol production, and synthetic fuel production from coal.

Environmental data

- For a first-cut GHG mitigation assessment, the users may be able to rely on the basic “Tier 1” emission factors published by IPCC (and included in LEAP). As the users refine their analysis, however, they may wish to collect local emission factor estimates that reflect the fuel and technology characteristics of the devices used in their country. For example, the cars in a user’s country may have particular emission characteristics. It is particularly important to have data on the chemical composition of the fuels used in their country as these can be used to refine the emission factor estimates from different devices.

• IPCC’s online EFDB database is a key source of data on emission factors. This is available at <http://www.ipcc-nggip.iges.or.jp/EFDB/main.php>.

Fuel data

• LEAP includes a good default list of fuels and their characteristics (energy content, chemical composition) that should meet the needs of most studies. Be sure to adjust the energy, carbon, and sulfur contents in this list, however, to reflect the characteristics of the fuels used in the country. In particular, the characteristics of coal and biomass fuels vary greatly between (and even within) countries and uses. In addition to their physical characteristics, the users will also need data describing the production cost of any primary fuel produced in the country, and the import and export costs of any relevant fuel (Heaps, 2012).

3.1.3 Data collection for the Mongolian LEAP model

The Mongolian LEAP model was used in this study to forecast the future energy supply and demand based on several alternative scenarios of energy development planning that are advanced with different input components of energy resource, demand and policy, and distinctive approaches such as coal-oriented power generation, renewable-energy-based green energy system, and mixed features of energy resources.

According to the data requirements of the LEAP model, the necessary data were collected from different information resources, including Websites, statistics books, and reports of relevant trusted domestic organizations and international institutes. The National Starter Data of the LEAP model was very helpful at the stage of data collection as it had all the required general data of Mongolia collected from the database of the collaborating institutes, such as the World Bank, United Nations, International Energy Agency (IEA), and U.S. Energy Information Administration. These datasets were designed for developing-country energy planners, as a starting point for their analyses. Each dataset has been developed for a single country, and one dataset has been created for each country whose energy data are available from IEA.

Besides, despite the availability of information resources like the yearbooks of the National Statistics Office of Mongolia; the reports of the Ministry of Energy, National Dispatching Center, Petroleum Authority, and power generation companies; and other useful Websites, finding energy-intensive data from the domestic information resources was one of the limitations of this study. In some cases, data as international averages or from countries that have the same conditions or context as Mongolia were used in the analysis.

Table 3-1. Data Collection Sample

Data Type	2010 Value	Data Type	2010 Value	Data Type	2010 Value
Income	USD2065	Apartment vs. ger in UB	50% vs. 50%	Losses in distr.	Heat - 7.7%; electricity - 14%
Population	2,761 million	Construction	722.40 thou.m^2	Losses in distr.	Electricity - 3%
Household size	3.72 people	Road and bridge	0.43 km^2	Electricity import	157.5 mil. kWh
Households	742,300	Mining & quarrying	10.8 mil. tons	Electricity export	20.7 mil. kWh
GDP	5,701,460 thousand	Manufacturing	456.2 thou. tons	Exogenous capacity	947.3 MW
Income growth rate	3.5%	Transport	2.76mill. Person	Historical production	4445.9 mil. kWh
Pop growth rate	1.6%	Agriculture (crops)	315.3 thou. hectares	Coal export	16.7 mil. tons
Urban vs. rural	62.5% vs.37.5%	Losses in station own use	Heat - 5.72%; electricity - 16.6%	Electricity import cost	USD0.61/ kWh

The Mongolian LEAP dataset is divided into five sectors of energy demand: households, industry, transport, commercial & others, and agriculture, as shown in Figure 3-3. The household sector was split into two branches: urban (capital city, Ulaanbaatar, and other cities) and rural (centers of 21 provinces and soums).

The "main energy consumer," the industry sector, has two categories: mining and quarrying, and manufacturing. The mining and quarrying sector consists of major mines such as Erdenet, Oyu-tolgoi, Tavan-tolgoi, and other mines considered the next decades' big energy consumers. The manufacturing sector includes various types of factors pertaining to the raw materials of the mining industry, such as steel, iron, cement, and bricking, and also to resources from livestock, such as cashmere, wool, and tanning.

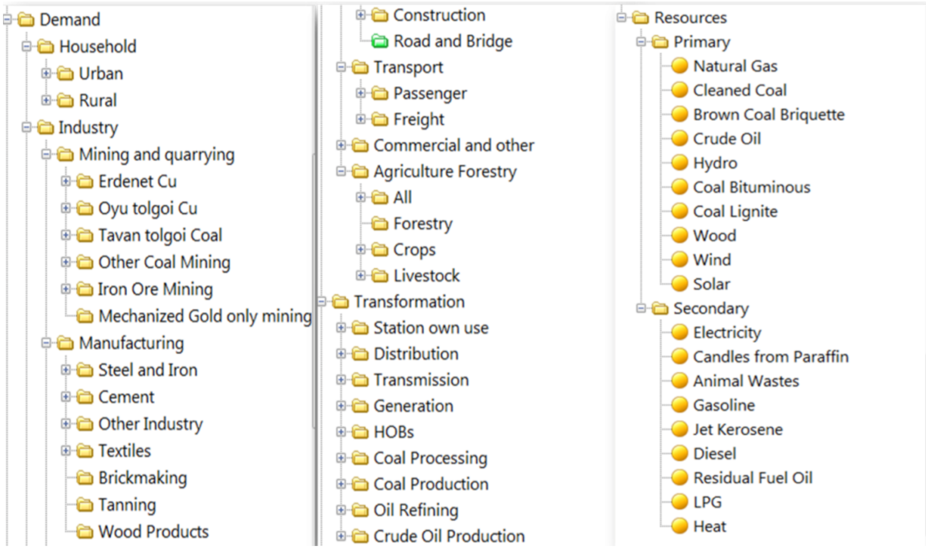

Figure 3-3. Mongolian LEAP model data branches.

In the transformation part of the dataset, all the subsectors are those that are involved in the conversion and transport of energy from the point of extraction of primary resources and imported fuels all the way to the point of final fuel consumption.

3.1.4 Building scenarios

Scenario development is different from forecasting, but the analysis presented here reevaluates how it is converging with the contemporary forecasting practice (Bunn, 199_).

To build scenarios for the future development of any sector, various issues of the social, economic, and energy sectors need to be considered beforehand, and based on such parameters or factors, different scenarios can be established, and the situations in each scenario can be analyzed. For instance, in a country's scenarios for energy development, to identify the kinds of energy trends that the country could follow in the future, the country's potential resources (e.g., energy resources), economic capability, and environmental sustainability could be considered.

Energy scenarios could be built based on the country's national strategies for long-term sustainable development and also on the results of the analysis of how the country's economy and environment will be affected in each scenario.

According to Roinioti (2012), there are four common trends in building energy scenarios, and along with these four trends, many different types of scenarios can be built.

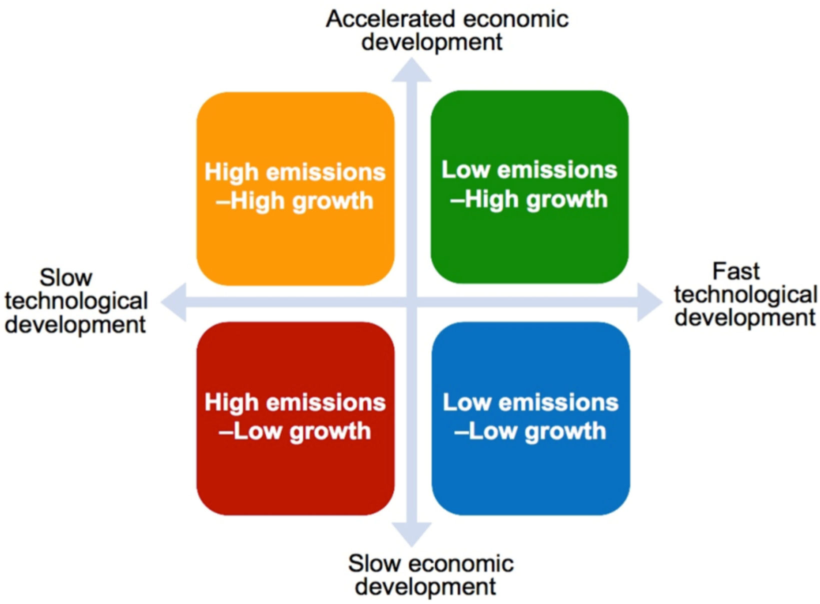

Figure 3-4. Principle of scenario creation.

In this research, three scenarios — the business-as-usual (BAU) scenario as reference, the energy efficiency (EE) scenario, and the renewable energy (REN) scenario — are assumed for the period 2010-2040 in Mongolia.

The BAU scenario reflects the impact of the existing policies and current technology levels on the future energy demand and energy choice of the country, and assumes which current trends in the development of new and renewable energy sources will continue into the future.

The EE scenario considers the potential for energy saving in both the demand and supply sides through the deployment of advanced and low-carbon technologies to increase the country's energy security.

The REN scenario aims to test the renewable energy target of Mongolia: "by 2020, 20-25% of the country's total power energy system should consist of renewable resources," which is reflected in the National Renewable Energy Program of Mongolia. The backcasting method, which is used in the REN and EE scenarios, helps determine the necessary policies, action plans, and financial and human resources that have to be taken or prepared to implement and achieve the targets.

In the BAU scenario, there are various existing policies, laws, regulations, and candidate power plant projects planned by the government of Mongolia in the energy sector. In the energy demand side, there are planned mega natural resource and infrastructure projects that are highly energy-intensive that are assumed as the base variables in the calculations of the scenario.

In the EE scenario, assumptions that can help reduce the energy demand and increase the use of energy-efficient technologies in the demand side while supporting generation technologies of renewable energy as low-carbon energy in the energy supply side to decrease the CO_2 emission and to ensure the diversification of the energy resource mix are reflected. For instance, the use of efficient and clean technologies for a building is a significant way of lowering the heat demand. In Mongolia, residential buildings use more heat energy than any other sector, and efforts to save energy for heating are also a key issue in the country. One of the assumptions in the EE scenario is efficient buildings, which can be described as buildings that have better technologies, such as better air sealing, triple-glazed low-e windows, dynamic solar control, and ultra-thin insulators for floors, windows, walls, and roofs.

Table 3-2. Principles of the Scenarios

	Business-as-Usual (BAU)	**Energy Efficiency (EE)**	**Renewable Energy (REN)**
Definitions	The government policies that had been enacted or adopted by 2013 continue unchanged, such as the plan to develop big mining projects and to build several coal-fired CHPs.	The government of Mongolia implements initiatives to reduce energy use and to conserve energy by using energy-efficient technologies. The Energy Conservation Law of Mongolia is still at the level of the Mongolian Parliament.	The government of Mongolia will pursue objectives that can help it achieve its renewable energy target of 20-25% by 2020.

Objectives	To provide a baseline that shows how the energy sector will evolve if the underlying energy trends will not be changed	To demonstrate a reasonable path towards exploring all ways of improving the country's energy efficiency that make economic sense	To test Mongolia's NREP, in which 20-25% of the total energy installed capacity will be renewable energy by 2020
Conditions	Government's long-term PPAs for new coal-fired condensing power plants at the least cost; HPP-300MW, which is already part of the government plan	Efficient lighting, reduced losses in T&D and station own use, energy-efficient buildings, diesel buses with CNG engines, and more natural-gas vehicles	Large-scale HPPs (Shuren-300 MW, Egiin-220MW, wind-250MW, and solar PV-400 MW) built, efficient lighting, reduced losses in T&D and station own use, and energy-efficient buildings

In the current government plan for the power generation industry, most of the projects in the list of preferred projects to be implemented are coal-fired CHP power plants, expect for the "Shuren" 300MW hydropower plant in Selenge River in northern Mongolia.

Table 3-3. Assumptions in All the Scenarios

Scenario/ indicator	Efficient lighting	Building energy efficiency	Losses in T&D		Diesel to CNG		Renewables		
			Electricity	Heat	Bus	Car	Solar	Hydro	Wind
BAU (current situation)	2%	District-90% Efficient-0%	14%	7.7%	Diesel-100% CNG-0%	CNG-0.3% Others-99.7%	1MW	23MW	50 MW
EE assumptions in demand	90%	District-10% Efficient-90%	8%	1.5%	Diesel-80% CNG-20%	CNG-20% Others-80%	N/A	N/A	N/A
REN assumptions in supply	N/A	N/A	N/A	N/A	N/A	N/A	400 MW	520MW	250 MW

Most of the projects that are currently at the stage of bidding and looking for financing are CHP#5, expansion of PP#4, refurbishment of PP#3, and expansion of Darkhan TPP, the 50MW Newcom wind farm, and the "Shuren" HPP.

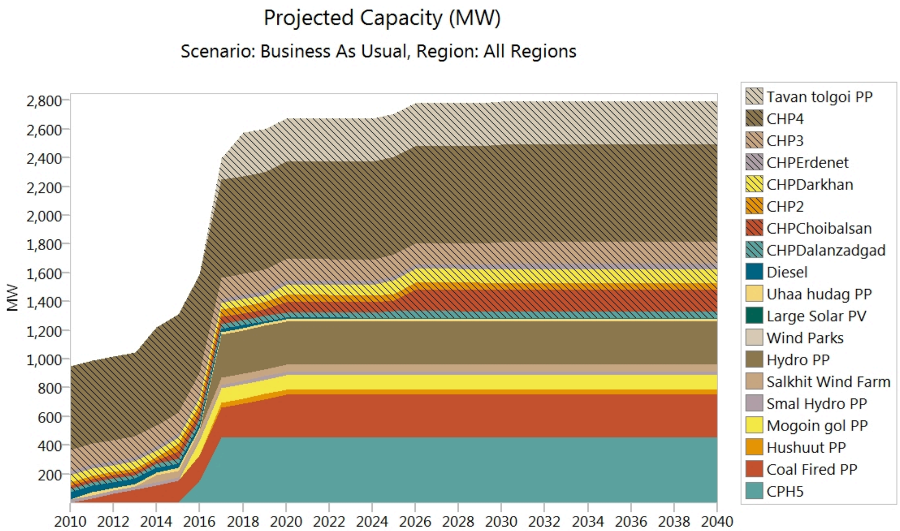

Figure 3-5. Projected capacity in the BAU scenario.

As planned in the BAU scenario, the renewable energy share in the total energy capacity could reach 13%, with a big contribution from the "Shuren" HPP and "Salkhit" wind farms, which means that Mongolia will not be able to accomplish its renewable energy target of 20-25% of its total installed capacity by 2020. The plants will be dispatched according to their specified merit orders as defined in the merit order[6] variables. Each plant will be run (if necessary) up to the limit of its maximum capacity factor in each dispatch period.

In contrast, more renewable energy projects are assumed to be

[6] The merit order is a way of ranking the available sources of energy, especially electrical generation, in ascending order of their short-run marginal costs of production.

implemented, such as the large-scale 400MW PV systems and a total of 250MW wind farms in the Gobi area, and also including two HPPs (Shure-300MW and Eg-220MW) in the REN scenario. In this case, the total installed RE sources account for 26% of the total capacity. Thus, with this scenario, Mongolia can achieve its goal. The potential to achieve the target is not the only positive aspect of implementing the REN scenario; its other benefits will be discussed in the results and analysis chapter.

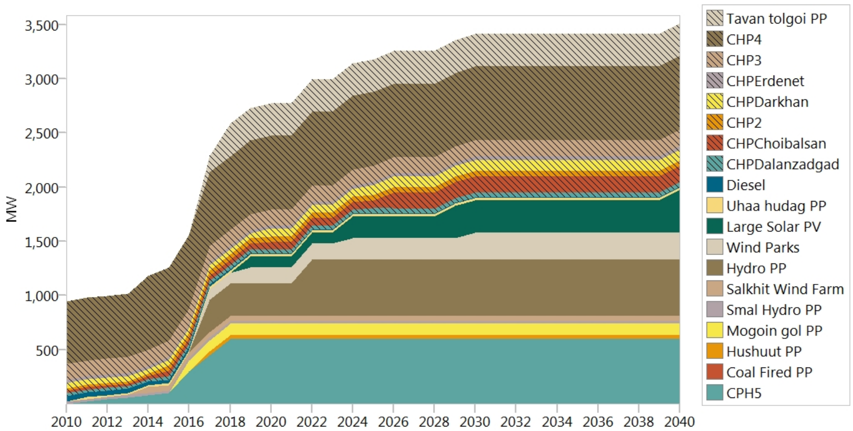

Figure 3-6. Projected capacity in the REN scenario.

The productions of the big mines (Tavan Tolgoi, Oyutolgoi, and others) mentioned above are projected to increase rapidly in the next decades, according to their development plans. For instance, the Oyu Tolgoi copper mine in South Gobi Desert, 80 km (50 mi) north of Mongolia's border with the People's Republic of China, where the mined copper is expected to be shipped, started to produce and export its copper and gold last July, and projected that it would reach its full capacity in 2018, which is 430,000 tons of copper per year, an amount equal to 3% of the global production. Also, its electricity consumption is expected to reach 300 MW when it is operated in full capacity.

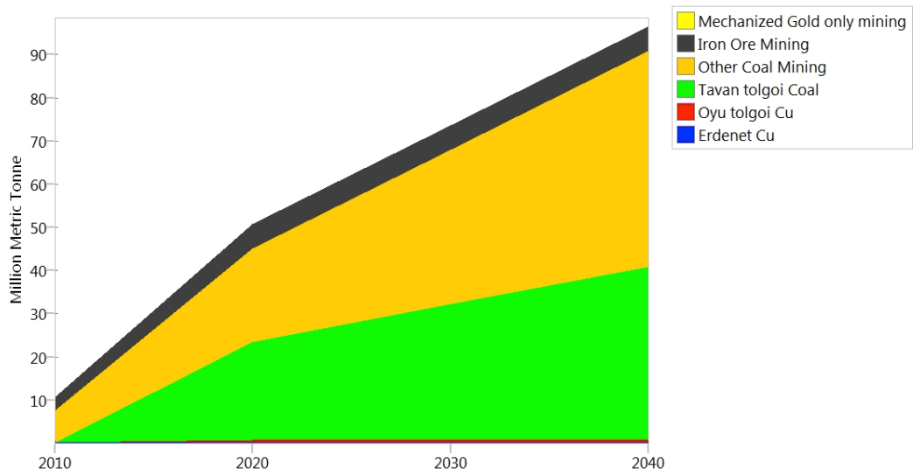

Figure 3-7. Projected mining production in Mongolia.

For the estimated mining production, it is assumed that the same amount will be produced in both the BAU and REN scenarios.

Chapter 4 – Results and Analysis

4.1 Energy Demand

It is assumed in the EE scenario that investing in efficient heating and lighting systems in household buildings and reducing station own use and the losses in energy transmission and distribution can result in 6.09 Mtoe energy savings compared to the BAU scenario.

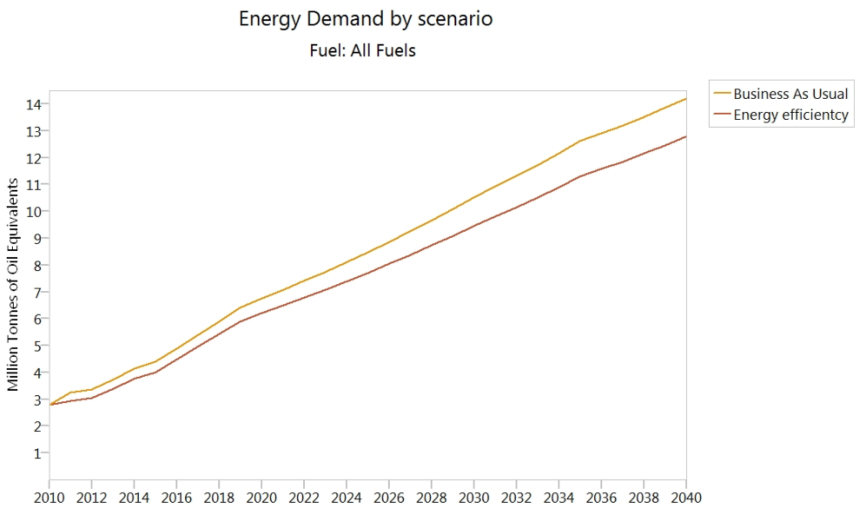

Figure 4-1. Energy demand by sector in the BAU and EE scenarios.

The total energy demand is expected to reach 14.39 Mtoe in 2040 in the BAU scenario, which is 4.53% higher than the 13.8 Mtoe in the EE scenario. (For detailed forecasting data, see Appendix A)

The industry and transport sectors are expected to be the main energy consumers in the next decades. These two sectors are expected to consume approximately 67.9% of the total energy by 2040.

Table 4-1. Energy Demand by Scenario (Unit: Mtoe)

Scenario/Year	2015	2020	2025	2030	2035	2040
Business-as-usual	4.48	6.68	8.61	10.69	12/79	14.36
Energy efficiency	4.40	6.75	8.47	10.53	12.61	14.21

By implementing activities for efficient lighting and building, the energy demand of households in the BAU scenario can be reduced in the EE scenario by 1.95 Mtoe energy. Increasing the use of an efficient heating system in households can also contribute to the reduction of the energy consumption and CO_2 emission in the household sector (Appendix E)

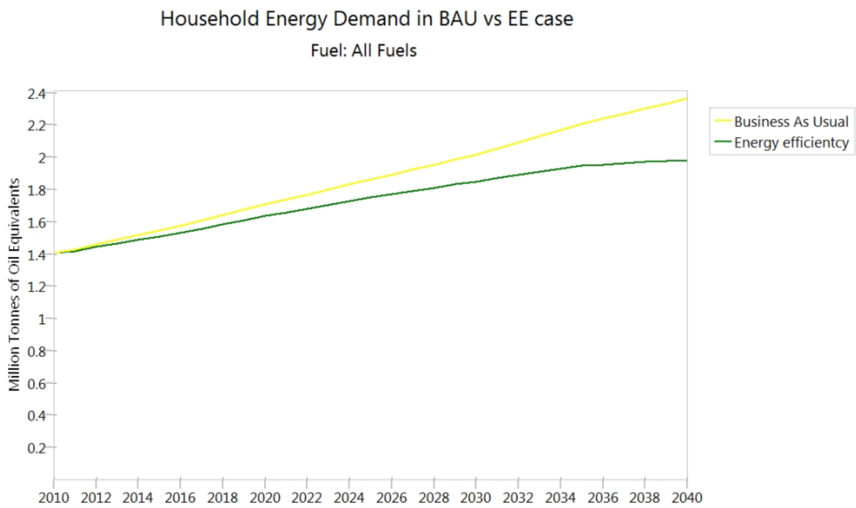

Figure 4-2. Energy demands of the BAU and EE scenarios in the household sector.

The growth in the transport sector, both passenger and freight, is expected to continue. Specifically, there has been a rising trend of buying private vehicles, which is the main factor that is expected to further increase the energy demand of the transport sector in the next decades. Figure 4-3 provides the details of the expected growth in the transport sector.

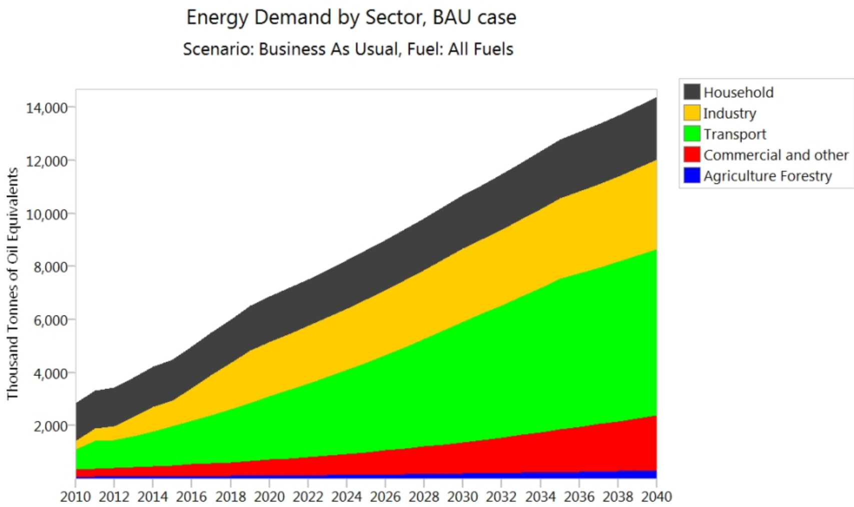

Figure 4-3. Energy demand by sector in the BAU scenario.

The electricity demand of the industrial sector will grow drastically due to the start of the operation of factories of mining and manufacturing facilities, including oil refining and iron ore. The government has a plan to establish an industrial park to produce value-added products in Mongolia. The "Tavan Tolgoi" 300MW coal-fired power plant is in the development stage; it is intended to supply Oyu Tolgoi Mine, which is now being supplied by the Inner Mongolia electricity system (Appendix D).

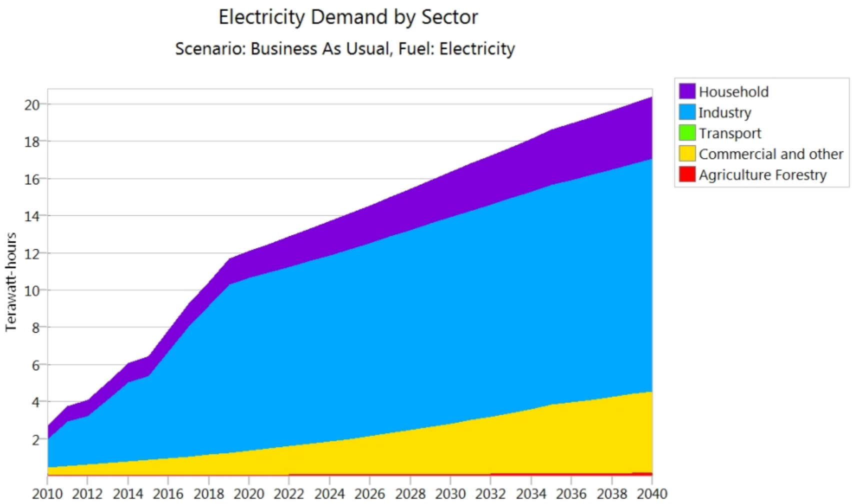

Figure 4-4. Electricity demand by sector in the BAU scenario.

Much of the electricity production will be generated by the coal-fired power plants that are built to produce only power energy. The existing TPP#3 and 4, the proposed power plants (Tavan-tolgoi-300MW, CHP5-450MW, and "Shivee Ovoo"-3600MW), and other power stations are projected as part of the government of Mongolia's plan for the future electricity demand in the BAU scenario (Appendix H). The projects mentioned above are the energy projects that are likely to be executed in terms of the feasibility and current progress of the projects.

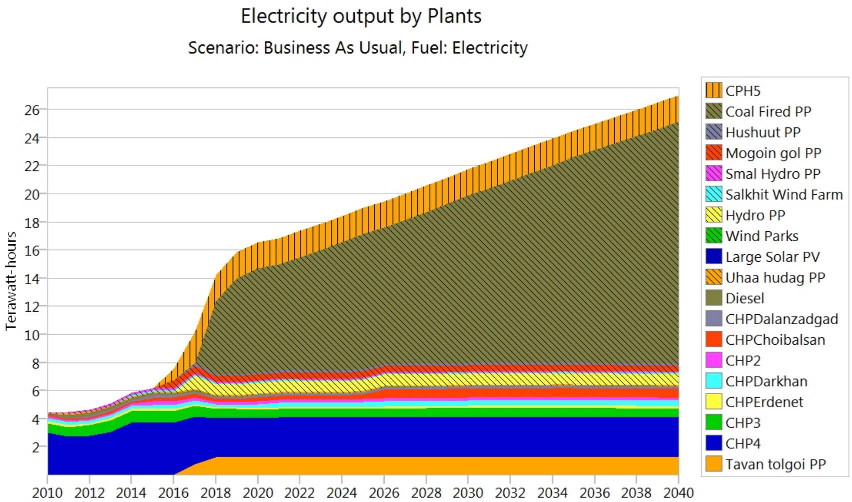

Figure 4-5. Projected electricity production of power stations in the BAU scenario.

The issues of heating shortage and the lack of facilities for extension are more serious than the electricity production. Besides, the heat consumption in the Ulaanbaatar area accounts for more than 80% of the total heat consumption. Another issue is the absence of reliable heating systems in the urban centers of the 21 aimags, where an industrial base has yet to be developed. The steam supplies could not support the ancillary heat and the electricity supplies to the local community. The heat usages of the consumers are basically classified as heating for apartment floors, and hot water is used for two purposes: as hot tap water and for space heating in the residential and industrial processes.

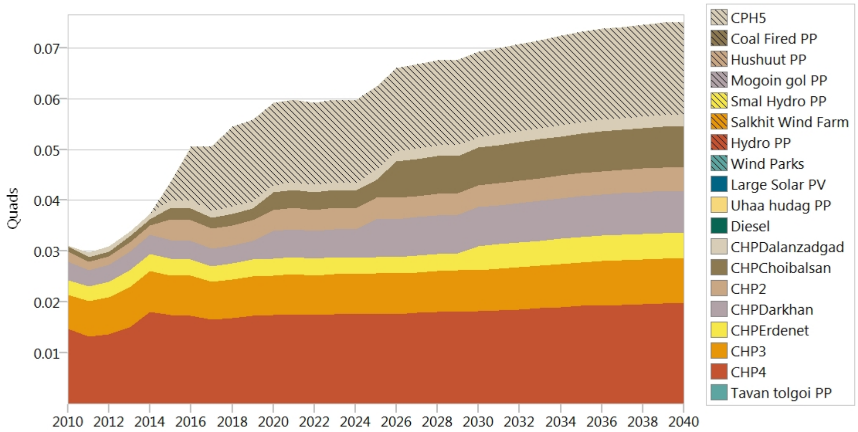

Figure 4-6. Heat production in the BAU scenario by plant.

The existing combined heat and power plants, CHP2, CHP3, CHP4, Darkhan, Erdenet, and the future CHP5, will remain major heat energy producers in CES for the next two decades. Figure 4-6 shows the projected heat production of the CHPs in the future (Appendix D).

In the EE scenario, the passenger sector is deemed to be a potential area where CO_2 emission and energy demand can be reduced. Given that CNG engine buses are expected to replace 20% of the existing diesel engine buses by 2040 from 0.3% in 2010, there would be a 10% CO_2 emission reduction compared to the 240.15 million metric tons of CO_2 in the BAU scenario. Figure 4-7 shows the CO_2 emission in the passenger sector in 2010-2040 (Appendix E, Appendix F, Appendix G).

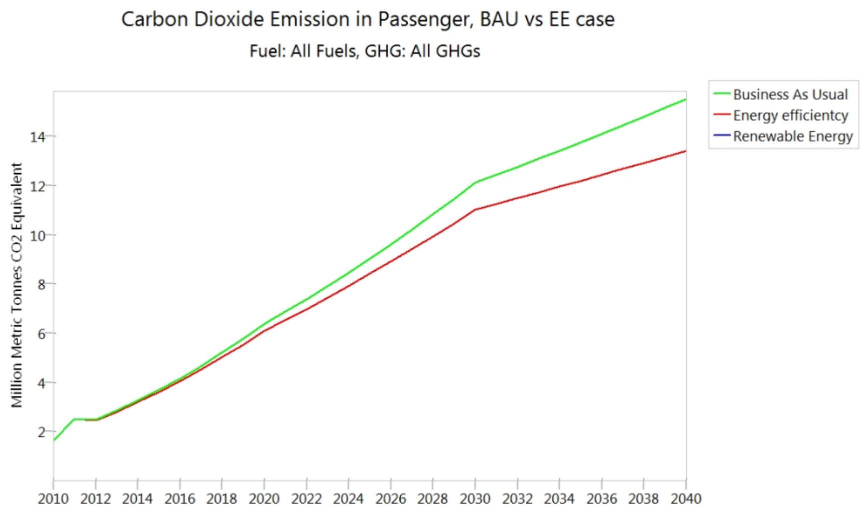

Figure 4-7. CO_2 emission in the passenger sector in the BAU and EE scenarios.

In terms of pollutant types, CO_2's non-biogenic effect will be the main pollutant among the elements, such as methane, nitrous oxide, carbon monoxide, and sulfur dioxide. The amounts of pollutant elements are compared and analyzed in Figure 4-8.

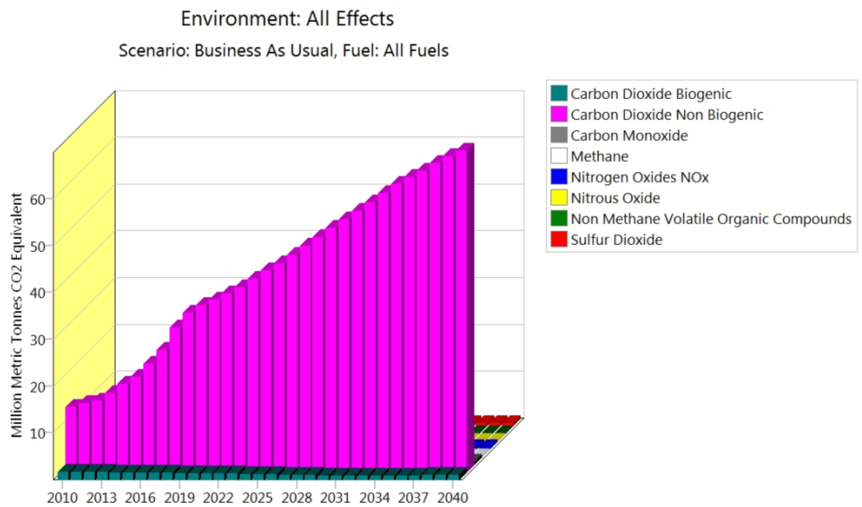

Figure 4-8. Environmental effects in the BAU scenario by pollutant.

The current CO_2 emission of energy transformation is 673.73 million metric tons, which is 18.6% higher than the 567.9 million metric tons CO_2 emission of the energy demand side in the BAU scenario. The dominant use of coal and its transformation process in the energy sector is expected to account for a large fraction of the above number in 2010-2040. In the above figure, the projected emissions of demand and transformation in the energy sector are compared.

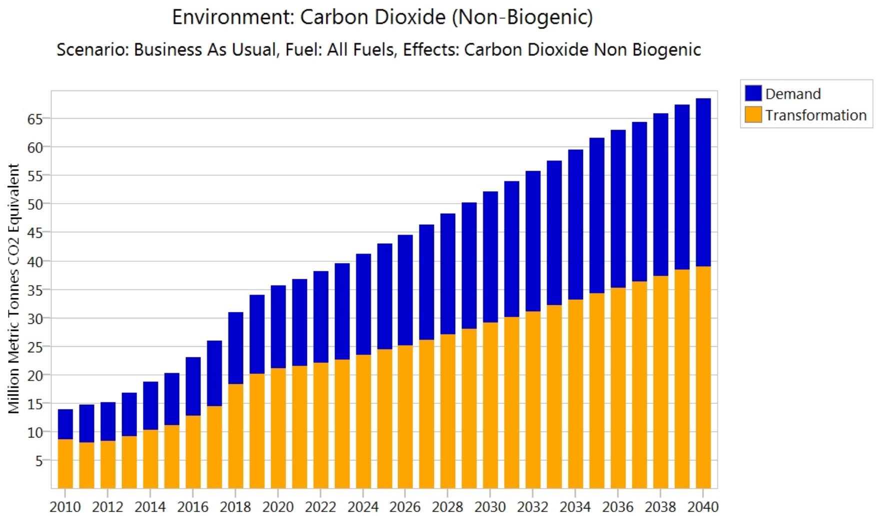

Figure 4-9. CO_2 emission of demand and transformation in the BAU scenario.

An additional USD1.48 billion is estimated to be needed to implement the REN scenario, in which large-scale renewable energy projects (hydro PP, wind farms, and solar PV systems) are assumed to be built. The additional cost is expected to be derived from the relatively high capital cost of renewable energy technologies. Financial support for the projects, however, like CDM and carbon trading, can cover the additional cost. The projected costs of the BAU and REN scenarios are shown in Figure 4-10. Apart from the financial cost comparison, there are other intangible benefits to the environment and society of more green energy projects that have to be taken into account for the scenario evaluation.

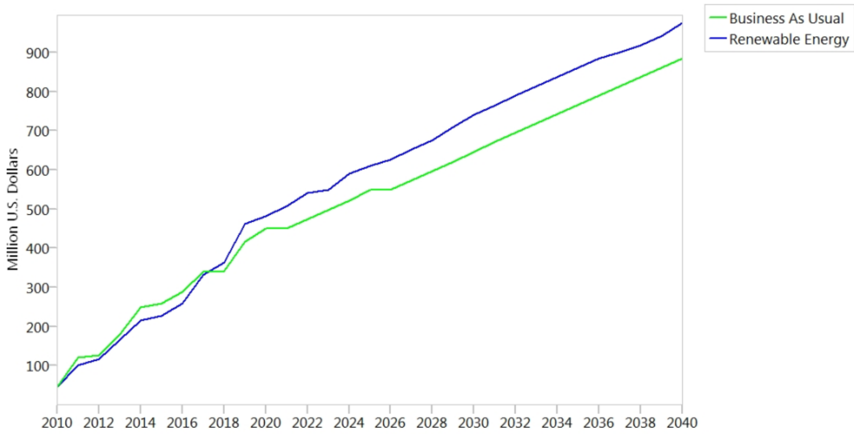

Figure 4-10. Transformation costs in the BAU and REN scenarios.

If the assumptions in the EE scenario will be implemented, the accumulated CO_2 emission will be decreased to 1273.65 million metric tons from 1321.64 million metric tons in the BAU scenario. For the REN scenario, it could reduce the emission more than the EE scenario could, with a difference of 32.05 million metric tons. The estimated CO_2 emission of REN is 1241.6 million metric tons, lower than that of the BAU scenario by 80.04 million metric tons. The CO_2 emissions of all the scenarios are forecasted in Figure 4-11 (Appendix E)

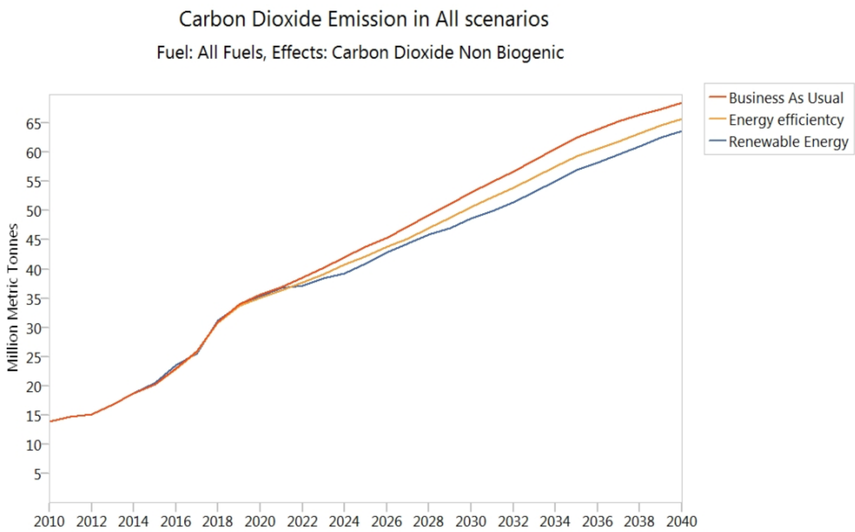

Figure 4-11. CO_2 emissions in all the scenarios.

Chapter 5 - Conclusions and Policy Implications

5.1 Conclusions

The industry and transport sectors are expected to still be the main energy consumers in the next decades. The demand of the sector will be 67.9% of the total energy demand by 2040. The development of big mine projects and the increasing number of vehicles in Mongolia are the main factors contributing to the increased demand.

In the REN scenario, the national renewable energy target — 20% of the total installed capacity by 2020 — can be achieved assuming that there will be more renewable energy deployment in the power generation industry.

Investing in improving the energy efficiency of buildings as well as of heating and lighting can save as much as 50.9 Mtoe energy. Also, reducing the losses in T&D and station internal use will help save energy.

The environmental impact issue of energy consumption (e.g., CO_2 emission) can be mitigated significantly in the combined EE-REN scenario. The CO_2 emission level in the combined scenario — 59.6 million tons of CO_2 — is 13.1% lower than that in the BAU scenario (68.51 million tons of CO_2).

Another promising sector where CO_2 emission and energy use can be reduced is the transport sector. Assuming that 20% of the existing buses will shift from a diesel engine to a CNG engine, and that up to 20% of all vehicles will use CNG (the current penetration rate of CNG cars is only 0.3%), by 2040, the EE scenario is expected to show a 10% higher CO_2 emission reduction compared to the BAU scenario.

Furthermore, while there already exist fuel-efficient vehicles, including hybrid, plug-in hybrid, and electric vehicles, the deployment of these vehicle technologies will face barriers like the lack of infrastructure development for fuel-charging stations, and insufficient incentives.

5.2 Policy Implications

Mongolia's abundant coal reserves make the Mongolian energy sector more dependent on fossil fuel, which accounts for about 70% of the primary energy consumption of the country, and 98.1% of the total power generation is being produced in coal-fired CHPs.

Not surprisingly, coal will be chosen as the main fuel for meeting the country's increasing demand from the perspective of energy security, economic benefits, and technical possibilities, but the impact of coal-fired CHPs on the environment is becoming more serious than ever. There is a possibility of applying carbon capture & storage (CCS), a technology that can significantly reduce the CO_2 emissions of coal-fired power plants, in the projected coal-fired power plants, but high cost and lack of deployment worldwide might constrain the efforts for CO_2 reduction in the power generation sector in Mongolia for the next few years.

The deployment of renewable energy (especially HPP, wind, and solar energy) can reduce the reliance on coal for energy generation in the face of the declining trend of the costs of renewable technologies.

Due to the intermittency of renewable energy, energy storage technologies (ESTs) are needed to fill the energy shortfall in the energy system.

Heat supply is important in Mongolia. Therefore, there is a need to increase the usage of other technologies that produce heat energy, such as heat pumps and boilers, if renewables are to replace the CHPs.

The government of Mongolia needs to revise or update the existing main policy and legal frameworks (e.g., Law on Energy, Law on Renewable Energy, Law on Mongolian Energy, etc.) to support the participation of the private sector in the energy sector.

Based on the energy plans, an energy sector investment structure with a clear mechanism that can describe the size and source of funds for projects must be established. In addition, a monitoring and evaluation system that can assess the performance of the targeted policy and programs based on the energy sector indicators needs to be established. More investment and actions are also needed to reduce the energy demand and to increase the energy efficiency in the sectors with great potentials, such as in achieving energy efficiency in buildings (heating system, building envelope, and lighting), district heating, and in reducing the electricity production, transmission, and distribution losses.

5.3 Future Research

In this thesis, the analyses of the three scenarios mentioned focused on the future energy demand and supply, and on the environmental effects (CO_2 emission) of those scenarios rather than on their costs. The data collection process was time-consuming and was a challenging part of the thesis due to the lack of information or data regarding Mongolia. Below are some important suggestions for the future research that can help make this thesis more comprehensive.

- Calculate and analyze the economic and social costs of the assumptions made in all the scenarios to determine if such assumptions can be implemented. Apart from the effects of energy technologies on energy security, their cost-effectiveness is also a critical factor for the energy planning policymaking of developing countries like Mongolia.
- Build more scenarios in the other sectors to expose the potentials to reduce the energy demand and the CO_2 emission, and also to increase energy efficiency, specifically in the sectors where more energy has been consumed and that are forecasted to have the same demand in the future, such as the mining and manufacturing industries (electricity demand), the vehicle passenger transport sector (oil demand), and the residential housing sector (heating demand for ger district heating and cooking). Also, increasing the electricity import can be another CO_2 reduction solution, but it will increase the level of energy security risk.
- Analyzing the possibility of reducing the CO_2 emission caused by energy-related activities was one of the purposes of this study, taking into account the fact that the CCS technology can radically reduce the CO_2 emissions of coal-fired power plants and industries in a county like Mongolia, where the use of coal dominates the power generation industry. The CCS technology can be introduced along with the construction of all the projected new coal-fired power plants, but the cost of additional fuel and storage as well as other system costs are valued at 30-60% of the total investment for the power plant, depending on certain conditions (McKinsey & Company, 2014).

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Appendix A

Demand: Energy Demand Final Units
Scenario: Business As Usual, Fuel: All Fuels
Branch: Demand
Units: Million Tonnes of Oil Equivalents

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Household	1.41	1.46	1.52	1.58	1.64	1.71	1.77	1.83	1.89	1.95	2.02	2.09	2.17	2.24	2.3	2.37
Industry	0.33	0.53	0.91	1.24	1.74	2.04	2.17	2.31	2.45	2.6	2.76	2.86	2.97	3.09	3.21	3.36
Transport	0.76	1.05	1.32	1.63	1.99	2.39	2.76	3.16	3.59	4.05	4.55	4.99	5.45	5.8	6.02	6.27
Commercial and other	0.27	0.32	0.38	0.45	0.52	0.6	0.69	0.8	0.91	1.04	1.18	1.34	1.52	1.7	1.88	2.08
Agriculture Forestry	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.16	0.17	0.19	0.21	0.23	0.26	0.28	0.31

Demand: Energy Demand Final Units
Scenario: Energy efficiency, Fuel: All Fuels
Branch: Demand
Units: Million Tonnes of Oil Equivalents

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Household	1.41	1.46	1.52	1.58	1.64	1.7	1.76	1.81	1.85	1.9	1.94	1.99	2.04	2.08	2.1	2.13
Industry	0.33	0.53	0.91	1.24	1.74	2.04	2.17	2.31	2.45	2.6	2.76	2.86	2.97	3.09	3.21	3.36
Transport	0.76	1.05	1.31	1.61	1.96	2.35	2.7	3.07	3.47	3.9	4.37	4.77	5.19	5.5	5.7	5.92
Commercial and other	0.27	0.32	0.38	0.45	0.52	0.6	0.69	0.8	0.91	1.04	1.18	1.34	1.52	1.7	1.88	2.08
Agriculture Forestry	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.16	0.17	0.19	0.21	0.23	0.26	0.28	0.31

Appendix B

Demand: Energy Demand Final Units Scenario: Business As Usual Branch: Demand Units: Million Tonnes of Oil Equivalents																
	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Animal Wastes	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.14	0.14	0.14
Brown Coal Briquette	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Candles from Paraffin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coal Bituminous	0.16	0.24	0.46	0.64	0.93	1.09	1.15	1.2	1.26	1.32	1.38	1.4	1.42	1.43	1.44	1.44
Coal Lignite	0.53	0.56	0.58	0.6	0.63	0.66	0.69	0.72	0.75	0.78	0.81	0.86	0.9	0.95	0.99	1.04
Diesel	0.36	0.43	0.49	0.56	0.65	0.74	0.86	0.98	1.13	1.29	1.47	1.66	1.87	2.12	2.4	2.72
Electricity	0.24	0.35	0.52	0.67	0.9	1.04	1.11	1.18	1.25	1.33	1.41	1.48	1.56	1.63	1.69	1.76
Gasoline	0.47	0.72	0.94	1.2	1.5	1.83	2.13	2.44	2.78	3.14	3.53	3.84	4.16	4.36	4.41	4.47
Heat	0.54	0.62	0.69	0.78	0.86	0.96	1.06	1.17	1.29	1.42	1.56	1.71	1.86	2.02	2.17	2.35
Jet Kerosene	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.15	0.16	0.16	0.17
LPG	0	0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.09	0.09	0.1	0.1
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	0.37	0.35	0.34	0.32	0.31	0.3	0.28	0.26	0.24	0.22	0.2	0.19	0.19	0.19	0.2	0.2

Appendix C

Demand: Energy Demand Final Units
Scenario: Energy efficiency
Branch: Demand
Units: Million Tonnes of Oil Equivalents

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Animal Wastes	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.14	0.14	0.14
Brown Coal Briquette	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Candles from Paraffin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coal Bituminous	0.16	0.24	0.46	0.64	0.93	1.09	1.15	1.2	1.26	1.32	1.38	1.4	1.42	1.43	1.44	1.44
Coal Lignite	0.53	0.56	0.58	0.6	0.63	0.66	0.69	0.72	0.75	0.78	0.81	0.86	0.9	0.95	0.99	1.04
Diesel	0.36	0.43	0.49	0.56	0.64	0.74	0.85	0.98	1.12	1.28	1.47	1.65	1.86	2.11	2.39	2.72
Electricity	0.24	0.35	0.52	0.67	0.9	1.04	1.1	1.17	1.24	1.32	1.39	1.47	1.54	1.61	1.67	1.73
Gasoline	0.47	0.71	0.93	1.18	1.46	1.79	2.06	2.36	2.67	3	3.35	3.62	3.9	4.06	4.1	4.13
Heat	0.54	0.62	0.7	0.78	0.87	0.96	1.05	1.16	1.27	1.38	1.5	1.62	1.75	1.88	2	2.13
Jet Kerosene	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.15	0.16	0.16	0.17
LPG	0	0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.09	0.09	0.1	0.1
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0.01	0.01
Solar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	0.37	0.35	0.34	0.32	0.31	0.3	0.28	0.26	0.24	0.22	0.2	0.19	0.19	0.19	0.2	0.2

Appendix D

Demand: Energy Demand Final Units Fuel: Electricity Branch: Demand\Household Units: Terawatt-hours																
	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Business As Usual	0.75	0.88	1.01	1.15	1.3	1.47	1.64	1.82	2.02	2.22	2.44	2.64	2.85	3.04	3.18	3.34
Energy efficiency	0.75	0.87	1	1.13	1.27	1.42	1.57	1.73	1.9	2.08	2.26	2.44	2.64	2.8	2.92	3.05
Renewable Energy	0.75	0.88	1.01	1.15	1.3	1.47	1.64	1.82	2.02	2.22	2.44	2.64	2.85	3.04	3.18	3.34

Demand: Energy Demand Final Units Scenario: Business As Usual, Fuel: Electricity Branch: Demand Units: Terawatt-hours																
	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Household	0.75	0.88	1.01	1.15	1.3	1.47	1.64	1.82	2.02	2.22	2.44	2.64	2.85	3.04	3.18	3.34
Industry	1.52	2.6	4.27	5.74	8.02	9.28	9.65	10.01	10.38	10.75	11.13	11.4	11.68	11.96	12.23	12.52
Transport	0	0	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Commercial and other	0.44	0.58	0.73	0.9	1.09	1.3	1.54	1.79	2.07	2.38	2.72	3.09	3.5	3.84	4.12	4.41
Agriculture Forestry	0.04	0.04	0.04	0.05	0.05	0.06	0.06	0.07	0.08	0.09	0.09	0.1	0.11	0.13	0.14	0.15

Demand: Energy Demand Final Units. Fuel: Heat Branch: Demand\Household Units: Million Gigajoules																
	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Business As Usual	14.71	16.77	18.8	20.91	23.08	25.35	27.63	30.05	32.48	35.03	37.65	39.91	42.28	44.03	45.11	46.2
Energy efficiency	14.71	16.85	18.93	21.05	23.15	25.29	27.34	29.4	31.34	33.24	35.01	36.33	37.55	38.03	37.74	37.3
Renewable Energy	14.71	13.89	15.56	17.27	18.99	20.8	22.61	24.55	26.49	28.54	30.65	32.77	35	36.6	37.49	38.4

Appendix E

Demand: Energy Demand Final Units
Fuel: All Fuels
Branch: Demand\Transport\Passenger
Units: Million Tonnes of Oil Equivalents

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Business As Usual	0.48	0.73	0.96	1.23	1.53	1.88	2.18	2.5	2.85	3.22	3.61	3.93	4.26	4.46	4.52	4.57
Energy efficiency	0.48	0.73	0.95	1.21	1.5	1.83	2.11	2.42	2.73	3.07	3.43	3.71	4	4.17	4.2	4.23
Renewable Energy	0.48	0.73	0.96	1.23	1.53	1.88	2.18	2.5	2.85	3.22	3.61	3.93	4.26	4.46	4.52	4.57

Environment: Carbon Dioxide (Non-Biogenic)
Fuel: All Fuels, Effects: Carbon Dioxide Non Biogenic
Branch: All
Units: Million Metric Tonnes CO2 Equivalent

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Business As Usual	13.91	15.13	18.76	23.04	30.89	35.65	38.55	41.98	45.37	49.17	53.17	56.76	60.57	63.97	66.38	68.51
Energy efficiency	13.91	15.1	18.7	22.93	30.72	35.13	37.65	40.71	43.82	47.01	50.62	53.96	57.48	60.57	63.2	65.74
Renewable Energy	13.91	15.13	18.72	23.53	31.13	35.38	37.23	39.24	42.8	45.88	48.6	51.4	55.02	58.28	60.97	63.63

Environment: Carbon Dioxide (Non-Biogenic)
Fuel: All Fuels, Effects: Carbon Dioxide Non Biogenic
Branch: Demand
Units: Million Metric Tonnes CO2 Equivalent

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Business As Usual	5.38	6.78	8.55	10.31	12.63	14.6	16.1	17.69	19.38	21.18	23.1	24.66	26.32	27.62	28.55	29.56
Energy efficiency	5.38	6.77	8.53	10.25	12.54	14.46	15.9	17.44	19.05	20.76	22.57	24.03	25.57	26.78	27.63	28.56
Renewable Energy	5.38	6.78	8.55	10.31	12.63	14.6	16.1	17.69	19.38	21.18	23.1	24.66	26.32	27.62	28.55	29.56

Appendix F

Environment: Carbon Dioxide (Non-Biogenic) Scenario: Business As Usual, Fuel: All Fuels, Effects: Carbon Dioxide Non Biogenic Branch: Transformation\Generation\Processes Units: Million Metric Tonnes CO2 Equivalent																
	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
CPH5	0	0	0	1.09	2.48	2.45	2.5	2.49	2.5	2.51	2.51	2.51	2.51	2.51	2.5	2.5
Coal Fired PP	0	0	0	0	5.67	8.17	8.91	10.09	10.72	11.94	13.16	14.35	15.56	16.74	17.88	19.03
Hushuut PP	0	0	0	0	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Mogoin gol PP	0	0	0	0.52	0.4	0.39	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Uhaa hudag PP	0	0.08	0.09	0.09	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Diesel	0.05	0.21	0.19	0.15	0.08	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
CHPDalanzadgad	0.05	0.23	0.26	0.38	0.29	0.29	0.29	0.29	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
CHPChoibalsan	0.21	0.23	0.26	0.52	0.39	0.58	0.59	0.59	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
CHP2	0.42	0.35	0.4	0.93	0.7	0.7	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
CHPDarkhan	0.69	0.62	0.7	0.71	0.53	0.79	0.81	0.81	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
CHPErdenet	0.41	0.43	0.49	0.49	0.37	0.37	0.37	0.37	0.37	0.38	0.52	0.52	0.52	0.52	0.52	0.52
CHP3	1.49	1.8	2.03	2.04	1.54	1.52	1.55	1.55	1.55	1.56	1.56	1.56	1.56	1.56	1.56	1.55
CHP4	4.13	4.39	5.79	5.82	4.4	4.35	4.43	4.42	4.44	4.45	4.46	4.46	4.46	4.46	4.44	4.43
Tavan tolgoi PP	0	0	0	0	1.19	1.17	1.19	1.19	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2

Appendix G

Environment: Carbon Dioxide (Non-Biogenic) Scenario: Renewable Energy, Fuel: All Fuels, Effects: Carbon Dioxide Non Biogenic Branch: Transformation\Generation\Processes Units: Million Metric Tonnes CO2 Equivalent																
	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
CPH5	0	0	0	2.09	3.05	3.15	3.16	3.19	3.21	3.29	3.31	3.38	3.45	3.51	3.55	3.57
Coal Fired PP	0	0	0	0	3.02	4.22	4.55	4.83	5.32	6.17	6.63	7.45	8.3	9.19	9.92	10.5
Hushuut PP	0	0	0	0	0.18	0.18	0.18	0.18	0.18	0.19	0.19	0.19	0.2	0.2	0.2	0.2
Mogoin gol PP	0	0	0	0.5	0.49	0.5	0.5	0.51	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.57
Uhaa hudag PP	0	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.1	0.1	0.1	0.1	0.1	0.1
Diesel	0.05	0.21	0.19	0.14	0.1	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03
CHPDalanzadgad	0.05	0.23	0.25	0.37	0.36	0.37	0.37	0.37	0.5	0.51	0.52	0.53	0.54	0.55	0.55	0.56
CHPChoibalsan	0.21	0.23	0.26	0.49	0.48	0.75	0.75	0.76	1.56	1.6	1.61	1.65	1.68	1.71	1.73	1.74
CHP2	0.42	0.35	0.4	0.89	0.87	0.89	0.9	0.9	0.91	0.93	0.94	0.96	0.98	0.99	1.01	1.01
CHPDarkhan	0.69	0.62	0.7	0.67	0.66	1.02	1.02	1.03	1.38	1.42	1.43	1.46	1.49	1.51	1.53	1.54
CHPErdenet	0.41	0.43	0.49	0.47	0.46	0.47	0.47	0.48	0.48	0.49	0.69	0.7	0.72	0.73	0.74	0.74
CHP3	1.49	1.8	2.02	1.95	1.9	1.96	1.96	1.98	1.99	2.04	2.06	2.1	2.15	2.18	2.21	2.22
CHP4	4.13	4.39	5.77	5.56	5.41	5.6	5.61	5.66	5.7	5.83	5.88	6	6.13	6.22	6.3	6.33
Tavan tolgoi PP	0	0	0	0	1.46	1.51	1.51	1.53	1.54	1.57	1.59	1.62	1.65	1.68	1.7	1.71

Appendix H

Transformation: Outputs
Scenario: Business As Usual, Fuel: Electricity
Branch: Transformation\Generation\Processes
Units: Terawatt-hour

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
CPH5	0	0	0	0.82	1.87	1.85	1.88	1.88	1.88	1.89	1.89	1.89	1.89	1.89	1.89	1.88
Coal Fired PP	0	0	0	0	5.13	7.39	8.06	9.13	9.7	10.8	11.91	12.98	14.08	15.15	16.17	17.21
Hushuut PP	0	0	0	0	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Mogoin gol PP	0	0	0	0.55	0.42	0.41	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Smal Hydro PP	0.08	0.11	0.13	0.13	0.1	0.09	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Salkhit Wind Farm	0	0	0.11	0.11	0.09	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Hydro PP	0	0	0	0	0.78	0.77	0.78	0.78	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.78
Wind Parks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large Solar PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uhaa hudag PP	0	0.09	0.1	0.1	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Diesel	0.05	0.2	0.19	0.14	0.07	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
CHPDalanzadgad	0.02	0.1	0.11	0.17	0.13	0.13	0.13	0.13	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
CHPChoibalsan	0.11	0.12	0.13	0.26	0.2	0.3	0.3	0.3	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
CHP2	0.12	0.1	0.12	0.27	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
CHPDarkhan	0.26	0.23	0.26	0.26	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
CHPErdenet	0.13	0.14	0.16	0.16	0.12	0.12	0.12	0.12	0.12	0.12	0.17	0.17	0.17	0.17	0.17	0.17
CHP3	0.67	0.72	0.81	0.81	0.61	0.61	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
CHP4	3	2.81	3.72	3.73	2.82	2.79	2.84	2.84	2.85	2.85	2.86	2.86	2.86	2.86	2.85	2.84
Tavan tolgoi PP	0	0	0	0	1.25	1.23	1.25	1.25	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.25

Appendix I

Transformation: Outputs
Scenario: Renewable Energy, Fuel: Electricity
Branch: Transformation\Generation\Processes
Units: Terawatt-hours

	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
CPH5	0	0	0	1.57	2.3	2.38	2.38	2.4	2.42	2.48	2.5	2.55	2.6	2.64	2.67	2.69
Coal Fired PP	0	0	0	0	2.73	3.82	4.12	4.37	4.81	5.58	6	6.74	7.51	8.31	8.97	9.49
Hushuut PP	0	0	0	0	0.18	0.19	0.19	0.19	0.19	0.2	0.2	0.2	0.21	0.21	0.21	0.21
Mogoin gol PP	0	0	0	0.52	0.51	0.53	0.53	0.53	0.54	0.55	0.55	0.57	0.58	0.59	0.59	0.6
Smal Hydro PP	0.08	0.11	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14
Salkhit Wind Farm	0	0	0.17	0.16	0.16	0.17	0.17	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.19	0.19
Hydro PP	0	0	0	0	0.96	0.99	1.72	1.73	1.75	1.79	1.8	1.84	1.88	1.91	1.93	1.94
Wind Parks	0	0	0	0	0.32	0.5	0.5	0.67	0.67	0.69	0.87	0.88	0.9	0.92	0.93	0.93
Large Solar PV	0	0	0	0	0	0.33	0.33	0.67	0.67	0.69	1.04	1.06	1.08	1.1	1.11	1.49
Uhaa hudag PP	0	0.09	0.1	0.09	0.09	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.11	0.11	0.11
Diesel	0.05	0.2	0.19	0.14	0.09	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03
CHPDalanzadgad	0.02	0.1	0.11	0.17	0.16	0.17	0.17	0.17	0.23	0.23	0.23	0.24	0.24	0.25	0.25	0.25
CHPChoibalsan	0.11	0.12	0.13	0.25	0.25	0.38	0.38	0.38	0.8	0.81	0.82	0.84	0.86	0.87	0.88	0.88
CHP2	0.12	0.1	0.12	0.26	0.26	0.26	0.26	0.27	0.27	0.28	0.28	0.28	0.29	0.29	0.3	0.3
CHPDarkhan	0.26	0.23	0.26	0.25	0.25	0.38	0.38	0.38	0.52	0.53	0.53	0.54	0.56	0.56	0.57	0.57
CHPErdenet	0.13	0.14	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.22	0.23	0.23	0.23	0.24	0.24
CHP3	0.67	0.72	0.81	0.78	0.76	0.78	0.78	0.79	0.8	0.81	0.82	0.84	0.86	0.87	0.88	0.88
CHP4	3	2.81	3.7	3.57	3.47	3.59	3.6	3.63	3.65	3.74	3.77	3.85	3.93	3.99	4.04	4.06
Tavan tolgoi PP	0	0	0	0	1.53	1.58	1.59	1.6	1.61	1.65	1.66	1.7	1.74	1.76	1.78	1.79

장기 에너지 대체 계획 시스템(LEAP) 모델을 사용한 몽고의 에너지 수요와 공급에 대한 장기 예측

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초록

제대로 관리될 경우 풍부한 천연자원으로 인해 독립적, 지속적이며 청정한 에너지 개발의 가능성이 크기 때문에, 에너지 수요 및 공급에 대한 장기 예측은 몽고에서 매우 중요한 주제 중의 하나이다. 본 학위 논문에서는, 몽고의 에너지 분야에 대한 현재 상황과 경제 및 환경에서의 역할 및 공헌에 대한 개요, 그리고 해당 분야의 포괄적인 평가까지도 제시하고 있다. 가장 중요한 점은, 몽고에서의 향후 에너지 수요 및 공급을 예측하고, 경제적 발전, 환경적 지속성 및 에너지 안보를 지속할 수 있는 가능한 시나리오들을 구축 및 비교하기 위하여 장기 에너지 대체 계획 시스템(LEAP) 모델을 사용하였다는 점이다.
본 학위 논문에서는, 2040 년까지 몽고에서의 장기 에너지 개발에 대한 세 가지 시나리오가 LEAP 모델을 통하여 구축되었으며, 2010 년이 기준 년으로 설정되어 있다. 에너지 수요 및 공급의 예측은 평상시 대로(BAU)의 사례에 따라 기존의 국가 에너지 계획 및 동향을 기준으로 한 것이며, 수력, 풍력 및 태양 에너지와 같이 몽고에서 사용 가능한 재생성 에너지 자원들을 기준으로 한 구성은 재생성 에너지(REN) 시나리오에서 제시된 대로이며, 에너지 효율(EE) 시나리오에서 가정 및 분석된 경제적 관점에 따라 에너지 효율이 향상되는 것으로 하였다. 각 시나리오는 상이한 특성을 보이며 명확히 구분되는 개발 경로를 나타낼 수 있으며, 이는 몽고의 에너지 분야로 적용될 수 있을 것이다.

학번 2012-22599
키워드: LEAP, 에너지 계획, 시나리오, 몽도, BAU, EE 및 REN