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Final Report

District Energy Systems Development Roadmap Study in APEC Economies

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Acronyms

APEC	Asia-Pacific Economic Cooperation
AEI	Advanced Energy Initiative
BCET	Buildings and Communities Energy Technology Program
CHP	Combined Heat and Power
CCHP	Combined Cooling, Heating and Power
CWSRF	Clean Water State Revolving Fund
CCTP	Climate Change Technology Program
CIEEDAC	Canadian Industrial Energy End-use Data and Analysis Centre
CED	Clean Energy Dialogue
CRCE	Canadian Renewable and Conservation Expenses
CCA	Capital Cost Allowance
CHPSOP	Combined Heat & Power Standard Offer Program
COMFIT	Community Feed-in Tariff
CEGB	Central Electricity Generating Board
CPS	Carbon Price Support
CHPQA	CHP Quality Assurance
CCA	Climate Change Act 2008
CERT	Carbon Emissions Reduction Target
CESP	Community Energy Saving Programme
CPF	Carbon Price Floor
DES	District Energy System
DHC	District Heating and Cooling
DH	District Heating
DC	District Cooling
DOE	Department of Energy
DEA	Danish Energy Agency
DoE	Department of Energy
EWG	Energy Working Group
EPAct	Energy Policy Act
EU ETS	EU Emissions Trading Scheme
ECO	Energy Companies Obligation
ECA	Enhanced Capital Allowance
FERC	Federal Energy Regulatory Commission
FCM	Federation of Canadian Municipalities
FIT	Feed-in-Tariff
GHG	Greenhouse Gas

GDP	Gross Domestic Product
GST	Goods and Services Tax
GIB	Green Investment Bank
IEA	International Energy Agency
IDEA	International District Energy Agency
ITC	Investment Tax Credit
LDC	Local Distribution Company
LNG	Liquid Natural Gas
LPG	Liquefied Petroleum Gas
LEB	Local Electricity Board
NARUC	National Association of Regulatory Utility Commissioners
NRSL	Net Revenue Support Level
NBP	National Balancing Point
nZEB	nearly Zero Energy Buildings
OECD	Organization for Economic Co-operation and Development
Ofgem	Office of Gas and Electricity Markets
OFFER	Office of Electricity Regulation
PURPA	Public Utilities Regulatory Policy Act
QECB	Qualified Energy Conservation Bonds
RECS	Residential Energy Consumption Survey
RPSs	Renewable Portfolio Standards
RPG	Renewable Portfolio Goal
REAP	Renewable Energy for America Program's
RAP	Repowering Assistance Program
RECs	Regional Electricity Companies
ROCs	Renewables Obligation Certificates
RHI	Renewable Heat Incentive
SPV	Special Purpose Vehicles
SGIP	Small Generator Interconnection Procedures
SGIA	Small Generator Interconnection Agreement
SEP	State Energy Program
SD	Sustainable Development
TPES	Total Primary Energy Supply
U.S.A.	United States of America
US/U.S.	United States
U.S.EPA	U.S. Environmental Protection Agency
UKCS	UK Continental Shelf
UK	United Kingdom

1. Introduction

1.1 Background

District energy systems (DES) produce steam, hot water or chilled water at a central plant and pipe them underground through a dedicated piping network to heat or cool buildings in a given area, reducing energy costs and greenhouse gas emissions. As a result, individual buildings served by a district energy system don't need their own boilers or furnaces, chillers or air conditioners, which frees up valuable space in customer buildings and optimizes the use of fuels, power and resources[1,2]. The district energy supply may come from a conventional boiler or chiller, geothermal wells, a water body such as lake or river, or waste heat captured from industrial processes or electrical generation (combined heat and power). DES is often more energy efficient than the conventional boilers and chiller systems, and is also advantageous in terms of reducing the burden on infrastructure and reducing fossil fuels usage, as well as limiting the associated carbon emissions. In the statement of APEC Energy Ministers' meeting held in St. Petersburg in 2012, more energy efficient transport, industry, buildings and power grids, combined in more energy-efficient communities, can reduce both the direct use of fossil fuels and the demand for electricity which continues to be generated in large quantities from natural gas and coal. The development roadmap study of DES in APEC economies directly respond to APEC Energy Ministers' statement and the EWG work plan in promoting energy-efficient measures.

Many other techniques and approaches, including solar power and biofuel, can be rather expensive measures for many developing economies. However, most DES techniques, e.g. Combined Heat and Power (CHP), are proved to be one of the most cost-effective options of heating and cooling for dense downtown areas, colleges and universities. Promotion of DES in APEC developing economies offers these members an affordable measure of energy conservation.

To be cost-effective, a DES system needs to be incorporated into a project early in the design phase. Careful consideration of the upfront costs versus the return potential is required with DHC, since not all projects are necessarily good candidates for the technology. In a larger scale, the promotion of DES might suit differently in different economies or regions for their diverse background. Nevertheless, DES technology has had well-established knowledge and implementation experiences in developed APEC economies, e.g. US, Canada and Japan. For example, District energy systems have been operating in the US for over 100 years and currently serve more than 4.3 billion square ft of building space. This project proposes to study the DES technology and implementation systematically, aiming to introduce these knowledge and experiences to APEC developing economies in a broader range and develop a practice guideline for local decision makers and urban planners. The seminar/workshop and the symposium, if approved, shall include more participants from APEC members in the study and campaign, hoping to have a significant impact on the governments of developing economies to realize the necessity of DES and resolve specific implementation problems. District energy systems are flexible with the energy source type, hence are able to incorporate with other alternative energy techniques. Promoting DES will reduce costs of these techniques and stimulate their growth.

Energy security is of another priority by APEC and EWG in a long term concern. District Energy Systems often distribute power supply plants into communities and use low-impact, renewable energy sources, which significantly lowers the possibilities of accidents related to power plants. The distributed energy sources can also reduce the energy loss due to long distance transmission.

1.2 Objective

The project intends to reconcile experiences and techniques in DES division, and provide a platform for better communication between APEC economies. In detail, the objectives of this project are to:

a) Provide surveys and in-depth examinations of a number of case studies of the development and implementation of District Energy Systems (DES) in selected APEC member economies;

b) Develop practice guidelines that will assist urban planners and other stakeholders of APEC economies, especially of developing economies, in their decision making and planning protocols of using DES in different development scales. In addition, the guidelines shall raise problems like barriers and limitations of DES in certain regions, as well as strategies to solve these problems.

2. Overall Information

2.1 Definition of District Energy

District energy refers to district heating, district cooling, district power supply and integrated systems which are to solve district energy supply within given regions. It is the local production and distribution of thermal and power energy and is a highly efficient means of providing locally generated thermal energy for heating and cooling residential, commercial and institutional buildings, and industrial processes.[3]

District energy systems produce steam, hot water or chilled water at a central plant and pipe them underground through piping networks to heat or cool buildings in a given area, reducing energy costs and greenhouse gas emissions.[1,2] It comprises of two main elements:

－ A central energy plant with equipment that produces thermal energy for heating, or chilled water for cooling. The central plant may also incorporate combined heat and power (CHP) units which produce electricity and useful thermal energy.

－ A insulated pipe network to distribute the thermal energy from the central plant to the buildings.[3]

The definition of DES varies in composition and scale, as well as in its regulatory and legislative treatment. The scope of a “district” could be as small as several neighboring buildings, and as big as a city. It can also refer to development zones and industrial parks etc.

The district energy system can be boiler heating system, chiller system, thermal power plant system, CCHP system and heat pump system etc. The applicable energy can be coal, oil, natural gas, renewables and biomass etc. The core target of district energy is to consider the energy and resources and application types of the energy comprehensively based on certain regions under the prerequisite of meeting the reasonable district energy demand and reduce the energy consumption, hazardous emission as much as possible to achieve the best economic and social benefits.

2.2 Typical District Energy System

From the energy type perspective, the energy is divided into primary energy and secondary energy. The primary energy can be divided into two types, i.e. non-renewable energy, e.g. coal, oil, natural gas, fissile material, nuclear fusion material etc. and renewable energy, e.g. hydropower, solar energy, wind power, biomass etc. While the secondary energy is mainly refer to electricity, coke, gas, oil products, biogas, steam, hot water etc. From the functional perspective, DES is defined in this report an energy option that incorporates District Heating, District Cooling and Combined Heating and Power (CHP), which are defined below.

District heating distributes heat generated in a centralized location for residential and commercial heating requirements such as space heating and water heating. The first and the most prevalent form of DES, has been operated over the centuries in Europe and North America. The first commercially successful district heating system was launched in Lockport, N.Y., in 1877 by American hydraulic engineer Birdsill Holly, considered the founder of district heating.

District cooling distributes thermal energy in the form of chilled water from a central plant to multiple buildings through a network of underground pipes for use in space and process cooling. District Cooling eliminates the need for separate systems in individual buildings. The main idea of District Cooling (similar to District Heating) is to use local sources that otherwise would be wasted or difficult to use. District cooling also has its roots in the nineteenth century. It was introduced as a scheme to distribute clean, cool air to houses through underground pipes. The first known district cooling system began operations at Denver's Colorado Automatic Refrigerator Company in the United States in late 1889. In the 1930's, large district cooling systems were created for Rockefeller Centre in New York City and for the U.S. Capital Buildings in Washington, D.C.

Combined Heat and Power (CHP) solutions, or Cogeneration, originated from a simple idea of utilizing the wasted thermal energy in a power plant. Early electrical developers provided electricity to customers and sent the waste heat through steam pipes for space heating. This concept of what has been referred to as cogeneration was first implemented in 1884 to provide energy for the Del Coronado Hotel in San Diego. Academic campuses are often great locations for this technology. CHP efficiencies can exceed 70%, making them the most efficient method available today for converting carbon based fuels into usable energy. As last reported in March 2008, the International Energy Agency (IEA) views combined heat and power (CHP), particularly in combination with district heating and cooling (DHC) systems, to be one of the easiest and most attractive strategies to improve energy supply efficiency and reduce greenhouse gas (GHG) emissions.

Combined Cooling, Heating and Power system, also referred to as Trigeneration, is the combination of cogeneration plants and absorption chillers and use the primary energy to provide heating, cooling and electricity to the customers which realizes the cascade utilization of energy and increase the energy efficiency.[4,5]

2.3 Advantages of District Energy

High efficiency with low cost. District energy systems produce and distribute thermal energy at a local level achieving higher energy efficient in converting primary energy into usable energy, especially when combined with power generation through CHP compared to conventional facilities.[3] For a traditional fossil-fueled power plants, it generally achieves a total system efficiency of approximately 33 percent with the rest 67 percent losing and venting as heat. [6]While a CHP system can achieve total system efficiencies of nearly 60 to 80 percent.[7] Although the initial investment will be large, considering the long-term economic benefits, this higher efficiency leads to lower costs, especially when using local fuels.[3]

Reduce greenhouse gas emissions and other environmental impacts. With the high efficiency in using fossil fuels, the district energy system could reduce the emissions of carbon dioxide and other pollutants like nitrogen oxides (NOx) and sulfur dioxide (SO_2) etc.[6] For example, a 5 MW CHP system with a natural gas turbine typically produces a yearly CO_2 emissions of 20,870 metric tons, while a conventional system achieved the same output would produce 44,450 metric tons. The GHG emissions reduced by a CHP system of this size are equivalent to the annual emissions of more than 5,400 passenger vehicles[8].

Increase flexibility and resilience. The district energy networks can take heat from various sources, fuels, and technologies which make it very flexible and enable communities to have a more secure energy supply [3]. As for the government, disruption on the energy supply can be a serious risk while the DES can be designed to disconnect from the grid, which enables the system to operate even if the grid electricity is lost due to extreme weather conditions or other circumstances. [6] In addition, district energy networks allow town and city managers to secure the optimum supply position and CHP can reduce peak load and the risk of blackouts. Lastly, district energy systems can provide “future proof” to communities, since new and emerging technologies like heat pumps, fuel cells, or biofuels can be easily and rapidly retrofitted, without the need to install equipment in each building. [3]

Ease of operation and maintenance. With district energy, customers do not need boilers or chillers, so there is less maintenance, monitoring and equipment requirements. District energy customers also avoid the need for fuel deliveries, handling and storage so that fewer safety and liability concerns should be paid by employees and building occupants. In addition, the use of district energy service spare valuable building space by eliminating the need for mechanical rooms, freeing up space to meet tenant needs. [1]

Local control. As district energy systems focus on energy supply in certain region, it can be operated and controlled on a local level. The local operation control ensures that investment decisions are being made close to the point of impact and conduct quick reaction once breakdown occurs. Moreover, thermal energy services can be delivered through community-owned, not-for-profit special purpose vehicles (SPVs), which allow surpluses to be taken as revenues by local municipalities to help deliver other front-line services. Or, by putting an asset lock on SPVs. [3]

Comfort and convenience for customers. District energy service enables building operators to manage and control their own indoor environments and get comfortable and satisfied surroundings whatever the outdoor temperature is. In addition, district energy can reduce vibrations and noise problems that may annoy building occupants. [1]

Support economic growth by job creation and market development. Investing in district energy systems can stimulate local, state, and regional economies. The demand for raw materials and for construction, installation, and maintenance services can provide jobs opportunities and develop markets for CHP technologies [9]. Apart from this, energy costs saved by the facilities can be invested elsewhere, often contributing to the local economy. [10]

Demonstrate leadership. Using district energy systems at local government facilities can be an effective and visible way of demonstrating environmental and fiscal responsibility to the public. The systems installed at facilities can lead to greater community awareness of local government leadership and the benefits of clean energy. [6]

3. Case Study of Selected Countries

3.1 District Energy System in United States

3.1.1 National Overview

3.1.1.1 General Information

The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the IEA.
Source: *IEA*.

Figure 3.1.1 the Map of United States [11]

The United States of America (USA or U.S.A.), commonly referred to as the United States (US or U.S.), is a federal republic with a covered area of 9.62 million km^2, which is the third or fourth largest countries around the world by total area. It consists of 50 states and a federal district. Among them, 48 contiguous states and Washington, D.C., are in central North America between Canada and Mexico, Alaska is in the northwestern part of North America, while Hawaii is an archipelago in the mid-Pacific. Moreover, the country has five populated and nine unpopulated territories in the Pacific and the Caribbean. [12] In 2014, according to U.S. Census Bureau estimates, the population of the U.S. is increasing to more than 317 million, which keeps the U.S. a country with the third largest population. [13] The major population areas are New York City and northern New Jersey on the east coast and Los Angeles, Long Beach and Santa Ana on the west coast. [11]

As a federal republic, the government is based on a strong division of power, with three main branches-the executive branch, the legislative branch and the judicial branch. It has the largest and most technically powerful economy in the world, with a per capita GDP of $49,800.[14] And the total GDP in U.S. is nearly 16,800 billion dollars in 2013, increasing by 3.7% comparing to $16,244.6 billion in 2012.[15] Moreover, the GDP by purchasing power parity is estimated $16.72 trillion in 2013, ranking 1st worldwide.[14]

The United States enjoys a market-oriented economy so that the private individuals and business firms make most of the decisions. The business firms are more flexibility in making decisions of expanding capital plant, laying off surplus workers, developing new products etc. than their counterparts in Western Europe and Japan. [14]

3.1.1.2 Climate

The United States has a wide range of climates, varying from the tropical rain-forest of Hawaii and the tropical savanna of S Florida to the subarctic and tundra climates of Alaska. [16] The eastern/northern parts of US suffer harsh winters with heavy snowfall while the summers are temperate. The western/southern parts experience extremely hot summers and comparatively tolerable winters. The annual average temperature in U.S. is around 52.7℉ (11.5℃) excluding Hawaii and Alaska, with an annual temperature for each states ranging from 70.7℉ (21.5℃) in Hawaii to 26.6℉ (-3.0℃) in Alaska.[17,18] In this case, heating and cooling play different role depending on various states.

3.1.2. Energy Background

3.1.2.1 Energy Structure

As the largest economy around the world, the United States enjoys a diverse source of energy supply, with energy sources shifting from wood, biomass and small amounts of coal to those used for higher forms of human socioeconomic organization such as industry, manufacturing, transportation and communication.[19] Moreover, it is the world's 2nd largest energy consumer and ranks 7th in energy consumption per capita after Canada.[20] It relies on fossil fuels for almost all its energy supply and is fully self-sufficient in coal and largely self-sufficient in natural gas, with around a fifth of gas supplied by imports from North American neighbors. Because of the high demand for oil, however, the United States is heavily dependent on oil imports, and the import dependence has increased since 1990 to reach over 50% in 2005. [11]

In the United States, there are five primary fuels, i.e. crude oil, natural gas, coal, nuclear and renewable energy. In U.S., because of the high demand of oil, its dependency on oil imports has increased from 1990 to reach above 50% in 2005. In addition, the U.S. produced 70% of its energy demand domestically in 2005 and its imports had nearly doubled from 16% in 1990 to 30% in 2005. While renewable energy plays a relatively small role in U.S. energy supply. [11]

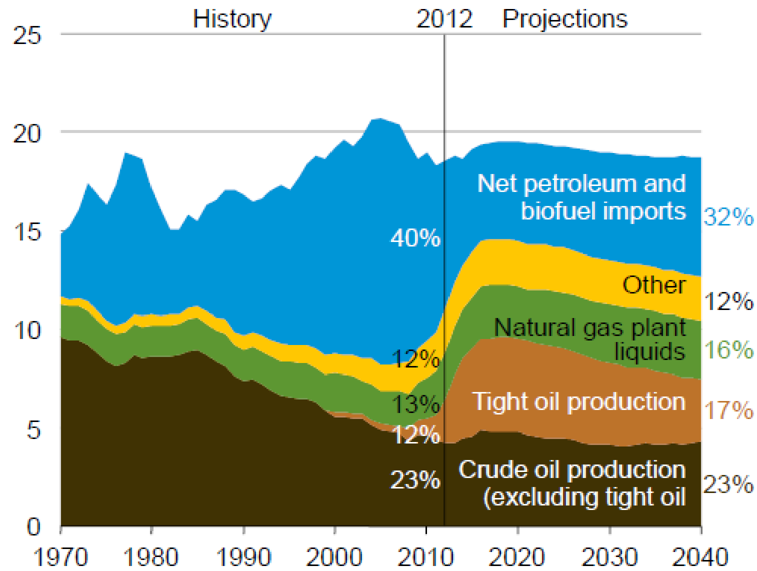


Figure 3.1.2 U.S. Petroleum and Other Liquid Fuels Supply By Source, 1970-2040 (million barrels per day) [21]

Since 1970, the net petroleum and biofuel imports supply has experienced a rising trend to 2005 and then decreased sharply to 2012, accounting for 40% of energy supply. For the crude oil production, it has seen a gradually decline since 1970, reaching 23% of the energy supply in 2012. Conversely, the tight oil production, natural gas plant liquids and others have seen a slightly increase, accounting for 12%, 13% and 12% respectively in 2012 (see figure 3.1.2).

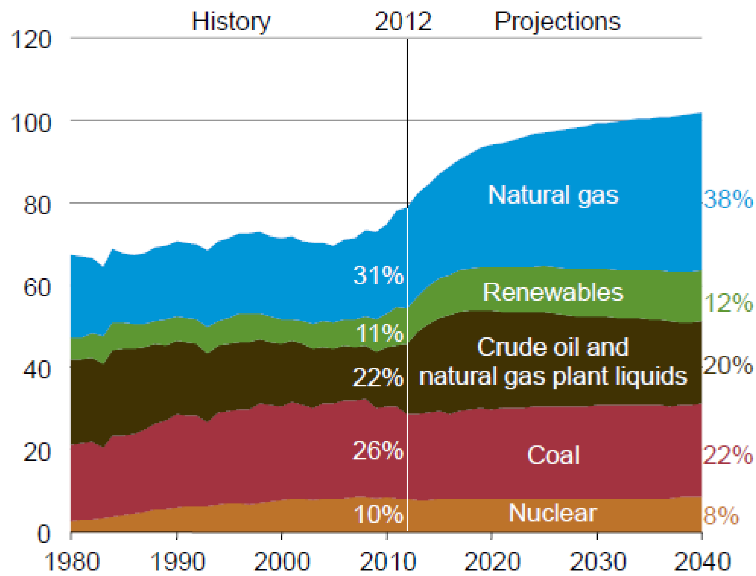
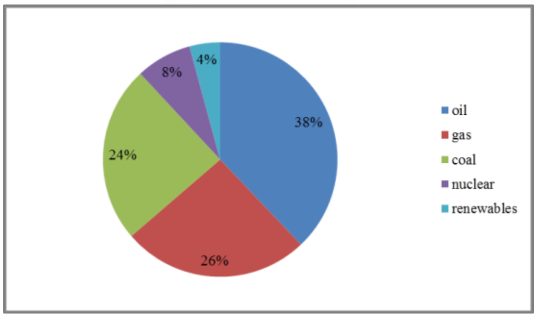


Figure 3.1.3 U.S. Energy Production By Sector, 1980-2040 [21]

In the United States, the natural gas produced the largest energy in 2012, accounting for 31% of the energy consumption and energy produced by coal accounts for the second-largest energy production, more than a quarter in 2012 (see figure 3.1.3).



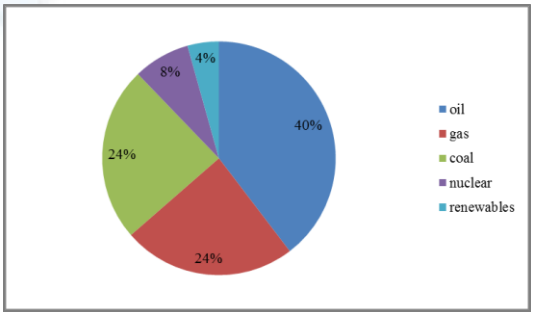
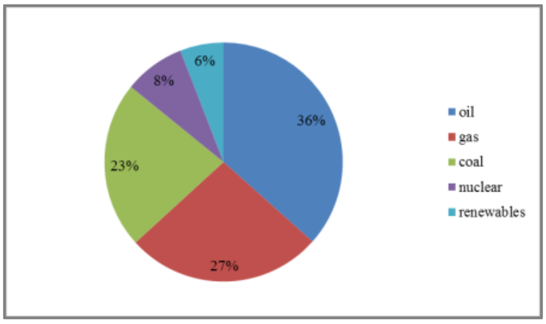


Figure 3.1.4 United States Energy Consumption in 2000[22] Figure 3.1.5 United States Energy Consumption in 2005[22]



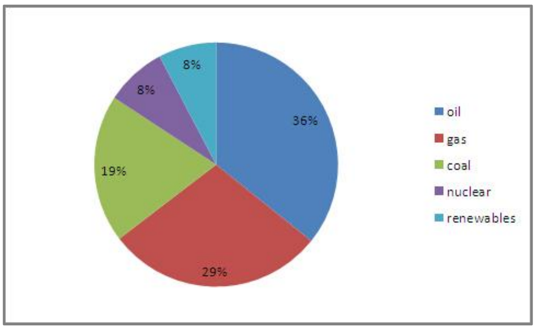


Figure 3.1.6 United States Energy Consumption in 2010[22] Figure 3.1.7 United States Energy Consumption in 2013 [22]

Seen from the four figures above, for the energy consumption, crude oil accounts for 36% of the total energy supple with natural gas followed, representing 29 percent of the total energy supply. Coal makes up 19% and nuclear and renewables accounts for the same, 8% respectively in 2013.

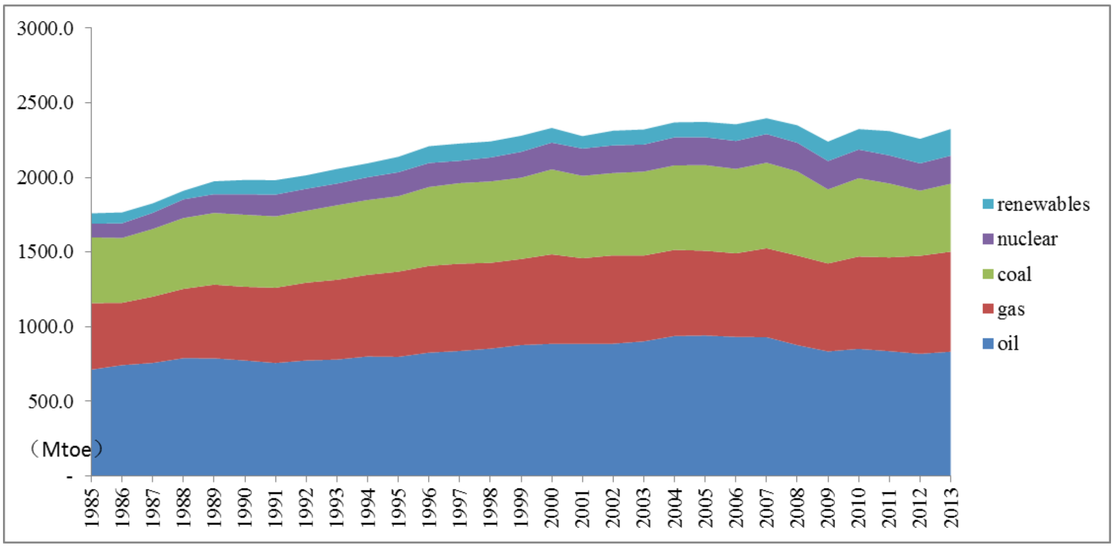


Figure 3.1.8 U.S. Total Energy Consumption, 1985-2013 [22]

Since 1985, the total energy consumption in U.S. has seen a gradual increase, reaching over 2300 Mtoe in 2006 and experience a small fluctuation until 2013, amounting to 2200Mtoe. Oil, natural gas and coal are three main sources for energy consumption, accounting for nearly 90 percent and all of the three sources have gradually increased over the decades. Although renewable energy, like hydro, geothermal, solar and wind have increased, it still accounts for a little share of the gross energy consumption (Figure 3.1.8).

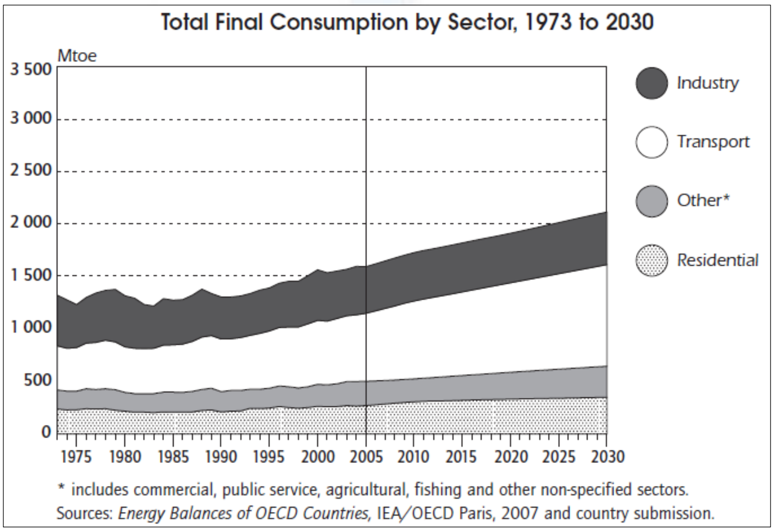


Figure 3.1.9 U.S. Total Final Consumption By Sector, 1973-2030 [11]

In U.S., industrial and transportation sector account for the most of the energy consumption. The energy consumption for transport has increased since 1973, to more than 500 Mtoe in 2005, while for industrial, residential and other sectors; the energy consumption has been leveled off since 1973. The energy demand in U.S. has increased by 22% from 1990 to 2005 and is predicted to increase at the same rate, by another 24% between 2005 and 2020. The demand is rising in all sectors of the economy, but is primarily driven by the increase of transport and residential units. Although the energy efficiency has improved in U.S., the improvements have not been able to halt the demand growth due to the rapid economic and population growth.

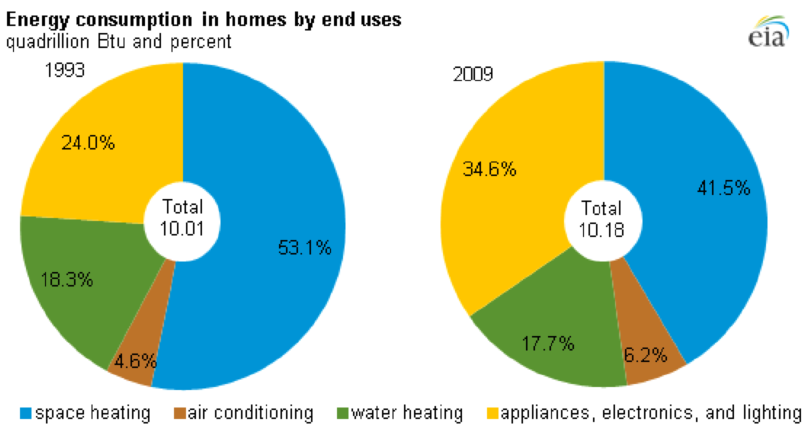
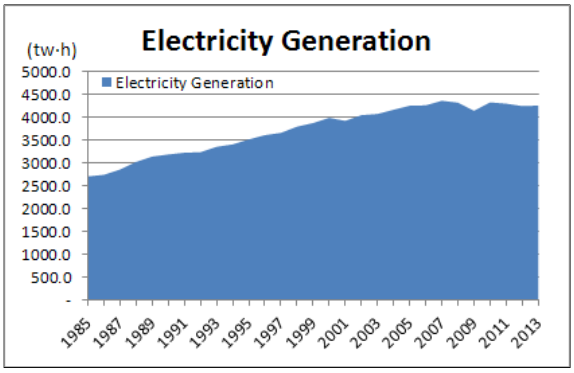


Figure 3.1.10 U.S. Energy Consumption in Homes by End Uses [23]

In 2009, for residential units, space heating accounts for the most of energy consumption, about 41.5%, electricity used for appliances, electronics and lighting represent 34.6 percent of energy consumption, ranking the second-largest end uses. Water heating made up 17.7% while air conditioning represented the least, only 6.2% of the households energy consumption. Comparing to house energy consumption in 1993, the energy for space heating and water heating decreased while for appliances, electronics, lighting and air conditioning increased.

According to the U.S. most recent Residential Energy Consumption Survey (RECS), newer U.S. homes built after 2000 are 30% larger but consume nearly as much as the old-built houses (before 2000), only 2% larger than the old ones.[23]



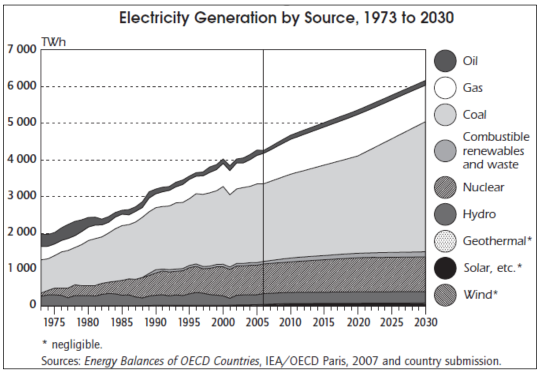


Figure3.1.11 U.S. Electricity Generation [22]

Figure 3.1.12 Electricity Generation by Sources, 1973-2020 [11]

Since 1975, electricity generated by coal has played a dominate role in electricity production, and its ratio is expected on a continued rise to the year 2030. While nuclear and natural gas accounted for around one fifth. Renewables, including hydro, generated 9.5% of electricity. [11]

In respect of capacity utilization, in 2006, nuclear plants operated at around 90% capacity and coal plants at about 73% while gas has a very low capacity of about 22%, indicating that the role of gas is to act primarily to supply medium and peak power demand, especially in summer. Hydro availability has been kept down because of dry conditions in several regions. [11]

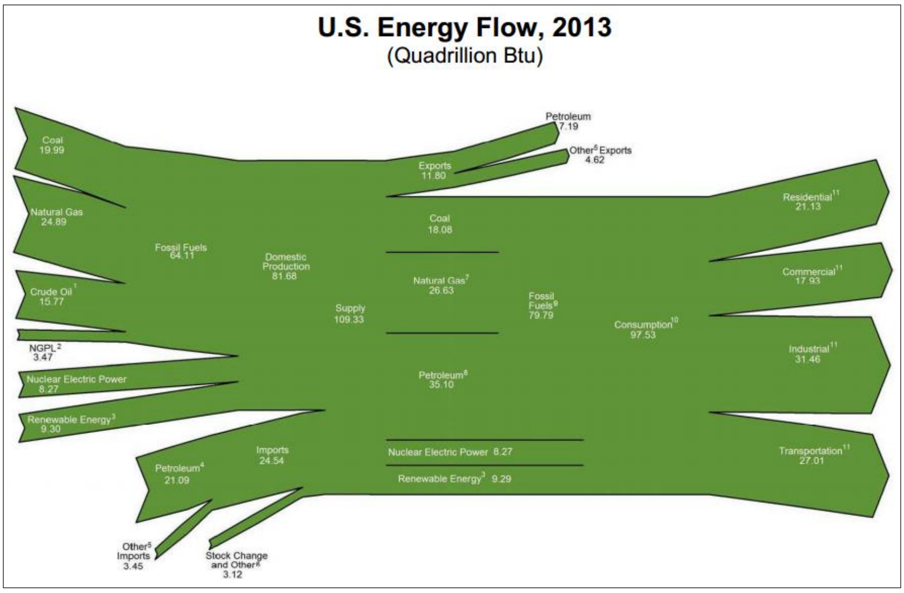


Figure 3.1.13 U.S. Energy Flow Chart, 2013[24]

In 2013, the total energy production and imports is 119.2 quadrillion Btu and the total final consumption is 97.785 quadrillion Btu. Energy is mainly used for residential, commercial, industry, transport.

3.1.2.2 Renewable Energy

In the United States, the contribution of renewable energy sources to total primary energy supply

(TPES) fell from 1990 to 2000, because of a lower growth rate of renewables production, compared to the growth of TPES. The share of renewables then remained stable until 2004, and between 2005 and 2006, renewables production has experienced a soaring increase, both in electricity generation and transport. And there has been a rapid increase in production of biofuels as well as in consumption of wind, hydro power and biofuels. The recent rapid increase is caused by a variety of reasons, i.e. a rapidly rising prices for fossil fuels since 2004, deeper environmental concerns, increased hydro availability after dry years in 2000 and 2001, and policies support. Renewable electricity portfolio standards (RPSs) now exist in half of all the states, and, together with federal tax credits for wind electricity production and other state-level support schemes, are very successful in stimulating production.[11] After 2010, the consumption of solar energy doubled in 2012 comparing to that in 2009.

Renewable Energy Production and Consumption by Source (Trillion Btu)

Year	Production			Consumption								
	Biomass		Total Renewable Energy	Hydro-electric Power	Geothermal	Solar/PV	Wind	Biomass				Total Renewable Energy
	Biofuels	Total						Wood	Waste	Biofuels	Total	
1985	93	3016	6084	2970	97	<0.5	<0.5	2687	236	93	3016	6084
1990	111	2735	6041	3046	171	59	29	2216	408	111	2735	6041
1995	198	3099	6558	3205	152	69	33	2370	531	200	3101	6560
2000	233	3006	6104	2811	164	66	57	2262	511	236	3008	6106
2001	254	2624	5164	2242	164	64	70	2006	364	253	2622	5163
2002	308	2705	5734	2689	171	63	105	1995	402	303	2701	5729
2003	402	2805	5947	2793	173	62	113	2002	401	404	2807	5948
2004	487	2998	6069	2688	178	63	142	2121	389	499	3010	6081
2005	564	3104	6229	2703	181	63	178	2137	403	577	3117	6242
2006	720	3216	6599	2869	181	68	264	2099	397	771	3267	6649
2007	978	3480	6528	2446	186	76	341	2089	413	990	3492	6541
2008	1387	3881	7219	2511	192	89	546	2059	435	1370	3865	7202
2009	1584	3967	7655	2669	200	98	721	1931	452	1568	3950	7638
2010	1884	4332	8128	2539	208	126	923	1981	468	1837	4285	8081
2011	2044	4516	9170	3103	212	171	1168	2010	462	1948	4420	9074
2012	1942	4419	8826	2629	212	227	1340	2010	467	1902	4379	8786
2013	2000	4614	9298	2561	221	307	1595	2138	476	2000	4613	9298
2014 (6months)	1038	2335	4938	1339	109	206	949	1069	229	1010	2308	4910

Table 3.1.1 U.S. Renewable Energy Production and Consumption by Source [25]

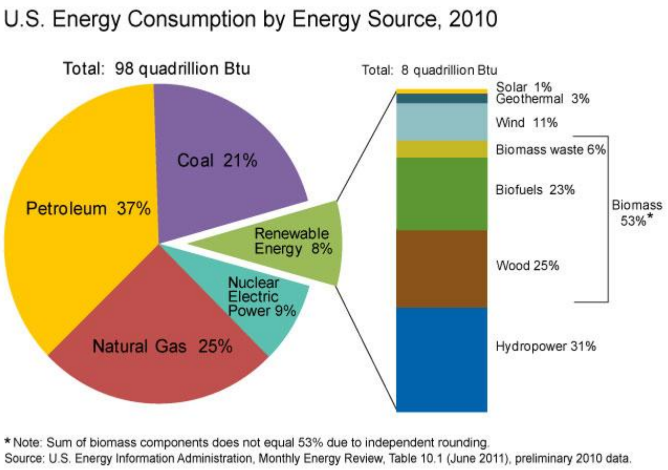


Figure 3.1.14 U.S. Energy Consumption by Energy Source, 2010 [26]

In 2010, the contribution of renewable energy to U.S. energy consumption accounts for 8%. Among all the types of renewables, biomass represents more than half, with wood 25%, biofuels 23% and biomass waste 6%. Hydropower is also of a high share (31%), with wind, geothermal and solar following.

In general, the renewable energy in U.S. is mainly used for electricity generation, as 4831 trillion Btu was consumed for electric power sector. The second-largest user is for industrial sectors, nearly half of that used for electricity. And the utilization for transportation accounts for around half of that used for industrial sectors. The residential and commercial sectors enjoyed the least share of renewables.

3.1.2.3 Energy Price

In the United States, markets are the most dominated mean to determine supply, demand, prices and trade while the government set policies to support and regulate the energy market. However, the energy prices differ from one state to another according to states sub-policies.

Natural Gas

Along with the rapid development of natural gas industry over the past decades, the largest and most competitive natural gas market has been formed in the United States. In 1989, the parliament promulgated "wellhead natural gas deregulation act" to abolish the limit for wellhead natural gas prices to promote competition among manufacturers. Secondly, the government prohibited the pipeline companies participating in wholesale of natural gas, together with the government monitor to introduce competition into the natural gas market. [27]

Wholesale natural gas prices over the last several years have been volatile, fluctuating significantly on a daily basis as well as with erratic monthly and seasonal price averages. The city gate gas prices have risen from around USD 3 per million British thermal units (MBtu) in 1999 to USD 7 per MBtu in 2006/07. [11]

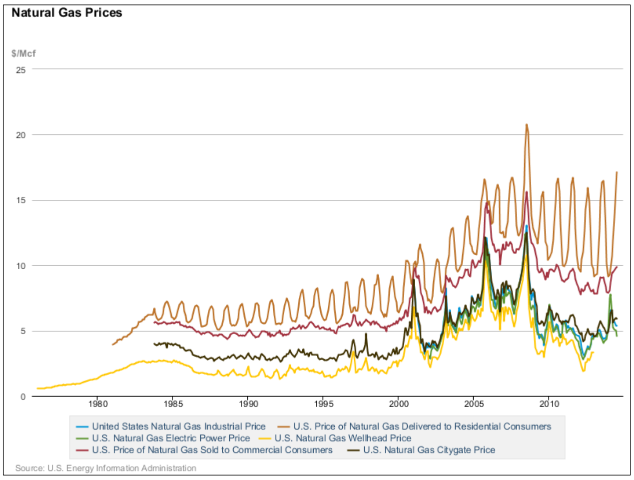


Figure 3.1.15 U.S. Natural Gas Prices [28]

The figure above indicates that all the types of natural gas prices have been fluctuating and has experienced an increase trend since 1985. During 2000-2010, there were four spikes of the wellhead natural gas prices, reaching as high as $10.79/Mcf in July, 2008. Correspondingly, gas prices for residential, commercial, industrial consumers and electric power were also reaching their peak in July, 2008, with $20.77Mcf, $15.64Mcf, $13.06Mcf and $12.41Mcf each. In July, 2014, the citygate price was $5.88Mcf, the price for residential consumers was $17.13Mcf, for commercial was $9.89Mcf, for industrial was $5.36Mcf and for electricity was $4.57Mcf. [28]

Comparing to other IEA member countries, the gas prices for industrial and residential sectors in the United States is among the lowest. Also, no federal excise tax is levied on natural gas sales, even though some states levy excise tax.[11]

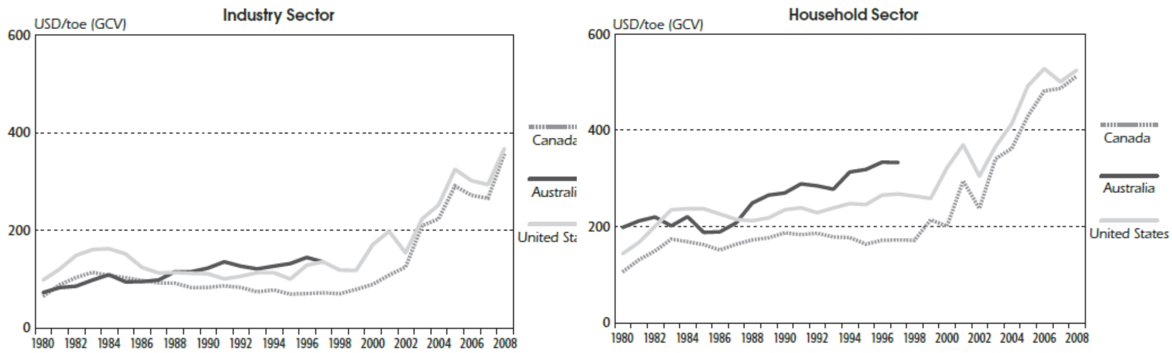


Figure 3.1.16 Gas Prices in U.S. and in Other Selected IEA Member Countries, 1980 to 2008[29]

From 1980 to 1982, the gas price increased rapidly to reach more than 200USD/toe, and then leveled off for a long period, and in 1998, when the prices increased greatly until 2008.

Oil Prices

The United States is the world's largest user of oil as well as the largest importer of oil. The price for oil products in the United States is the lowest among IEA/OECD member countries, due to a very low tax component. Pre-tax prices are at the lower end of the IEA scale as well, with only five member countries reporting lower pre-tax prices than the United States. This indicates that the oil product and refining market in the United States is generally very competitive. The low taxation levels and the fact that oil is traded in US dollars on the world market, make the transport fuel prices much more responsive to world market developments than, for example, European or Japanese prices.[11]

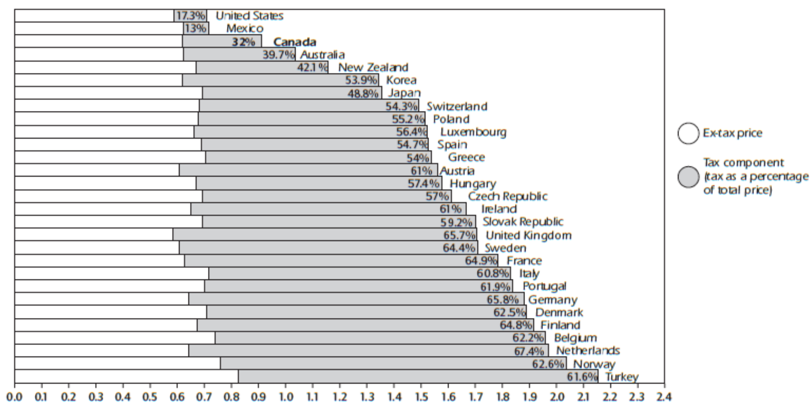


Figure 3.1.17 OECD Unleaded Gasoline Prices and Taxes, Third Quarter 2009[28]

Electricity Price

Recent years have seen significant electricity price rises in retail and wholesale markets, caused by higher gas prices (the marginal fuel for power generation in many locations). The acceleration of gas prices from 2000 to 2012 has created significant pressure to reduce the role of gas in the generating mix, but with nuclear and coal power plants running close to their maximum potential in many areas, this scope is limited, and gas price rises are therefore being reflected in higher power prices, especially in summer.

The state regulatory commissions have authority to regulate retail rates charged to consumers for their private (and some co-operative and public) electric utilities. Under this authority, many states have acted to allow competition in the retail (business-to-consumer) market by allowing their consumers a choice of suppliers. In general, the states with the highest electricity rates, such as California and states in the north-east have done the most to promote competition to apply downward pressure on prices.

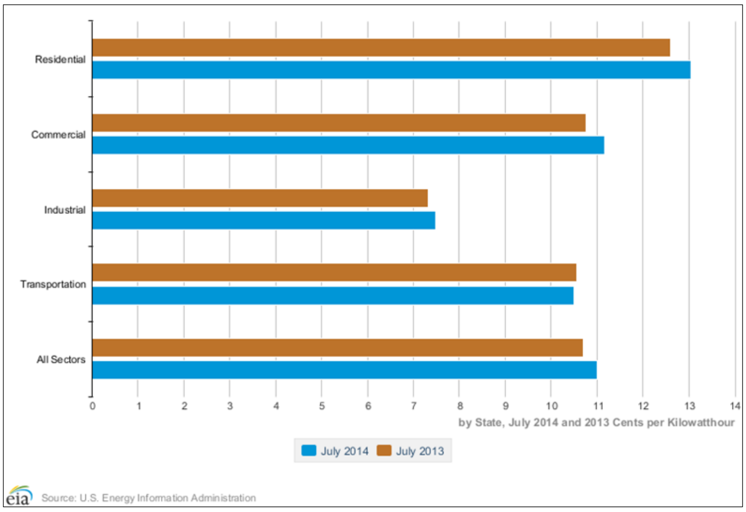


Figure 3.1.18 Average retail prices of electricity to ultimate customers by end-use sector, U.S. total [30]

In the United States, the electricity price for the residential unit is the largest, around 12-13 cents per kilowatt-hour, and for commercial and transportation sectors are about 10-11 cents per kilowatt-hour, while for industrial units is among the lowest, around 7-8 cents per kilowatt-hour.

3.1.3. District Energy Development History

The first modern district heating network was created in 1853 at the US Naval Academy in Annapolis, Maryland. From there, district heating systems conquered the large cities, the first of which was Denver, Colorado. It is the oldest continuously operated district heating network that in operation since 1880 and still serves 135 customers. New York got its start in 1882, initially installing a district heating network for lower Manhattan. Over the years, the New York City’s steam system has developed into the largest commercial district heating network in the world. The network boasts 2,000 customers in 100,000 commercial and private buildings, including laundry and restaurant chains, as well as indoor heating in public and private buildings. On the heels of the Big Apple, Boston installed a 40 km long district heating network in 1887. Shortly thereafter, Boston was followed by Cambridge and several dozen large cities on the east and west coasts of the United States. Another unique fact is that numerous universities have their own district heating networks. Nevertheless, district heating in the United States in its current state is anything but future proof. Since the 1970s an increasing number of utility companies have lost interest in heating networks, investing less and less money in maintenance. “Some of these networks are energy wasting monstrosities,” says Wulf Hohmann, a project engineer at Lahmeyer International, a German engineering company that counts energy systems among its specialties. As a result of the neglect, the district heating networks have lost customers.[31]

District cooling has its roots in the early 1800's when plans were made to distribute clean, cold air to buildings through underground pipes. It is not known if these plans were actually carried out, and district cooling was not introduced on a practical level before the Colorado Automatic Refrigerator Company was established in Denver in 1889. Many of the earlier systems used ammonia and salt water to freeze meat and cool buildings used by the public such as restaurants, theatres etc. In the 1930's, large cooling systems were built in Rockefeller Centre in New York City and the United States Capitol buildings. In the 1960's, the first commercial district cooling systems were installed in the USA in commercial areas near cities. The potential for district cooling that was estimated in the 1990's for the entire country has now been surpassed. The amount of energy per year doubled at the outset, and it currently appears that growth will continue at about a pace of 20% per year. District cooling has been of the highest quality since it was introduced thanks to being able to draw upon the more than 50 years of technical development related to the production of district heating and distribution.[32]

3.1.4. District Energy Development Status

In North America, district energy systems (DES) are typically located in dense urban area in the central business districts of larger cities; on university or college/research campuses; on hospitals, military bases and airports. These DES is opted to serve "clusters" of buildings which are commonly owned by a private or public university campus or hospital. However, the downtown systems, which have distinct owners, are usually located near each other in a central business district or segment of the cities and are interconnected individually to the distribution piping network. The number of customer served by a DES may range from as few as 3 or 4 in the early stages of new system development to as many as more than 1,800customer buildings served by Con Edison Steam Business Unit in Manhattan, the largest district steam system in the world.[33]

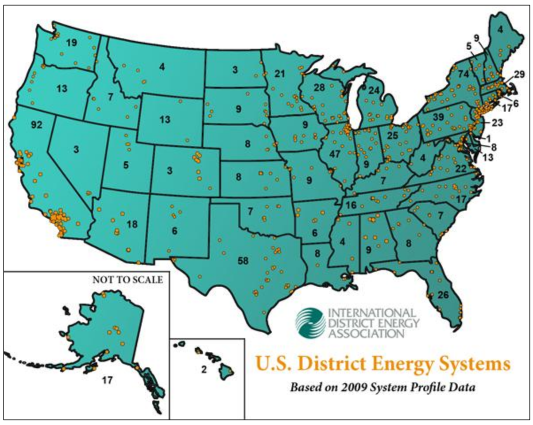


Figure3.1.19 U.S. district energy system map [34]

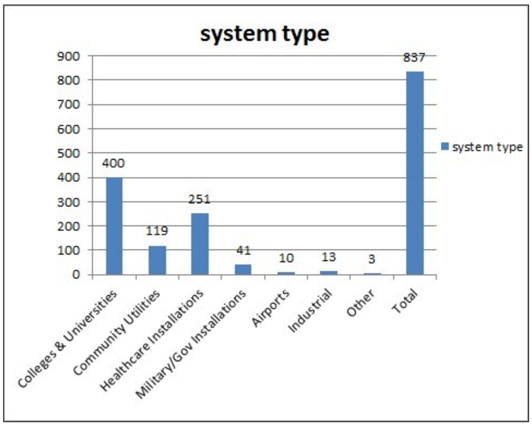


Figure3.1.20 U.S. CHP facilities by types, 2009[34]

Based on the data from IDEA2009, there are 837 district energy systems in total built in the United States until 2009. Among them, nearly a half was for colleges and universities and 251 for healthcare installations. Community utilities accounted for 119 of the total facilities.

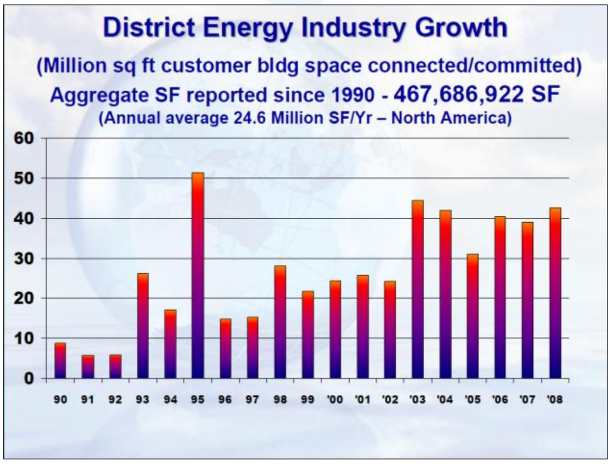


Figure 3.1.21 U.S. District Energy Industry Growth [35]

Since 1990, the district energy in the United States has been a gradual increase and experienced a spike in 1995, when more than 50 systems have been built. After 2003, the growth of district energy system is relatively stable, with nearly 50 facilities built for each year (Figure 3.1.21).

More recently, urban systems have undergone a revival of sorts in several U.S. cities. Currently, the United States has the largest installed CHP electrical capacity at 85 gigawatts (GW) which provides about 8% of US electricity generation, this was the result of a federal law in the 1980s (the Public Utilities Regulatory Policy Act- or PURPA), combined with active State policies in a handful of markets in the late 1990s and in this decade, including California, New York and other Northeastern states. [36]

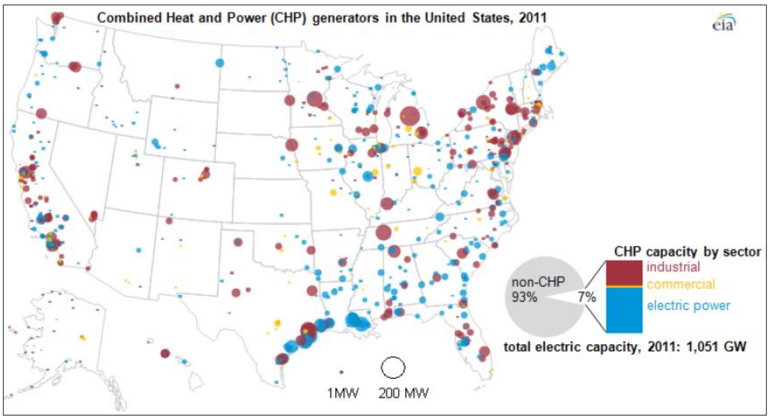


Figure 3.1.22 U.S. combined heat and power (CHP) generators, 2011[37]

CHP units tend to be built in conjunction with certain industries that have heat or steam demands. The map above displays that along the Gulf Coast, there is a concentration of CHP generators, which is corresponding with the location of refineries and chemical plants. A number of smaller installations are located near pulp and paper mills in the South, in northern Wisconsin, and in Maine, burning the wood waste byproducts as fuel. Some larger projects are located in the central and northern areas of this country. CHP installations are also common in states with a history of utility regulation that is favorable toward CHP, such as California and New York.

CHP capacity additions followed the pattern of the electric power industry, peaking in the early 2000s, building an average of more than 2,960 megawatts (MW) per year for the period of 2000-2005. CHP capacity additions slowed in the period of 2006-2011 (as did most non-CHP capacity additions), averaging less than 500 MW of new CHP capacity per year.

At the end of 2011, there were nearly 70 gigawatts (GW) of combined heat and power (CHP) generating capacity spread across the United States, representing about 7% of total U.S. capacity, with 25 GW in the industrial sector, 2 GW in the commercial sector, and 43 GW in the electric power sector. In 2011, the average capacity factor for generators at industrial CHP plants was 57%, the equivalent of running at full capacity of the time. [37]

In 2012, six CHP generators have come online, totaling 209 MW. New generators proposed for 2013-2016 include more than 3,700 MW of CHP. In general, CHP growth can be slowed by institutional barriers, such as an unfavorable regulatory environment, or by risk factors in cost-benefit analysis, such as the additional capital expense of a CHP unit. [37]

3.1.5. District Energy Policy

As the world's largest economy entity, the United States has been facing two key problems which affect all debates on the future energy supply. One is how to increase energy security by reducing the current dependency on imported fuels and the other is how to address the growing increase of greenhouse gas (GHG). While so far, no comprehensive federal government action is planned to place a value on CO_2 emissions, and it is the only major IEA member country where the share of fossil fuel consumption in total energy supply is expected to increase and one of the few without a policy designed to internalize the external cost of CO_2 emissions. [11]

As early as 1992, the United States Environmental Protection Agency set up the ENERGY STAR program to reduce energy consumption and GHG emission. It is a voluntary program that helps businesses and individuals save money and protect the climate through superior energy efficiency. Statistics show that with help from ENERGY STAR, by 2013, Americans had cumulatively prevented more than 2.1 billion metric tons of GHG emissions. [38]

On January 1st 1997, the non-profit organization, the Climate Trust, published "Offset Request for Proposals" to purchases greenhouse gas (GHG) offsets from energy efficiency and renewable energy projects in the assets which is equal to the lifetime CO_2 reduction of the company multiplied by the price to be paid for these reductions. And later in May, 1999, the U.S. Environmental Protection Agency (U.S.EPA) provided a loan, Clean Water State Revolving Fund (CWSRF), to water quality protection projects for wastewater treatment, nonpoint source pollution control, and watershed and estuary management under sections 212, 319, and 320 of the Clean Water Act. The CWSRF has funded over 33,000 low-interest loans totaling more than $100 billion. [39]

Moreover, the federal government enacted renewable portfolio standards (RPS), which requires electricity supply companies to produce a specified fraction of electricity from renewable energy sources. Certified renewable energy generators earn certificates for every unit of electricity they produce and can sell these along with their electricity to supply companies.[40] As of March 2013, RPS requirements or a renewable portfolio goal (RPG) have been established in 37 states, the District of Columbia, Guam, N. Mariana Islands, Puerto Rico and the U.S. Virgin Islands.[41]

In order to promote the development and utilization of renewable energy in the rural area, The Renewable Energy for America Program's (REAP) Renewable Energy System and Energy Efficiency

Improvement Guaranteed Loan and Grant Program was issued in May, 2002, to provide financial assistance to purchase and install renewable energy systems and energy efficient improvements in rural areas. $12.38 million in grant funding and $578 million in guaranteed loans are available, as well as funding for grant/loan combination requests.[39] Apart from this, the Climate Change Technology Program invested in a diverse portfolio of energy technologies with the potential to yield substantial reductions in emissions of greenhouse gases and organized about $3 billion in federal spending for climate change-related technology research, development, demonstration, and deployment.[42]

In 2003, the National Association of Regulatory Utility Commissioners (NARUC) represented the state public service commissions to regulate electric utilities by assisting to ensure the rates and conditions of utility services fair, reasonable and nondiscriminatory for all consumers. Later NARUC published "NARUC Model Interconnection Procedures and Agreement for Small DG Resources" in which CHP was included. Moreover, the Bush government enacted FutureGen or the Hydrogen Initiative, to provide a $1 billion government/ industry partnership to design, build and operate a nearly emission-free, coal-fired electric and hydrogen production plant.[43] In addition, in order to accelerate the technical and cost viability of alternative energy technologies, the Bush government enacted Advanced Energy Initiative (AEI) in 2005, investing $3.17 billion in the FY 2009 Budget, a 25% increase over the enacted 2008 level and $1.4 billion more than the 2006 investment.

In 2005, a new Energy Policy Act, the EPAct 2005 was enacted. It is the first comprehensive energy policy act since 1992, and has set important new directions of clean energy use.[11] The EPAct 2005 authorized the Department of Energy (DOE) to finance more than $10 billion in loan guarantees for energy efficiency, renewable energy and advanced transmission and distribution projects and CHP is eligible for particular solicitations under this funding opportunity.[39]

In the following two years, the Federal Energy Regulatory Commission (FERC) issued "FERC Small Generator Interconnection Procedures (SGIP) and Agreement (SGIA)" in 2006 and the DOE issued and "Distributed Energy Interconnection Procedures, Best Practices for Consideration" in 2007 to set interconnection standard which would affect CHP projects.[39] Also, the Climate Change Technology Program was issued. It is a multi-agency programme, which is led by the DOE. In September 2006, the CCTP issued its Strategic Plan, which provides a comprehensive, long-term look at the nature of the climate change challenge and potential technology solutions over near-, mid- and long-term deployment.[11]

Later in 2008, a tax credit "Business Energy Investment Tax Credit (ITC)" was set and was expanded by the Energy Improvement and Extension Act of 2008 in which new credits was established for CHP. For CHP, the credit is equal to 10% of expenditures, with no stated maximum, for the first 15 MW of CHP properties. This tax will be expired in the end of 2016. [39]

In 2009, four grants and policies were issued. The Business and Industry Guaranteed Loans (B&I) was to improve, develop or finance business, industry and employment and improve the economic and environmental climate in rural communities with a maximum of 80% guarantee for loans of 5 million or less, 70% for loans between $5 and $10 million, and 60% for loans exceeding $10 million and totaling less than $10 million. And the Model Interconnection Rules issued by a non-profit organization to expand renewable energy use such as rules that support renewable energy and distributed resources in a restructured market and connecting small-scale renewables to the utility grid and develop model interconnection rules. In addition, the State Energy Program (SEP) offers financial and technical assistance to states through formula and competitive grant. The SEP distributed $3.1 billion of funding to the states and U.S. territories under the 2009 Recovery Act and the competitive grant is mainly for the application of energy efficiency/renewable energy products and technologies are issued annually based on available funding. Moreover, the Energy Improvement and Extension Act of 2008 authorized the issuance of Qualified Energy Conservation Bonds (QECBs) and a maximum of 30% of QECB allocations may be used for private activity purposes. [39]

In March, 2011, the Repowering Assistance Program (RAP) was enacted to provide payments to bio-refineries that i use renewable biomass to produce heat and power for plant operations and replace the use of fossil fuels. Assistance can be awarded in amounts up to 50% of the total project costs as long as it does not exceed the maximum award for the fiscal year. Also, the program will provide reimbursement payments (not more frequently than once per month) for eligible project costs of the renewable biomass system during the construction phase of the repowering project. Up to 90% of the funds can be used during project construction, with the remaining 10% made upon demonstration of successful completion of the project. [39]

In most recently, in 2014, the Loan Programs Office of the U.S.DOE has enacted the Advanced Fossil Energy Projects Solicitation, which offers up to $8 billion in loan guarantees available to support innovative, advanced fossil energy projects in the U.S. CHP is listed as a potential qualifying technology under technology area 4: efficiency improvements. And in April, the Biogas Technology Grants was founded to help agricultural producers to enter into value-added activities related to the processing and/or marketing of bio-based value-added products is available for economic planning activities or working capital expenses. Moreover, the U.S. DOE issued Deployment of Clean Energy and Energy Efficiency Projects on Indian Lands which is only provided for applications from an Indian tribe, tribal energy resource development organization, or tribal consortium on whose Indian land the project will be located. The program invested $4-$7 million EERE anticipates making awards that range from $50,000 to $500,000 for Topic Area 1 and from $250,000 to $1,000,000 for Topic Area 2. [39]

3.1.6. Conclusion

As the world’s largest economy, the United States suffers greatly with high greenhouse gas emissions. Under this circumstance, district energy system can be an efficient way to relieve such high emission problems and increase energy efficiency. The United States is among the earlier countries which developed the district energy system and have formed an industry of DES. Although in the 1970s, the development of DES suffered from low ebb due to the high price of natural gas and oil, it sparked in recent years. Apart from this, the federal government has formulated a number of policies and grants to promote the growth of district energy system and opted to utilize renewable energy as energy sources to operate these systems. Moreover, depending on the local conditions, the states government could allocate the grants and enacted policies to facilitate the growth of the systems. But still, more policies and incentives as well as feasible researches are needed.

3.2 District Energy System in Canada

3.2.1 National Overview

3.2.1.1 General Information

The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Figure 3.2.1 The Map of Canada [44]

Canada is the furthest north country of the North America, which consists of ten provinces and three territories. Located in the northern part of the continent, the Canada extends from Pacific Ocean to its west to Atlantic Ocean to its east and northward into the Arctic Ocean. To the south, it borders with the United States, which is also the largest energy market for Canada and they shares the longest land border around the world. [45]

Canada is the world's second-largest country, with the total area of 9,980,000 square kilometers. A census conducted in May 2011 showed that the official record of population was 33,476,688 and it expected to increase to 35,427,524 in 2014.[46] It is a federal parliamentary democracy and a constitutional monarchy, with Queen Elizabeth II as its head of state. It is also a member of the Commonwealth of Nations and is one of the countries with the most ethnical diversity and multi-culture. Canada is one of the wealthiest state in the world, with the gross domestic product (GDP) of nearly 1432,140 Billion, ranking 14th worldwide. While in purchasing power parity, it is up to 1265.838 billion dollars in 13th place.[47] relying on its abundant natural resources and well-developed trade networks, its economy is one of the largest in the world.[45]

Since the early 20th century, the development of Canada's manufacturing, mining and service sectors has transformed the nation from a largely rural economy to an urbanized and industrial one. Just like the other developed countries, the dominated economy in Canada is service, which contributes to nearly three-quarters of the country's workforce. And for its primary sector, unlike other developed countries, logging and petroleum industries are the most important components.[45]

3.2.1.2 Climate

The climate of Canada is as diverse as its landscape and it mainly enjoys four very distinct seasons, especially in the more populated regions along the US borders. In winter, temperature falls below freezing point for most of the areas while the south-western coast enjoys a relatively mild climate. Along the Arctic Circle, mean temperatures are below freezing for seven months a year. [48]During summer, the daylight temperature can reach as high as 35°C and can be hot and dry on the prairies, humid in central Canada, and milder on the coasts. In spring, it is generally pleasant across the country while autumn is usually crisp and cool.[49] In Canada, due to the climate features, heating and cooling are of equal importance.

3.2.2. Energy background

3.2.2.1 Energy structure

(1) Overall

Canada enjoys the advantage of diverse and balanced energy resources and is one of the world's top energy producers. The significance of the energy sector for the Canadian economy and for the global energy security has grown steadily over the past decades. Canada is one of the highest per-capita emitters in the APEC economies and has higher energy intensity, adjusted for purchasing power parity, comparing to any IEA country, largely due to its size, climate (i.e. energy demands), and resource-based economy. [44] Canada is well known for its adequate supply of energy resources, with abundant reserves of oil, natural gas, coal and uranium in its western provinces, and great hydropower resources in its provinces of Quebec, British Columbia, Newfoundland, Ontario, and Manitoba.[50] However, the Canadian power sector is one of OECD's lowest emitting generation portfolios, producing over three-quarters of its electricity from renewable energy sources and nuclear energy combined.[44]

In Canada, there are five primary fuels, i.e. crude oil, natural gas, primary electricity, coal and natural gas liquids. While for the primary electricity, renewable energy like nuclear and hydropower accounts for the most. Energy demand has increased by 35% between 1990 and 2007 and is predicted to increase by 25% between 2007 and 2020. In 2013, the total primary energy supply is 251 million tonnes of oil equivalent (Mtoe), with an annually gradually decrease of 0.4% since 2003. It is since 2010, when the production of crude oil exceeds that of natural gas to become the largest share of the total primary energy production. Canada relies on fossil fuels (70%) for almost all of its energy supply and it is among the world's largest producers of oil, natural gas, hydroelectricity and uranium. Moreover, it is also a net exporter of oil, natural gas, coal and uranium. [44]

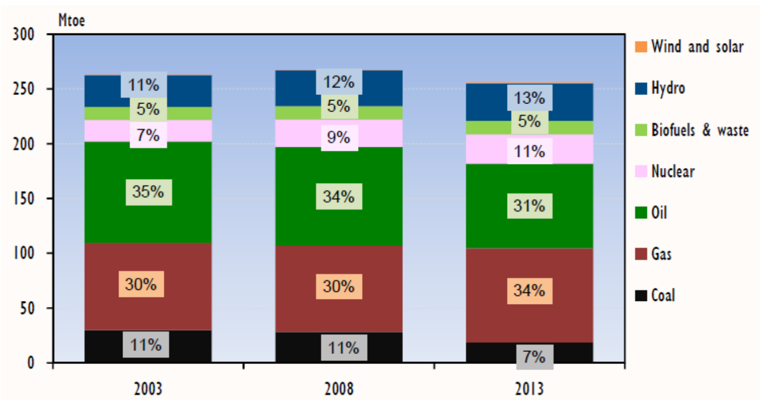


Figure 3.2.2 Canada Primary Energy Supply, 2003 to 2013[51]

In 2012, the total final consumption in Canada is 208 Mtoe, with an average annual growth of 0.7% since 2002. Among them, crude oil accounts for the most, with a share of 31%, and the consumption of renewables (29%) follow. The share of natural gas accounts for 27%. [44]

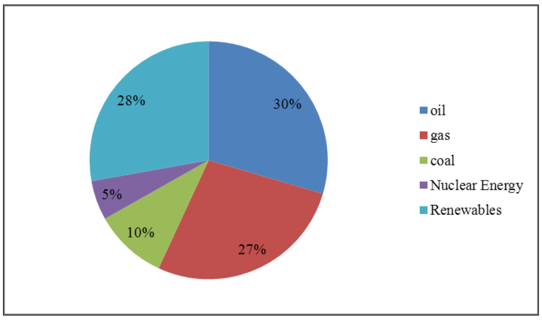


Figure 3.2.3 Canada Energy Consumption in 2000[22]

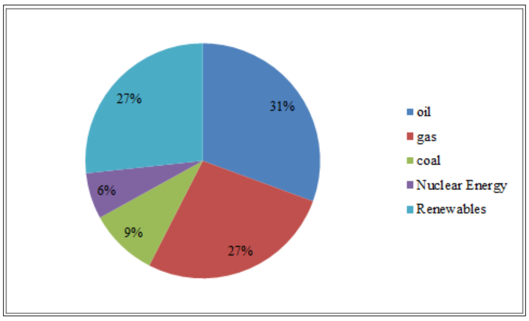


Figure 3.2.4 Canada Energy Consumption in 2005[22]

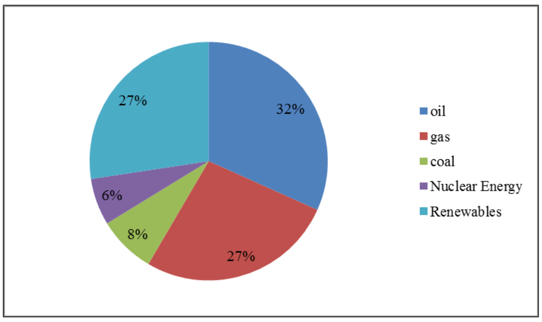


Figure 3.2.5 Canada Energy Consumption in 2010[22]

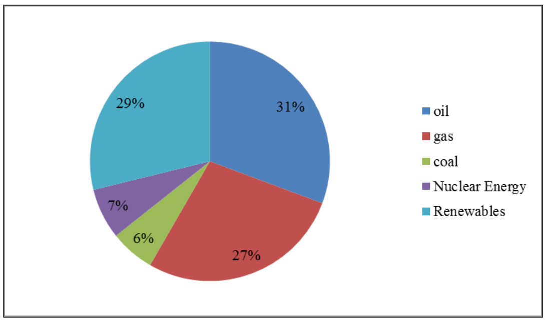


Figure 3.2.6 Canada Energy Consumption in 2013[22]

Since 1985, the total energy consumption has increased gradually, reaching 340 Mtoe in 2013. The consumption of oil and natural gas have represented the largest amount of energy consumption and have experienced a gradual increase as the production of oil has increased by around 70% since 1990 due to the increased exports to the United States. The consumption of the renewables has also seen an increase trend since 1985 and has been the third largest primary energy consumption in Canada. The consumption of nuclear remains stable and the hydropower consumption has been relatively stable since 1985. (Shown in Figure 3.2.7)

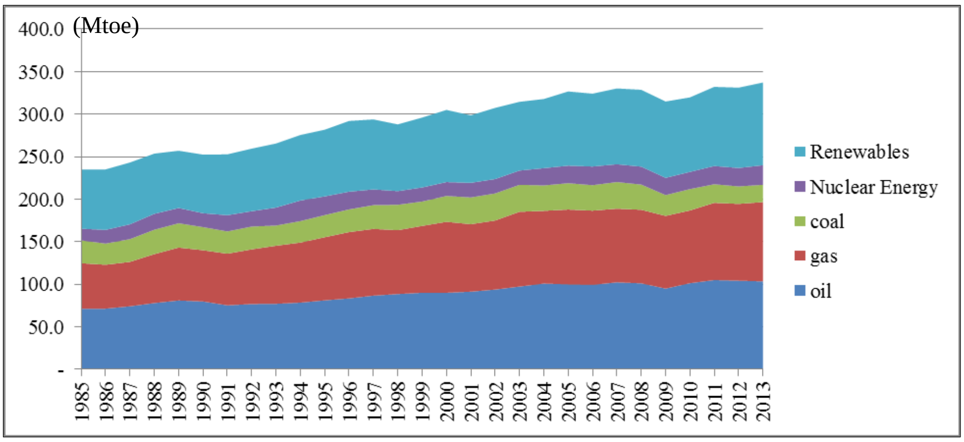


Figure 3.2.7 Total Primary Energy Consumption, 1985 to 2013 [22]

Among all the sectors, the industries consumed the most, represents 41% of the nation's energy use and 34% of related greenhouse gas (GHG) emissions (Office of Energy Efficiency, 2013). The consumption of transport follows, accounting for approximately 29% of total energy use and 37% of greenhouse gas emissions (Energy Efficiency Trends in Canada, 1990 to 2010). Commercial and the residential units enjoyed an equal consumption, representing 15% respectively. Demand is increasing in most sectors, with the strongest growth in the industrial sector (see figure 3.2.8).[44]

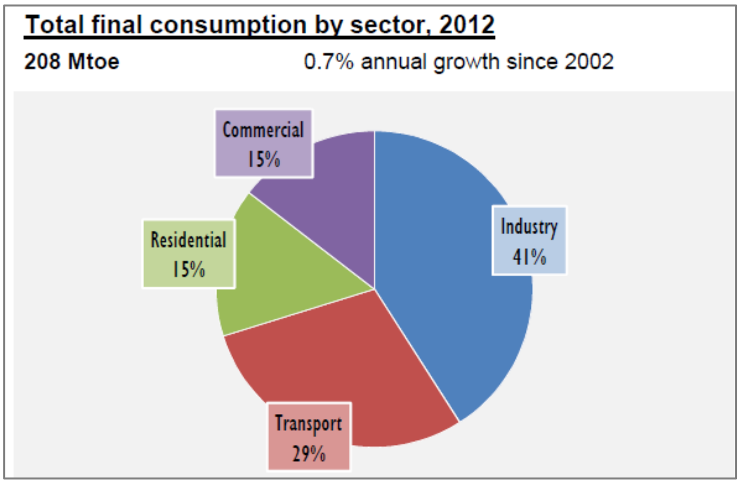


Figure 3.2.8 Canada Total Final Consumption by Sector, 2012[51]

In Canada, the oil is mainly used for transportation and industries while natural gas plays a dominant role in industrial and residential/commercial sectors. The electricity used for residential/commercial units have observed a continuously increase trend while for industry, the consumption of electricity remains stable since 1973. Coal consumed in Canada is only for industry, with a small share and remains stable for the past decades. For the industrial sectors, there is an increase in the consumption of combustible renewables and waste.

For the energy use in residential buildings, heating accounts for the most energy consumption, with a percentage of 80%, including space heating (63%) and water heating (17%), while space cooling represents the least, only 1% of the energy consumption using for the aspect.

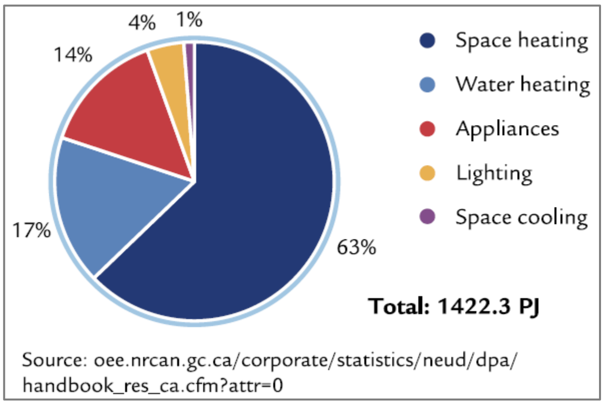


Figure 3.2.9 Distribution Of Residential Energy Use By Purpose, 2009[52]

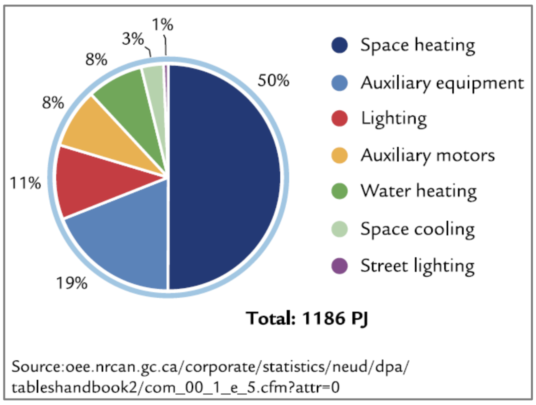


Figure 3.2.10 Commercial/Institutional Energy Use By Purpose, 2009[52]

The mix of the energy used in the residential units changed slightly over the period. Specifically, electricity and natural gas became more dominate while the use of heating oil decreased. Natural gas and electricity represented 87 percent of all residential energy use in 2009, compared with 78 percent in 1990, while the share of heating oil decreased from 15 percent to 4 percent over the period.[53]Five main elements had an impact on commercial/institutional energy use between 1990 and 2009 – activity, weather, structure, service level and energy efficiency effect. Similarly to the residential units, space heating accounts for the most energy use. Because of improvements to the thermal envelope of buildings (insulation, windows, etc.) and increased efficiency of energy-consuming items, the actual energy increase is 37%, comparing to the expected percentage of 54%, from 1990 to 2009[52].

For the commercial/institutional sectors, electricity and natural gas continued to be the main energy supply while the consumption of heavy fuel oil had seen an increase in these sectors.

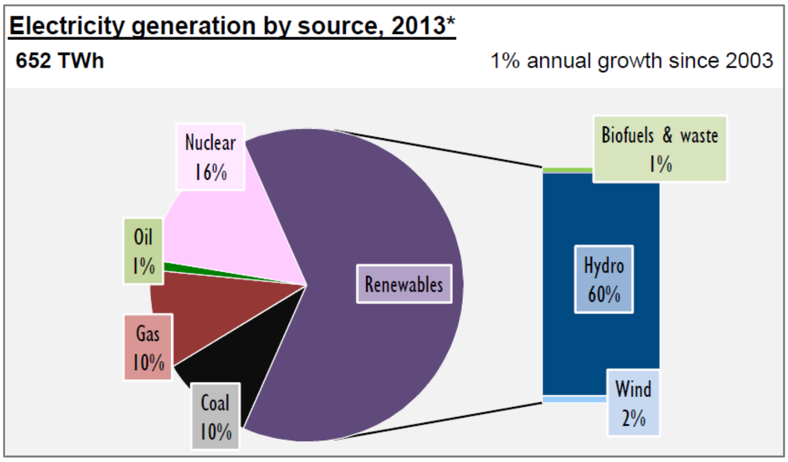


Figure 3.2.11 Electricity Generation By Source, 2013[51]

Canada have already boasted one of the cleanest electricity systems around the world, with more than 77% of the electricity generated from non-greenhouse gas emitting sources. In addition, Canada is the world's third largest producer of hydroelectricity, making up more than 10 percent of the world's total hydroelectricity production.[54]The total electricity generation in Canada in 2013 is 652 TWh, with a 1% annual increase from 2003. Renewable energy, especially the hydropower, contributes to the most, accounting for 60% of the total electricity generation. Nuclear is the second largest source of electricity generation, representing 16% of the total production. Oil accounts for the least share, nearly 1% of the total electricity generation.

(2) Energy Flow Chart

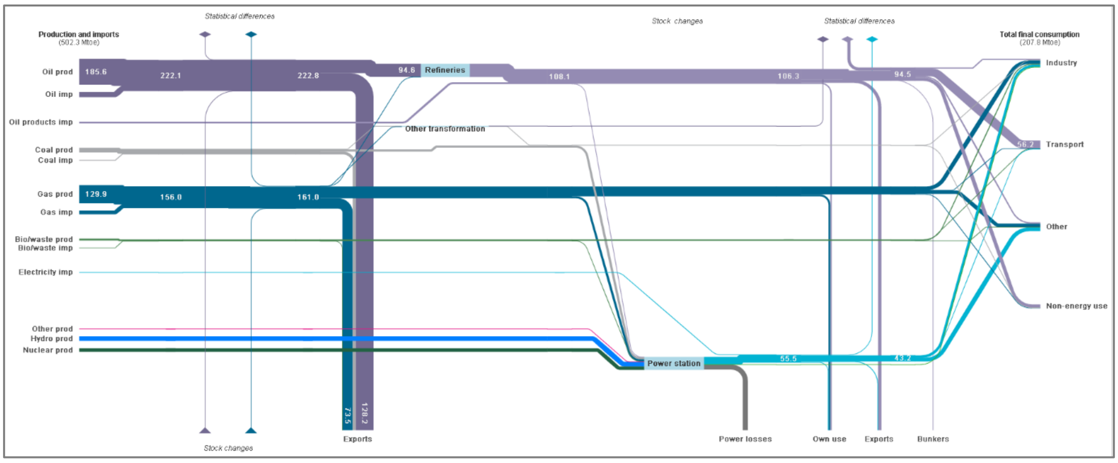


Figure 3.2.12 Canada Energy Flow Chart [55]

In 2012, the total energy production and imports is 502.3Mtoe and the total final consumption is 207.8Mtoe. Energy is mainly used for industry, transport, non-energy use and other.

3.2.2.2 Renewable Energy

As one of the largest and geographically diverse countries, Canada possesses a great deal of renewable energy, including hydropower, wind, solar, biomass, geothermal and ocean energy, which accounts for nearly 16.9% of the total primary energy supply.[44,56] Moving water is the most important renewable source, as 60% of the electricity generated from hydropower. However, other sources like wind, solar, biomass etc. are among the lowest in the OECD (Figure 3.2.13). Although wind is the second largest renewable energy source, it only accounts for 1.6% of electricity generation in Canada. The third largest one, the biomass, represents 1.4% of electricity production.[56]

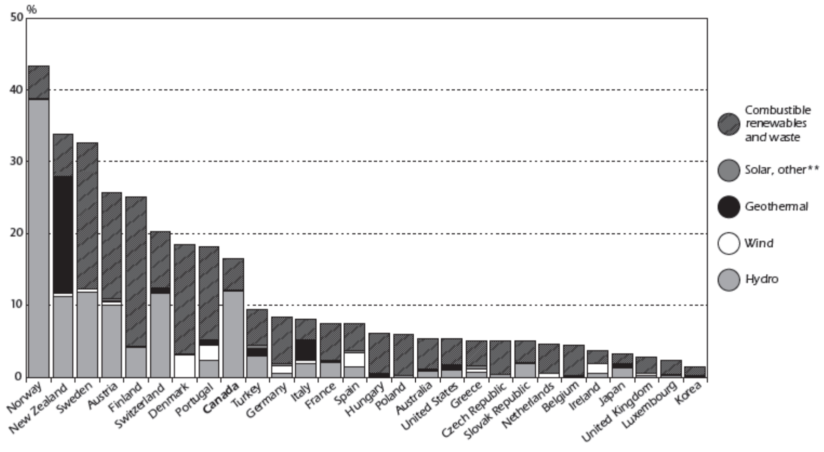


Figure 3.2.13 Renewable Energy as A Percentage of Total Primary Energy Supply in IEA Member Countries, 2008[44]

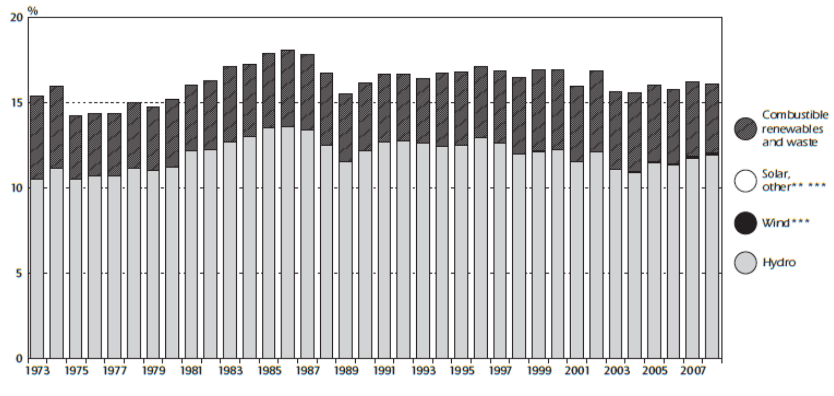


Figure 3.2.14 Renewable Energy as A Percentage of Total Primary Energy Supply 1973 to 2008 [44]

Since 1973, the hydropower remained to be the dominant renewable energy source in Canada, accounting for more than 70% of the total renewable energy supply. And the combustible renewable and wastes contributes to the second largest renewable energy supply.

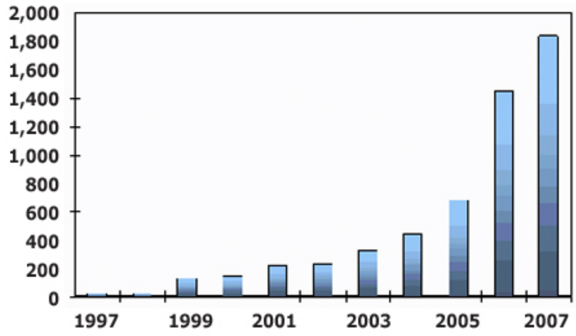


Figure 3.2.15 Installed Wind Power Capacity in Canada In Megawatts[56]

Canada has a number of areas with excellent wind resources and thus has a significant potential to expand its wind-generated power. From 1997 to 2007, there has been a great increase of wind power, particularly form 2005, when a sharp increase of wind energy can be seen (figure 3.2.15).

3.2.2.3 Energy Price

In Canada, markets are the most efficient ways to determine supply, demand, prices and trade while the government set the minimal energy commodity price.[44] However, some price controls remain in place in Newfoundland and Labrador, Nova Scotia, New Brunswick, Prince Edward Island and Québec.

Coal Pricing

There is neither market price available for steam coal nor coal production or consumption subsidies in Canada. This lack of pricing data is largely due to the existence of long-term contracts between coal producers and most large coal consumers. The prices of Coking coal and export steam coal are set on a yearly basis according to negotiations between coal producers-exporters and their customers in importing countries.[44]

Natural Gas

The natural gas prices received by producers have been deregulated in Canada since 1985. And then, the price of natural gas is determined in the open market by supply and demand -- no price limits exist for producers. However, the tolls charged by transmission and distribution companies remain regulated. Among the selected countries, the ratio of the tax to the total gas prices is one of the lowest both for the industrial and residential sector.[44]

Customers can buy natural gas from a local distribution company (LDC) at the commodity price, plus a regulated transportation and distribution charge; or, if they value an assured price, they can enter a long-term contract with a natural gas marketer, or retailer. In British Columbia, Alberta and Ontario, residential and commercial customers can purchase one- to five-year fixed price contracts for natural gas directly from retailers. Thus, these customers have the chance to avoid price volatility by purchasing a fixed price contract.[44]

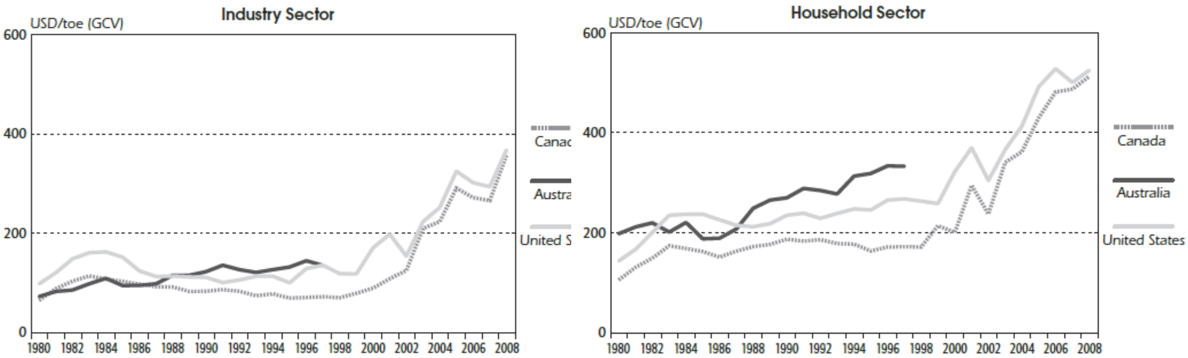


Figure 3.2.16 Gas Prices in Canada and in Other Selected IEA Member Countries, 1980 to 2008[57]

Since 1980, the gas prices in Canada have increased gradually, while since 2000, it has experienced a soar, increasing from 200USD/toe in 2000 to nearly 500 USD/toe in 2008. Also, prices in countries like United States has seen a corresponding trend with that in Canada.[44]

Oil Prices

In Canada, Since January 1991, a federal goods and services tax (GST) is levied on all petroleum products. Initially at 7%, and then it was reduced to 6% in July 2006, and to 5% in January 2008. There are also excise taxes, which vary from product to product. In addition, provinces also set their own sales and consumption taxes, which vary across provinces.[44]

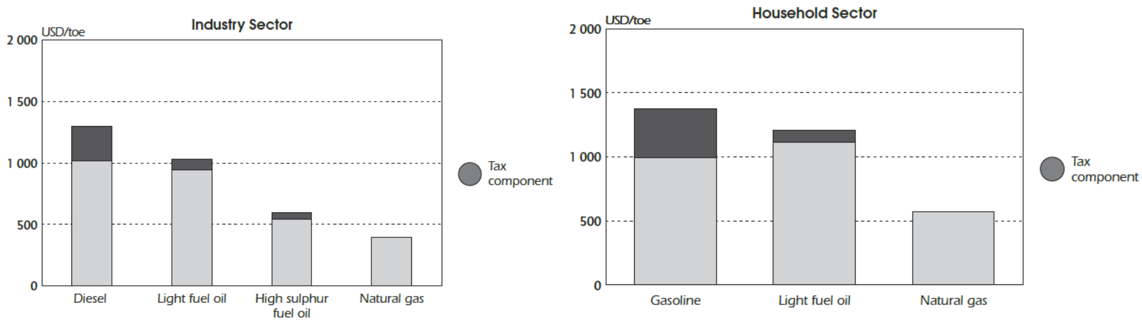


Figure 3.2.17 Fuel Prices for Industry and Household Sector [57]

Electricity Price

In Canada, electricity pricing varies among provinces or territories according to the volume and type of generation and whether prices are market-based or government-regulated. Prices are regulated by a quasi-judicial board or commission except Alberta and Ontario. Likely, the price of electricity is affected by both the cost of production and the cost of transmission and local distribution, which may vary depending on factors such as geography and population density.

In Québec, Nova Scotia, Prince Edward Island and Newfoundland and Labrador, electricity rates are regulated on a cost-of-service basis. In Alberta, prices are set through the market, although households and smaller commercial consumers have the alternatives of subscribing to a regulated rate. Ontario householders who purchase electricity from their local companies are charged a rate set by the Ontario Energy Board as part of the regulated price plan. The threshold that defines higher and lower electricity prices for residential regulated price plan consumers is set at 600 kWh per month during the summer (1 May to 31 October) and 1 000 kWh per month during the winter (1 November to 30 April). This difference recognizes that consumers use more electricity for lighting and indoor activity in the winter and that some Ontarians are reliant on electricity for their heating. Ontario customers with smart meters pay time-of-use rates based on three weekday time periods – off-peak, mid-peak and on-peak – whose times vary in summer and winter seasons. Weekends and holidays are always off-peak during both the winter and summer periods. All Ontario householders also have the option to purchase electricity from an electricity retailer, under rates stated in the retailer’s contract.[44]

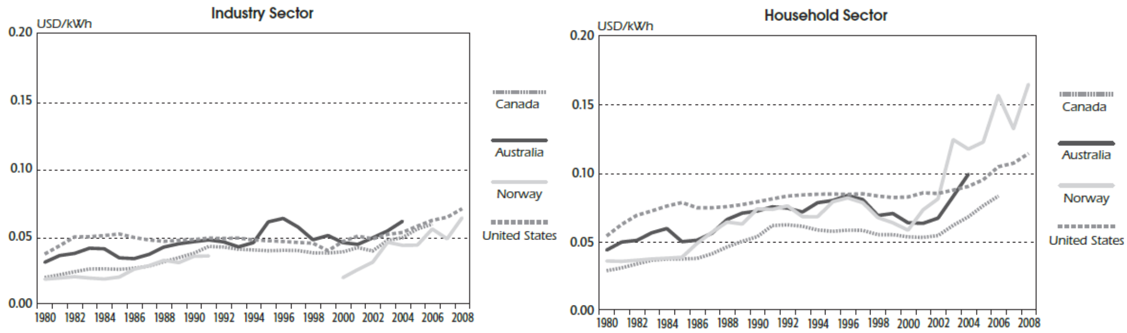


Figure 3.2.18 Electricity Prices in Canada and in Other Selected IEA Member Countries, 1980 to 2008[57]

Since 1980, the electricity prices for industrial have increased gradually to 1991, and then it remains stable for nearly a decade. From 2002, it began to increase again to reach above 0.05USD/kWh. And the electricity prices for household sectors have experienced a similar trend with that for the industries, increasing from 0.05 USD/kWh to above 0.10 USD/kWh.

The average electricity prices vary by volume and type of users. In 2007, the price for residential users, small users, medium users and large users is 11.08, 11.35, 9.94 and 6.73 CADcents per kWh respectively. [57] Thus, the large the users scale is, the lower the electricity price is.

3.2.3 District Energy Development History

The first district energy system in Canada was installed in the 1880s in London, Ontario to deliver heat to neighboring government, university and hospital facilities. And then, the University of Toronto launched a district heating system in 1911 while the Winnipeg's commercial core introduced the first commercial district heating system in 1924[58]. In the mid-1960s, due to the use of heavy oil, the development of DES slowed down and then by 1970s, because the gas companies made the access to natural gas more easily, it’s difficult to promote these systems. In the history of Canada, there have been two distinct spikes in district energy development in Canada. The first spike of activity occurred in response to the oil crisis in the 1970s when the Europe countries suffered a similar impact and paid attention to develop district energy, which helped Canada to grow its own district energy market. Another spike of district energy occurred resulting from technological improvements and government support in the late 1990s and early 2000s. [59] And so far, there are more than 150 district energy facilities in Canada.

3.2.4 District Energy Development Status

In Canada, approximately 150 district energy systems are in operation so far [58]. But for the study which was conducted by the Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC) in 2013, 60 out of 116 responded, providing insight of the district energy systems in Canada.[60]

In Canada, the provinces of Ontario and British Columbia have the greatest number of systems. Of the systems the study identified, 34 are in Ontario and 25 are in British Columbia, combined accounting for half of all systems in Canada. In addition, the facilities offer a range of services, including heating, cooling and electricity.[59]

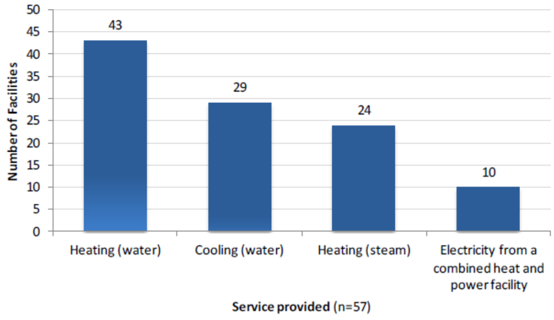


Figure 3.2.19 Facilities by type of service provided [60]

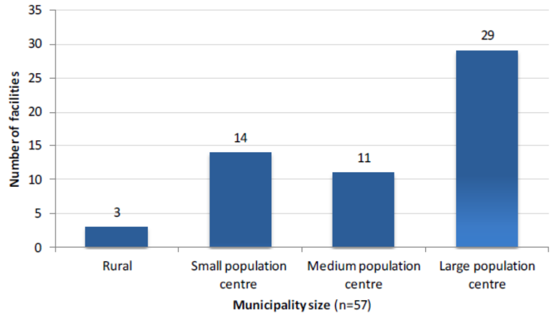


Figure 3.2.20 Facilities by size of municipality [60]

Among all the types of services provided, heating dominated, as half of all facilities provide heating only. One third of the facilities learned offer heating and cooling and one fifth offer electricity through combined heat and power facility.[59]

In Canada, over half of the DESs are located in the large population center with more than 100,000 people. Others are mainly in small population center (1,000 to 29,999 people) and medium population center (30,000 to 99,999 people). While only 3 are in rural areas.[59]

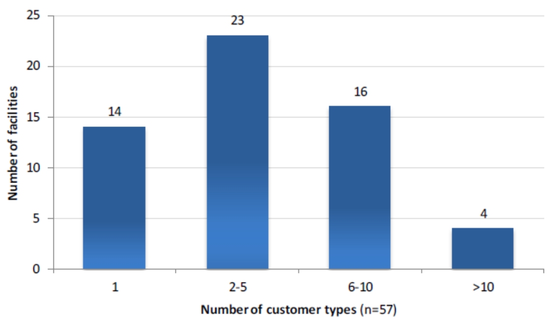


Figure 3.2.21 number of customer types served by each facilities [60]

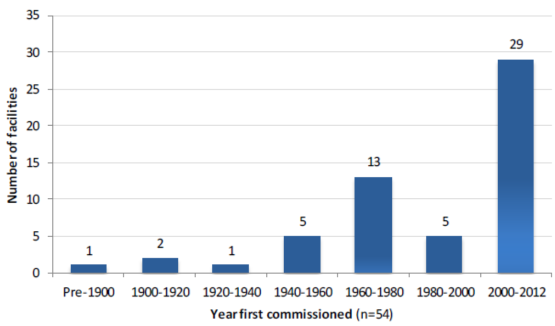


Figure 3.2.22 facilities by year first commissioned [60]

District energy systems serve a variety of customers. Most facilities (75%) serve more than one customer type. Some of the most common customer types include commercial and institutional blocks, community and recreational facilities, government offices and educational facilities.[59]DES in Canada has experienced two periods when the number of commissioned facilities increased significantly during 1960-1980 and 2000-2012. Half of all the facilities have been implemented since 2000.[59]

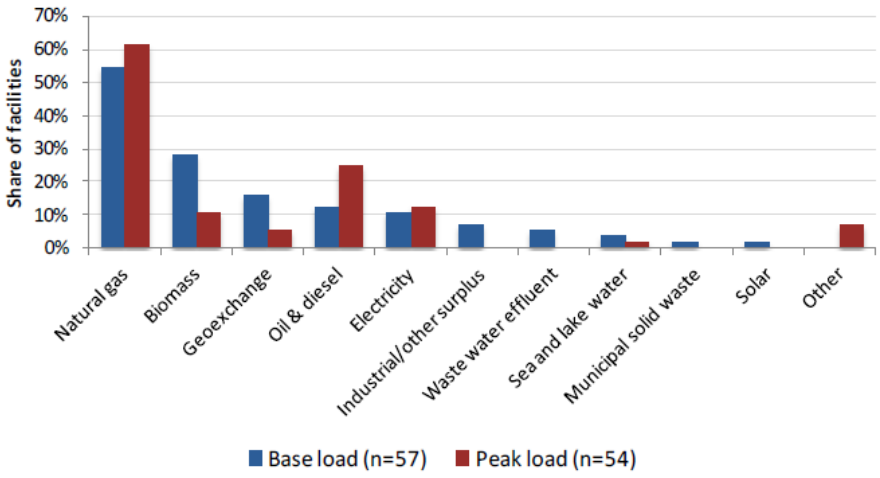


Figure 3.2.23 Base and Peak Load Fuels Used for Heating and Cooling [60]

District energy facilities use a wide variety of fuels. Natural gas accounts for the most, more than 50%, for both the base load and the peak load. For the rest, biomass, geoexchange, oil & diesel and electricity are mainly for base load while biomass, oil & diesel and electricity are used for peak load. Energy sources form waste, sea and lake water, solar etc. account for a little share in the facilities.

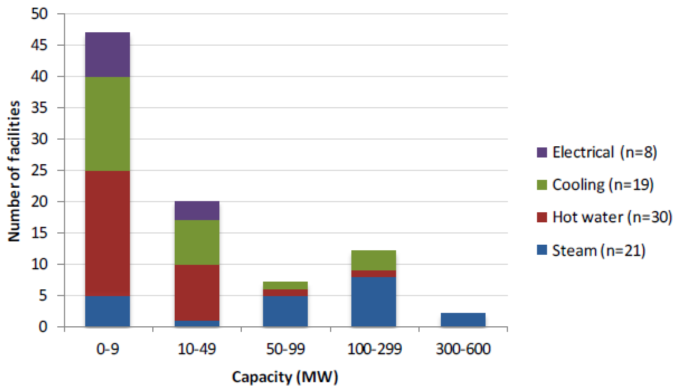


Figure 3.2.24 Base and Peak Load Fuels Used for Heating and Cooling[60]

The total thermal energy conveyed by heating and cooling systems in 2012 reached 5.2 million MWh which accounts for around 1% of the total building energy consumption for space heating & cooling and water heating in Canada. Most of the capacity of the facilities is less than 300 MWh.

	Number of buildings served	Total floor space area served	Total distribution system trench length
Units	No.	1000 m^2	km
Average	43	568	5.3
Median	18	93	3.0
Minimum	2	3	0.2
Maximum	302	5,576	35.0
Sum total	2,478	26,109	304.6
Number of responses (n)	57	46	57

Table 3.2.1 Summary of Physical Characteristics for All Systems [60]

The district energy facilities reported serving a total of 2,478 buildings. The average number of buildings served is 43. The largest number of buildings served by a single facility is 302.

3.2.5 District Energy Policy

3.2.5.1 Policy

Canada, as a parliamentary democracy and constitutional monarchy, has a federal government, ten provinces and three territories. In Canada, there is no overall federal legislative framework for sector regulation. A unique characteristic is that provinces are owners of their ground resources except resources located in the aboriginal land lands and some federal lands such as nation parks. In this case, provinces have the primary responsibility to shape their own policies and run their judicial power. While, unlike provinces, territories do not own their ground resources, but they do have some management responsibility, especially in the Yukon.

In 1978, the EnerGuide Program was first introduced in Canada as part of the Consumer Packaging and Labelling Act, which make Canada one of the first countries in the world to use a labeling program for appliances. It required that the major electrical household appliances which were to sold in Canada should test the energy consumption, show the monthly energy consumption of each model on a standardized, round EnerGuide label.[61] Later in 1992, Parliament passed the Energy Efficiency Act which is then to be a primary element of Canada's national environmental action plan. Under the Act, minimum energy standard was set for some types of energy-consuming products. Also in 1992, ENERGY STAR was first introduced in United States as an indicator for energy efficiency for computers and monitors, and since 2001, it began to appear on an EnerGuide label and includes almost 40 types of products so far.[61] The ENERGY STAR® in Canada promotes energy efficiency guidelines which enable new houses to be approximately 30% more energy efficient than those built to minimum provincial building codes. Typically, an ENERGY STAR qualified product is in the top 15 to 30 percent of its class for energy performance.[44] Apart from the ENERGY STAR symbol, the federal government also adopted EnerGuide Rating System which shows a standard measure to demonstrate exactly how energy efficient the home is and provides solid guidance to homeowners to improve the energy efficiency of their homes[62]

In 1993, the federal government published “National Round Table on the Environment and the Economy Act” to play the role of catalyst in identifying, explaining and promoting principles and practices of sustainable development across Canada by undertaking researches and analyze critical issues of sustainable development, integrating environmental and economic considerations into the government’s decision-making processes etc..[63]

In order to manage and tackle the environment-related problems, the federal issued “The Canadian Environmental Protection Act” in 1999 to contribute to sustainable development and acts to cope with any pollution issues not covered by other federal laws.[64,65]

Moreover, the federal government published “Moving Forward on Energy Efficiency in Canada” in 2007 to provide political leadership and to offer a range of tools to realize the Canada’s energy efficiency potential. Also, the document also represents the collaboration of provincial and territorial governments, federal government and a wide cross-section of non-governmental organizations and industry. In the same year, another document “Turning the Corner” was issued, which set the greenhouse gas reduction goal for Canada with 20% reduction relative to 2006 levels by 2020, and reductions of 60 to 70 percent below 2006 levels by 2050. In addition, it set mandatory requirements to promote the use of renewable energy and energy efficiency projects [66, 67]

Two years later, the Canada government established cooperation with the United States through United States-Canada Clean Energy Dialogue (CED) and a United States-Canada-Mexico trilateral co-operation through Trilateral Energy Science and Technology Agreement (TESTA) to address climate change and promote the development of clean energy science and technologies. [68, 69]

In the same year in 2009, Built Environment Sub-sub Activity was introduced to intent to be the science and technology foundation to influence the way Canadians build, buy and use their homes, buildings and communities, to reduce energy usage.[70]

In 2010, the Canada government set their emission reduction target in the Copenhagen Accords, which is an economy-wide 17% reduction from 2005 levels in 2020, and at least 50% reduction by 2050.[44]

3.2.5.2 Incentives

Apart from policies, the Canada government also provides a number of incentives to promote the development of energy efficiency projects, including district energy systems.

Since 1995, the government established ecoACTION programmes, which include a variety of programmes to encourage Canadians to take action to address clean air, clean water, climate change and natural issues and to enlarge the capability of communities to sustain these activities into the future.[71] The government has invested nearly $5 billion to support energy technology innovation to produce and use energy in a cleaner and more efficient way under these programmes. It consists of two separate funding streams: one for R&D projects, and one for demonstration projects. Both were launched in August 2011.

Under the Canadian Federal Budget in March, 1996, “Canadian Renewable and Conservation Expenses” (CRCE) was first introduced as a new category of deductible expenses and new amendments were added in the March 2012 Canadian Federal Budget which were enacted in December 2012. CRCE generally includes intangible expenses incurred by a "principal-business corporation" (as defined in the Act) and payable to an arm's length party in connection with the development of an energy project wherein at least 50% of the capital cost of the depreciable property in the renewal energy project is property described in Class 43.1 (a “Class 43.1 Asset”) or Class 43.2 (a “Class 43.2 Asset”), under the Canadian taxation system for capital cost allowance ("CCA") under Schedule II to the Regulations. And district energy systems which distributes thermal energy primarily generated by one or more of an eligible co-generation system, a ground source heat pump, active solar heating equipment heat recovery equipment and/or waste-fuelled thermal energy equipment are eligible for such taxes reduction.[72]

Later in Mar 2000, the government endowed $550 million to establish the Green Municipal FundTM, to support both public and private-sectors funding to acquire high standards in environment quality, in which district energy systems are included. Since 2000, Federation of Canadian Municipalities (FCM) has committed to provide $735 million to support 1,040 green initiatives in 495 communities across Canada. [44,73]

In order to make up for the gap between research and commercialization, in 2001, the federal government established a CAD $550-million scheme, the Sustainable Development (SD) Tech Fund, to support the late stage development and pre-commercial demonstration of clean technology solutions. The funding is allocated in five sectors, namely: brownfields, energy, transportation, waste and water. Also, the government set up what is known as "Buildings and Communities Energy Technology Program" (BCET) to provide the scientific approximately CAD $33.7million to offer scientific and technical information for achieving a sustainable energy future, and to accelerate the development and application of building and community energy innovations. [44, 74]

In Budget 2007, the government endowed CAD $1.5 billion to give direct support to the provincial and territorial support to reduce GHG and air pollution emissions. What's more, under the "Clean Air and Climate Change Trust Fund", it's the provincial and territorial responsibility to allocate the fund to specific projects without reporting to the federal government.[44,75]

To promote energy efficiency, the federal government invested more than CAD $675 million between 2007 and 2011 across all sectors of the economy under the ecoENERGY Efficiency Initiative which is comprised of a number of programmes, each targeted on a specific sector. In addition, it is investing $268 million over five years (2011-2016) in renewable energy and clean energy technologies.[76] Along with the ecoENERGY Efficiency Initiative, the ecoENERGY Retrofit offers a CAD $520 million programme to give financial support to implement energy-saving projects.[77]

In 2009, the Economic Action Plan was issued, which provides more than CAD $2 billion in programmes designed to protect the environment, stimulate the economy and transform energy technologies. Apart from this, a further CAD $1 billion was committed over five years for clean energy research and demonstration projects, and CAD $1 billion for a Green Infrastructure Fund that will support modern development of energy transmission lines and sustainable energy projects.[44]

The Energy Efficiency Act, which started in 2010, set up a CAD $32 million regulatory agenda to introduce or raise energy efficiency standards for a wide range of energy production.[78,71]

3.2.5.3 Policies for Provincial and Territorial Government

British Columbia

BC Hydro, British Columbia's largest utilities, doesn't own or operate any district energy systems from 2009 to 2011, while it does provide assistance to the government through the Power Smart Sustainable Communities Program to accelerate the market recognition of district energy within the province. The program offers access to education, expertise and financial incentives for community energy and emissions planning, district energy pre-feasibility studies, detailed engineering feasibility studies and an electricity savings-based capital incentive to make up for capital costs for district energy systems.[79]

Also, under LiveSmart BC and the Energy Efficient Buildings Strategy, the BC government endowed CAD $160 million to energy efficiency programmes and set new goals to maximize energy efficiency, conserve energy and reduce GHG emissions.[44] Apart from this, the provincial government provides CAD $25 million under "Innovative Clean Energy Fund" to support pre-commercial energy technology that is new, or commercial technologies not currently used in the province.[80]

Alberta

Alberta policy and regulation currently imposes barriers to the application of innovation in the building and use of energy efficient facilities and service delivery for communities and business, especially under Section 30(2) of the Municipal Government Act, which states: *If a council or a municipal public utility proposes to make an agreement regarding the supply of electric power for a period that, with rights of renewal, could exceed 5 years, the agreement must be approved by the Alberta Utilities Commission before it is made*.[81] In contrast, heat generated in a boiler has no specific regulatory framework. The extended approval process may diminish the attractiveness of district energy to private investors. Although Alberta has set a price for carbon, at current levels of $15/tonne, the effect to act as a price stimulant for district energy projects is limited.[79]

Ontario

In 2009, the Ontario's government issued "Green Energy and Green Economy Act" to expand energy generation, encourage energy conservation and to promote the creation of clean energy jobs. It includes a Feed-in Tariff program which allows homeowners, business owners and private developers to generate renewable energy and sell it to the province at a guaranteed price for a fixed contract term.[82] Ontario's Municipal Act restricts the municipality's ability to borrow capital for a variety of projects, including district energy, limiting their scope to initiate such projects.[80]

Also, in response to the directive received from the Minister of Energy authorizing the procurement of Combined Heat & Power projects no more than 20 megawatts (MW), the Combined Heat & Power Standard Offer Program (CHPSOP) was introduced in Ontario in May, 2011. The program mainly facilitates the development of CHP systems and provides financial incentives to eligible CHP projects based on a monthly Net Revenue Support Level (NRSL) in $28,900/MW-month, for a 20-year contract.[83,84]

Québec

Québec has a plenty of programs that support efficient energy projects and the incorporation of renewable fuels. Régie de l'Énergie of the Province of Québec will offer financial assistance for feasibility studies for sustainable urban development projects incorporating with renewable district energy systems. The program provides proponents with $0.45/kWh so that a maximum of $8m can be saved per project. Additionally, the Québec Energy Strategy provides energy reduction strategies through sustainable urban development. The program includes an optional component designed to incentivize the development of renewable district energy systems. Since 2007, the province has collected a tax on "hydrocarbons" (petroleum, natural gas and coal), making Québec the first North American state or province to charge a carbon tax.[79]

Saskatchewan and Manitoba

The Saskatchewan province allows electricity produced through CHP facilities to be exported to the grid.[79] And under Energy and Climate Change Plan issued by Saskatchewan, it expands purchases of green power, establishes a new efficiency code for government buildings, and ensuring sustainable practices are a part of all provincial government planning.[44] And in Manitoba, district geothermal systems which serves multiple buildings are eligible for refundable tax credits of up to 15% and a provincial grant up to a maximum of CAD $150,000.

Atlantic Canada

According to the federal's Clean Air and Climate Change Trust Fund, the Nova Scotia government got about $42.5 million and formed ecoNova Scotia to administer the fund to invest in developing innovative environmental technologies, commercializing environmental technologies etc. The ecoNovia Scotia officially ended on March 31, 2011.[85] In 2010, Nova Scotia commenced its Renewable Electricity Plan, which intends to increase the province's new renewable energy sources by 25% before 2015 and by 40% before 2020. The plan provides guaranteed feed-in tariffs for renewable energy based on project size and type through its Community Feed-in Tariff (COMFIT) program. The qualified projects must be connected at the distribution level (in most cases, under 6MW) and community owned. COMFIT does not include specific provisions for district energy although the program does support the development of CHP facilities.[79]

Yukon Territory, Northwest Territories, Nunavut

Canada's north has numerous unique opportunities for district energy system development. The City of Yellowknife is currently studying the feasibility of capturing waste heat from a closed gold mine for a citywide district energy system. Also, the Northwest Territories Power Corporation and Oulliq Energy Corporation in Nunavut have reduced operational costs by recovering heat from diesel generators to heat their own facilities. New, high efficiency boilers have made biomass a reliable source for energy in large-scale applications such as institutional, office, or hospital facilities. Building on the interest in using biomass as a clean and efficient source of heat, the Northwest Territories has developed a Biomass Energy Strategy to promote greater deployment. The Yukon is developing a similar strategy where local forestry resources could play a role in the development of a regional biomass industry.[79]

3.2.6 Conclusion

The starting of district energy systems in Canada is early and the Canada government has fully realized the potential of the systems in greenhouse gas emissions reduction and energy conservation. During the past, the two energy crises have sparked the development of energy efficiency projects, including district energy systems. For Canada, firstly, the government adopts a market-based energy price and only regulated the prices by taxes, which enable the energy prices regulated by the market and contribute the benign competition among different energy companies. Such context is beneficial for the development of district energy systems. Apart from this, a large amount of capitals has been endowed by both the federal and provincial and territorial government to support the development of energy efficiency projects, including the district energy systems. In addition, a feature unique in Canada is that the province government is responsible for the use of energy and ground lands within provinces, which enable energy policies applied varies among provinces and increase the policy efficiency. Last but not the least, the co-operation between the provincial government and the energy companies facilitates the application of district energy. Because of the policies support and incentives stimulation, energy companies prompt to develop energy efficiency facilities, and tax reduction can relieve the pressure of the high capital invested during construction process.

3.3 District Energy System in Japan

3.3.1 National Overview

3.3.1.1 General Information

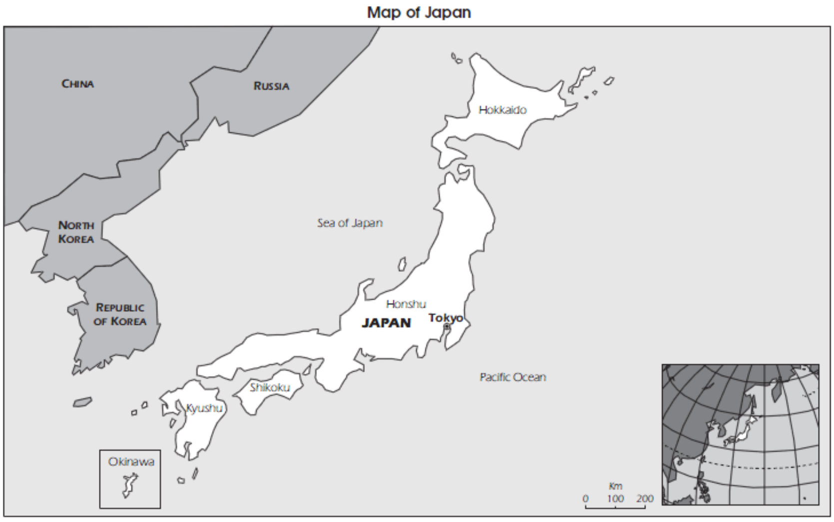


Figure 3.3.1 The Map of Japan[86]

Japan is comprised of 6,852 islands extending along the Pacific coast of East Asia lying between latitudes 24°N and 46°N, and longitudes 122°E and 146°E. The main islands, from north to south, are Hokkaido, Honshu, Shikoku and Kyushu. The Ryukyu Islands, which includes Okinawa, are a chain to the south of Kyushu. Together they are usually known as the Japanese Archipelago. [87]

About 73 percent of land in Japan is forested, mountainous, and unbefitting for agricultural, industrial, or residential use.[88] As a consequence, habitable zones, mainly situated in coastal areas, have extremely high population densities. Japan is one of the most densely populated countries around the world. [89]

3.3.1.2 Climate

Japan has a predominantly temperate climate, but varies significantly from north to south. The average winter temperature in Japan is 5.1 °C (41.2 °F) and the average summer temperature is 25.2 °C (77.4 °F).[90] The highest temperature ever measured in Japan, 40.9 °C (105.6 °F), was recorded on August 16, 2007.[91] In most of Honshu, the rainy season begins before the middle of June and lasts about six weeks. In late summer and early autumn, typhoons often bring heavy rain. [92]

Its geographical features divide it into six primary climatic zones: Hokkaido, Sea of Japan, Central Highland, Seto Inland Sea, Pacific Ocean, and Ryūkyū Islands. The northernmost zone, Hokkaido, has a humid continental climate with long, cold winters and very warm to cool summers. In the Sea of Japan zone on Honshu's west coast, it enjoys cool summer and winter with heavy snowfall. In the summer, The Central Highland has a typical inland humid continental climate, with large seasonal and daily temperature variation and precipitation is light. The mountains of the Chūgoku and Shikoku regions shelter the Seto Inland Sea from seasonal winds, bringing mild weather there year-round. The Pacific coast enjoys a humid subtropical climate with milder winters with occasional snowfall and hot, humid summers owing to southeast seasonal wind. The Ryukyu Islands enjoys a subtropical climate, with warm winters and hot summers. [90]

3.3.2 Energy Background

3.3.2.1 Energy structure

Overall

Japan does not own plenty of domestic fossil fuel resources, except for a small amount of coal. Thus, Japan is the top hard coal and natural gas importer around the world. In fact, since 1970s, Japan has mainly been dependent on oil from the Middle East. Although Japan relied on oil for 75.5% of its total energy resources in 1973, because of oil costs, the country gradually converted its main energy use resources from oil to other resources, such as natural gas, nuclear energy and coal, or it tried to develop new energy technologies. As a consequence, Japan has promoted the diversification of its energy resources and the current energy supply, including not only oil and coal, but also natural gas, nuclear energy and renewable energy, such as hydropower and geothermal(ground heat) energy etc..[93]

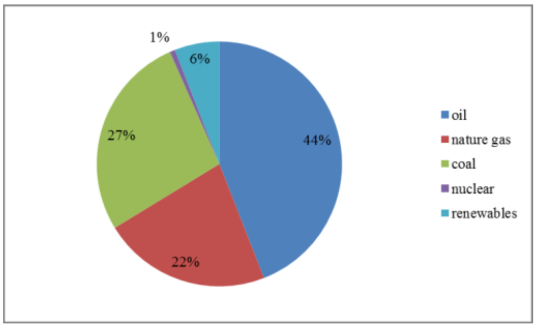


Figure 3.3.2 Japan Energy Consumption in 2013[22]

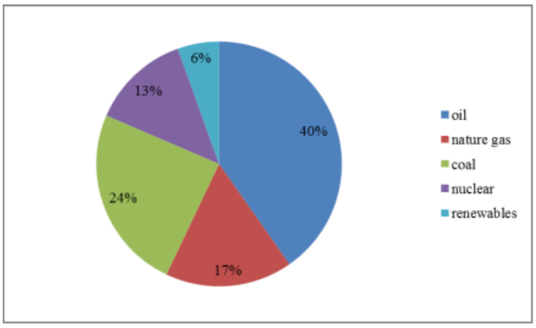


Figure 3.3.3 Japan Energy Consumption in 2010[22]

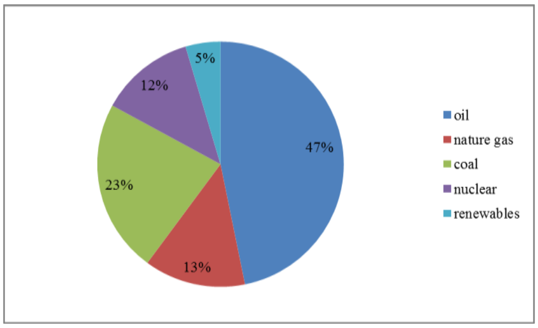


Figure 3.3.4 Japan Energy Consumption in 2005[22]

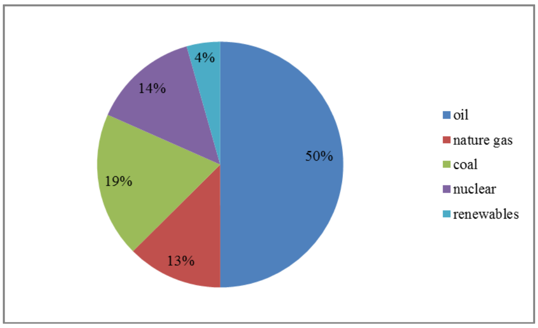


Figure 3.3.5 Japan Energy Consumption in 2000[22]

In 2010, oil was the main source and accounted for 44% of all energy used in Japan. The second largest energy supply was from coal, followed by natural gas and nuclear energy. Japan is the third largest consumer of nuclear power all over the world, just lower than the United States and France. As for renewable energy, it represented only 7% of energy used in 2010, which implies the low self-sufficiency energy rate in Japan, compared to that in other countries like France or Germany.[93]

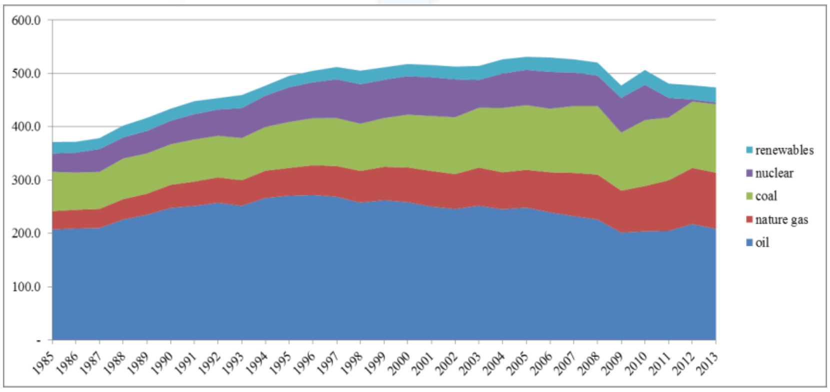


Figure 3.3.6 Japan Energy Consumption Diagram [22]

According to the Japanese government statement in 2010, the nation must reduce 25% of its CO_2 emissions by 2020 compared to 1990 levels to achieve a sustainable environment, and a clear plan should be set up based on actual results in other countries.[93]

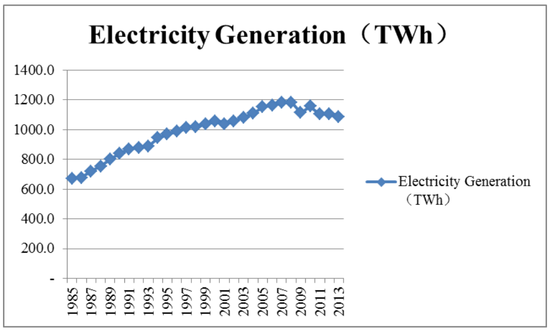


Figure3.3.7 Electricity Generation in Japan (TWh)

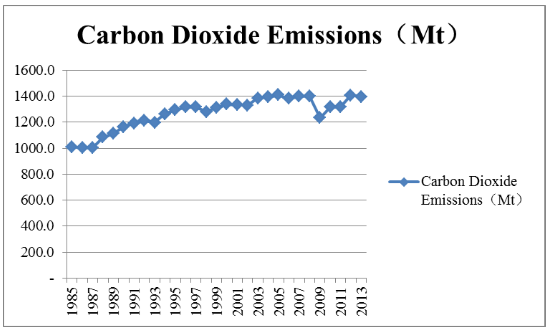


Figure3.3.8 Carbon Dioxide Emissions in Japan (Mt)

In the last 20 years, Japan has tried to decrease its greenhouse gas emissions, but has not achieved a lot of progress. Japan is among the largest energy consuming countries in the world. In 2011, according to the World Bank, Japan consumed 858.5 billion kilowatt-hours (kWh) of electricity. Japan has around 282 GW of installed power capacity; but, after the great damage to power generator caused by the March 2011 Tohoku earthquake, IHS Global Insight estimates capacity declined to approximately 243 GW in mid-2011. [93]

The gross energy consumption has been as far as it can go, and it has been declining for a couple of years. After the earthquake in Tohoku in 2011, the total energy consumption declined more rapidly than before, because there was not sufficient energy supply. As the Japanese people, particularly those in the Kanto and Tohoku area, survived for one year with this total amount of energy supply, they will probably be capable of coping with the same level from next year then on. As a result of the shutdown of all the nuclear power plant, a major concern is how to offset the loss of nuclear energy. In the current years, the Japanese government is addressing this problem by growing its dependence on fossil fuels, like natural gas, coal and oil used in thermal power stations. The imports of its liquid natural gas (LNG) rose 52% to 5.4 trillion yen in the 12 months through March, 2012. [93]

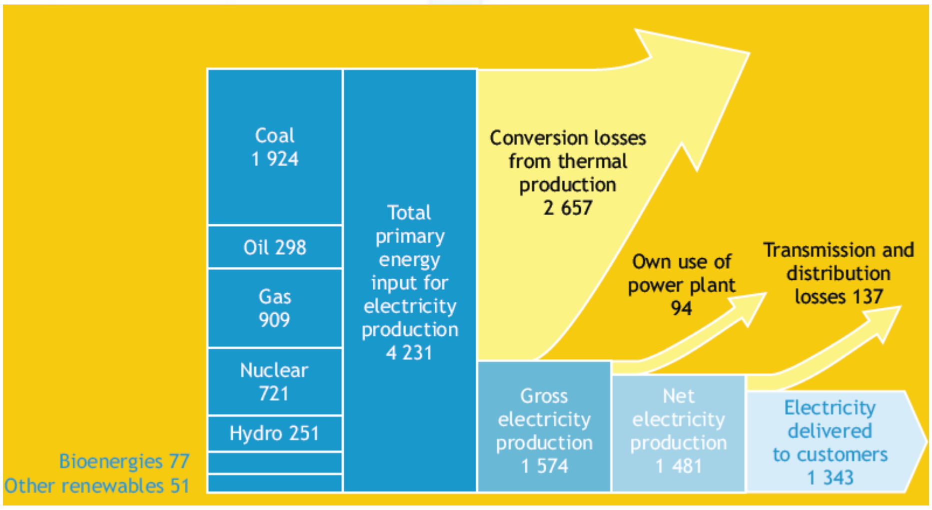


Figure3.3.9 Japan Energy Flow Chart [94]

3.3.2.2 Renewable Energy

Wind Power in Japan

Wind power has increased dramatically over the last decade and is considered as one of the biggest resources of renewable energies worldwide. So far, Japan produces proximately 2.2 gigawatts (GW) per year. Whereas global installed capacity currently is reaching over 200 GW. Based on Ministry of the Environment Research, the potential capacity of wind power in Japan is estimated to be approximately 1800 GW in theory, including 283 GW from onshore turbines and 1572 GW from offshore turbines. [93]

Solar Power in Japan

Solar photovoltaic (PV) power has become the fastest-growing renewable power technology over the last 10 years all over the world. In Asia, Japan continues to lead this sector, and produced 4.7 GW in 2011. In Japan, nearly all solar PV is linked to the power grid which indicates that Japan is likely to build smart cities easier than other countries. In order to enhance the economic efficiency and facilitate the use of solar power, the Japanese government introduced feed-in tariff system and the tariff for solar energy is $0.35/kwh, which is the highest around the world and approximately three times higher than that of France or Germany,.

Moreover, the Japanese government will set up a plan that will demand solar panels to be constructed on the top of every new building in Japan and will standardize this by 2030.[93]

Geothermal Energy Production in Japan

Because of Japan's typical geographical location with nearly 200 volcanoes and 28,000 hot springs, Japan has a significant potential to develop geothermal energy, although it only accounts for less than 1% of Japan's total electricity mix. It was not until recently that Japan considered using geothermal plant as an important source of energy. Japan produces only 0.5 GW with 18 existing geothermal power plants, ranking eighth in the world according to the 2010 Geothermal Congress in Bali, Indonesia. [93]

According to the Ministry of the Environment Research, the geothermal power in Japan is estimated around 30 GW. Moreover, the total potential of geothermal power is estimated around 14 GW.

However, this does not include national park area, where more than 80 percent of the nation's resources are located. Thus, Japan would be likely to achieve more capacity if national park areas are exploited. [93]

Hydropower in Japan

Electricity production through hydropower constitutes the biggest share of renewable energy in Japan. So far, the installed capacity of hydropower is about 27 GW. According to Agency for Natural Resources and Energy in the Japanese Ministry of Economy, Trade and Industry, the total installed capacity of small and medium hydropower plants is about 10GW in2011. [93]

Because of the typical topography with considerably steep gradients due to the narrow and mountainous, Japan has abundant water resources and hydropower, which means that Japan, by making the most of this feature, will be capable of producing a large amount of energy with small to medium hydropower plants. [93]

Biomass Energy in Japan

Biomass power produces energy and electricity by burning lumber, agricultural or construction/demolition wood waste that drives a turbine and could be one of the best resources when it is used, not as electricity, but as heat. Japan's current installed capacity of biomass energy is 3.2 GW. The ratio of biomass energy accounts for less than 1% in Japan's energy mix, and most of which came from waste.[93]

After the 2011 Tohoku earthquake and tsunami, woods from the nuclear power plants is being used as a source of biomass energy. And from then on, Japan is spare no effort to utilizing biomass energy. [93]

3.3.2.3 Energy Price

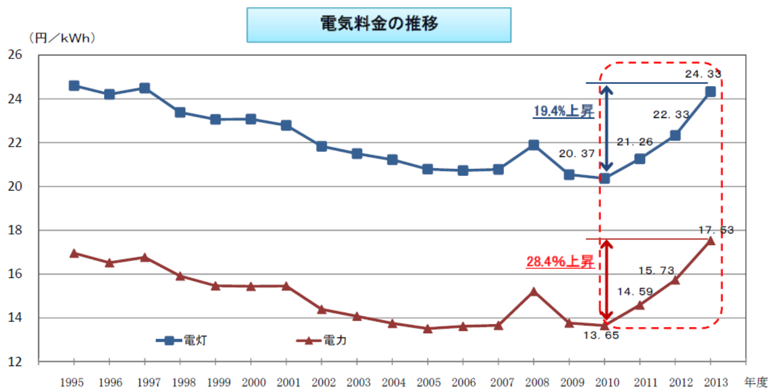


Figure 3.3.10 Electricity Prices in Japan [95]

Household electricity price (the blue line) is the unit-price of electricity for residential use. It can be seen that the residential electricity price has experienced a gradual decrease since 1995 and then increased sharply from 2010, reaching ¥24.33/kWh in 2013. Industrial electricity price (the red line) including free network power generation enterprises, refers to as the unit-price of electricity for plant offices and it suffered a similar trend as the household electricity price, reaching ¥17.53/kWh in 2013

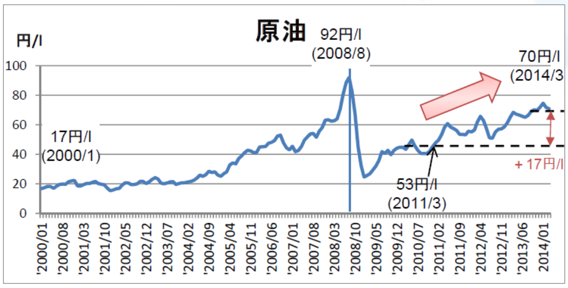


Figure 3.3.11 The Oil Prices in Japan [95]

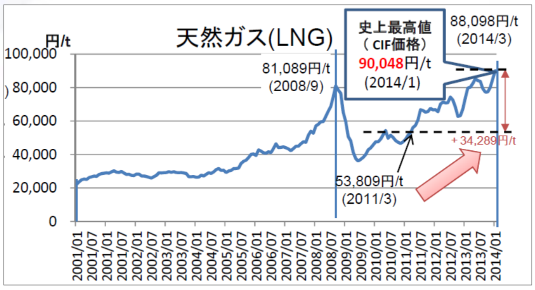


Figure 3.3.12 The Nature Gas Prices in Japan [95]

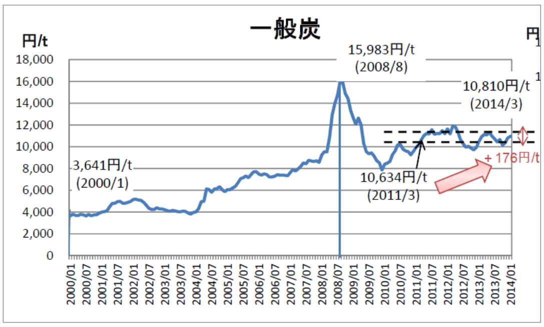


Figure3.3.13 The Coal Prices in Japan [95]

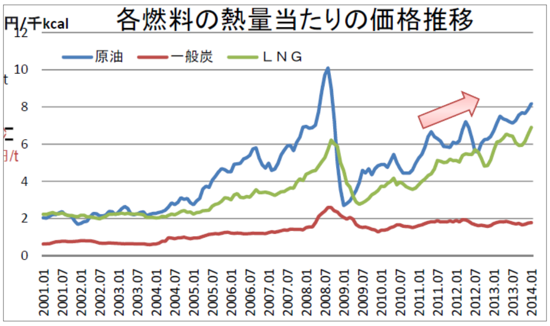


Figure3.3.14 All Kinds Of Fuel Equivalent Energy Prices in Japan [95]

3.3.3 District Energy Development History

In 1970, district cooling in Japan started to provide cooling or heating to the Osaka world exposition and nearby central area. In the following year, residential units in Shinjuku heart of Tokyo began to be offered cooling and heating. The formulation of heating enterprise law in 1992 created a new era in the development of regional air conditioning. Later, district energy began to popularize around Japan in the following 20 years before experiencing a downturn due to the oil crisis. After 1985, along with the rapid progress of urbanization, the regional air conditioner has entered an adjustment period, especially since 1989, the district energy systems have had a yearly increase of 10%. According to statistics, among all the projects introduced in Japan, the DES represented 60% since 1989 and until 1996, there are 78regional air conditioning utility companies and permitted such projects about 129 and 114 of them have district cooling and heating[96].

3.3.4 District Energy Development Status

Japan has increased its CHP capacity during the last 20 years as well as the CHP's share in total national capacity. By March 2012, over 9.5 GW of CHP offered proximately 3.5% of the country's electricity generation. The growth of CHP capacity has decelerated since 2007 and new annual additions have been below 200 MW since 2008, which was caused by the relatively high LNG import prices and low electricity prices that reduced the competitiveness of gas-fired CHP. Moreover, the 2008 economic crisis had also dramatically affected the industrial sector, slowing large-capacity CHP additions. In 2009 and 2010, there are losses of CHP capacity recorded for the industrial sector (11 MW and 37 MW respectively). Since 1990, there has been a conversion towards smaller projects – the average size of projects has decreased from around 2.4 MWe in 1996 to around 0.25 MWe in 2008, which reflects a trend of transforming from larger industrial projects to smaller commercial and residential projects. In Japan three major CHP technologies are used: gas turbines (43%), mainly in industrial applications; diesel engines (31%) and gas engines (25%), predominantly in commercial applications. The main fuels for CHP in Japan are natural gas (49%) and oil (35%) consistent with Japan's import fuel mix, with others playing a lesser role.

Industrial CHP installations account for 79% of total national installed capacity. The chemical and machinery sectors lead in terms of capacity, and the food industry owns the highest number of installed units. The largest CHP production facilities in Japan are installed at oil refineries and other energy industry sites. Market activity in the industrial units has been constrained in current years, as high oil prices have increased the operating costs of oil−fired CHP. In addition, the global economic crisis was a catalyst for some businesses with CHP facilities to convert production from their factories in Japan to other countries within the region.

CHP systems are installed more in commercial units than in the industrial sector which account for 22% of the national installed CHP capacity. Hospitals and other healthcare facilities are the largest CHP users, with 367 MW of commercial CHP capacity. The power disruption caused by the March 2011 earthquake has urged many commercial end users to seek backup technologies for electricity supply. And CHP is a potential beneficiary of such strategies even though gas distribution networks may also be influenced by a natural disaster.

Japan is the world leader in the development and application of micro−CHP technologies at the household level. Micro−CHP technologies are developed for single households, and are usually smaller than 5 kWe. This includes gas−engine CHP and fuel cell CHP, among others. There have been more than 170 000 micro−CHP systems installed by Japanese gas companies in residential units, with a total capacity of around 200 MWe, or less than 3% of the installed CHP.

District heating and cooling (DHC) is recently uncommon in Japan, but it is slowly growing in prevalence. Since the construction of the first district heating and cooling system in 1970 at the Senri Chuo Area in Osaka, the number of licensed DHC utilities has grown to 81 as of 2011. The government is seeking to expand its role through Area Energy Networks, representing a combination of traditional small−scale district heating and cooling networks connected to existing distributed heat resources. These networks are included in Japan's Kyoto Protocol Target Achievement Plan and are incentivized through low - interest loans and subsidies. An example of a DHC scheme is the largest DHC scheme, the Shinjuku development (2.2 million m^2) in Japan as of 2013. It has two gas turbine CHP units installed which produces 33 GWh electricity and 225 TJ heat annually. It is aided by additional centrifugal chillers, steam absorption chillers, and boilers. [94]

3.3.5 District Energy Policy [97, 98]

Year	Policy	Main Content
1974	"New energy development plan" (Sunshine Plan)	The core content of the plan is the development and exploitation of solar power and also includes geothermal development, coal liquefaction and gasification technology, wind power generation, ocean energy development and overseas clean energy transportation technology

1978	"Energy saving technology development plan" （Moonlight Design）	Put forward effective energy development and utilization technology, promote energy-saving technology development based on fuel cell power generation technology, heat pump technology and superconducting power technology etc.
1980	"Alternative energy law"	In order to develop alternative energy, the law sets that setting up development institute for new energy and industrial technology, providing vigorously support to research, development and the utility of new energy technologies and application; clarifying the responsibility of the government, enterprises and citizens in the promotion of new energy industry, as well as institutionalizing the testing system of new energy enterprises in the financial or other owners
1993	New sunshine plan	This plan includes research projects in seven fields, which are renewable energy technology, fossil fuel application technology, energy storage and transportation technology, system technology, fundamental energy saving technology, efficient and innovative energy technologies and environmental technology. In order to guarantee the application of this plan, the Japanese government finances 57 billion yen for this plan and among them, 36.2 billion yen is for the development of new energy technology.
1997	Special measures for the promotion of new energy utilization	The government provides soft loan and guarantee and various information and technology. In the administration, the government accelerates the application of new energy and renewable energy through necessary measures.
1998	Set up new energy strategy again	Develop nuclear power vigorously and develop alternative energy
2003	《New energy special measures law》	The law stipulates that any power company should be obliged to promote the development of wind power and solar power. And apart from this, the law is also applicable to bioelectrogenesis, medium- or small-scale hydraulic electrogenerating without a dam as well as geothermal power generation. The government set new energy goals every year and assign tasks to every power company based on previous yearly delivery. The retail electricity business owners are obliged to report the utilization of new energy to the Ministry of Economy, Trade and Industry.

2006	《National new energy strategy》	At first, the Japan government will develop energy saving technology, revise energy saving datum, increase the energy effective utilization rate and increase the energy efficiency by 30% in 2030. Secondly, decreasing the dependency on oil from 50% to 40% of the total energy consumption and try to reduce the dependency of transportation on oil from 100% to 80% through the development of solar energy, wind power, fuel cell and vegetal fuel etc. Thirdly, fostering Japan's own core petroleum exploitation enterprises and increasing the proportion of overseas oil exploitation from 15% to 40% through the acquisition of overseas oil companies and participating overseas oil exploitation to avoid the changes of political and diplomatic relations between countries affecting the oil imports stabilization and reduce the risk caused by oil price fluctuation. Fourthly, developing a new generation of nuclear power facilities, ensuring uranium resources for generation, improving the investment and construction environment and increasing the proportion of nuclear energy to gross generation from 30% to over 40%. Fifthly, promoting the international co-operation on new energy and nuclear electric power generation etc., trying hard to carry out Japanese's energy saving mode, assisting Asian countries to increase petroleum reserve, as well as improving schemes on development of energy saving technology and new energy technology and supporting enterprises to develop and exploit new technology.
2009	Kyoto target achievement plan	1. The city function transforms to Intensified and low carbon city; 2. Within regions and streets, the architectural complex promotes the application of centralized new energy equipment; 3. Within regions and streets, the architectural complex adopts centralized energy to increase energy efficiency.
2010	The basic principle of energy, environmental strategy	The infrastructure adopts various energy types and ensures the maximum utilization efficiency, including surplus heat and low-grade heat etc.
2011	About "the continued vitality, promote the sustainable development of regional land"	1. Promote the development of low-carbon, circular building (zero energy consumption, storage utilization and energy management); 2. Promote the construction of regional intensive city gradually.

2011	The basic strategy of regeneration in Japan	1. "zero energy consumption" buildings and intensive city construction promote the society to low carbon, circular sustainable society development; 2. The promotion of "the future of urban environment" and the comprehensive use of energy.

3.3.6 Conclusion

Because of certain historical elements, the development of district energy in Japan started late, around 1970s. As a country with scarce resources, energy resources, especially fossil fuel resources dependent mostly on importation, so that the price fluctuation of energy plays an important role in Japan's energy supply. According to the circumstance, the Japan government pays great attention to energy efficiency and promotes the promulgation of a series of energy laws as well as grant loans. However, the development cost of gas-fired or oil-fired district energy system is still high, so Japan has experienced a conversion from large-CHP to micro-CHP, and has made some achievements in micro-residential-CHP projects development. Up until now, the energy efficiency of district energy in Japan is among the leading level around the world, with an average utilization efficiency of 0.749. Until March, 2012, the number of the total CHP base stations reached 8783 with a total electricity generation of 9.5GW. So far, the Japan government gives strongly support to district energy system development and provides subsidies to various types, new-built or exist-built buildings and forms a perfect development scheme. The Japan's case offers a good example to other countries and regions.

3.4 District Energy System in Denmark

3.4.1 National Overview

3.4.1.1 General Information

Figure 3.4.1 the Map of Denmark[99]

Denmark, a Nordic country in Northern Europe, situated at southwest of Sweden and south of Norway, and bordered to Germany by the south. The Kingdom of Denmark consists of Denmark and two autonomous constituent countries in the North Atlantic Ocean, the Faroe Islands and Greenland. Denmark has an area of 43,094 square kilometers, with a population of nearly 5.64 million. The country comprises a peninsula, Jutland, and the Danish archipelago of 443 named islands, 70 out of which are inhabited. The islands feature flat, arable land and sandy coasts, low elevation and a temperate climate. As a Scandinavian nation, Denmark shares strong cultural and historic connections with its overseas neighbors Sweden and Norway. [100]

Denmark is a relatively wealthy country, which ranks tenth among OECD countries in regard to GDP per capita, at US$ 37 680 in 2009, according to OECD statistics. Unemployment, at 7.4% in 2010, is lower than the OECD average of 9.6%. [99]

3.4.1.2 Climate

Denmark has a temperate climate, featured mild winters, with an average temperature of 0.0 ℃ (32.0 ℉) in January and February, and cool summers, with a mean temperature of 15.7 ℃ (60.3 ℉) in August. With an annual average 121-days precipitation, Denmark enjoys a total of 712 millimeters (28 in) per year of as autumn is the wettest season and spring the driest.[101] Because of Denmark's northern location, there are large seasonal variations in daylight with short days in winter and long summer days.[102] While for the Faroe Islands, it has an annual average temperature of 6.7 ℃ (44.1 ℉), with a mean temperature in January of 4.5 ℃ (40.1 ℉) and in July of 10.1 ℃ in 2012 [103]

3.4.2. Energy Background

3.4.2.1 Energy structure

In Denmark, there are five primary fuels, i.e. crude oil, natural gas, biofuel, wastes and wind power. Total primary energy supply (TPES) in 2010 was 19.7 million tonnes of oil equivalent (Mtoe). Energy production was 23.2 Mtoe, less than 2009 levels, which indicated the falling production of oil and natural gas over the past six years. Energy exports amounted to 17.2 Mtoe in 2010 while imports were 13.8 Mtoe, so that Denmark is a net exporter of oil and natural gas. Renewables, largely wind and biomass represented 20.7%, which is relatively high compared to other countries. [104]

In regards to production, Denmark is one of the most efficient energy users compared with other countries. This is also applicable to CO_2 emissions from production. Disregard of relatively low energy consumption, Denmark is among the best in the EU and the OECD at continuously reducing its energy dependency and CO_2 emissions and over the past 25 years, Denmark is able to reduce its energy and CO_2 intensity on an above-average level. [104]

Primary energy production has increased rapidly since 1990. Production of crude oil and natural gas grew gradually up to 2004 and 2005 respectively, after which they declined. In 2012, the primary energy production was 801 PJ, as opposed to 870 PJ in 2011, which represents a drop of 7.9%. Primary energy production peaked at 1315 PJ in 2005. Production of crude oil and natural gas decreased by 8.8% and 11.9% respectively in 2012, while production of renewable energy etc. increased by 1.3%, amounting to 137.7 PJ in 2012. Production of renewable energy has increased by 201% during the period 1990 to 2012. [10] Wind power generation was 37.0 PJ in 2012, which is 5.1% more than that in 2011. Production of straw, wood and renewable waste represented 17.5 PJ, 43.9 PJ and 20.6 PJ respectively in 2012, with a total fall by 1.4% compared with 2011. [106]

Since 1980, the total energy production has experienced an increase trend to 2000, reaching 1165PJ and then decreased, being 801PJ in 2012. Among all the production, crude oil accounts for the most, with more than half of the production from oil. Natural gas production followed and the production of renewable energy has grown rapidly (Figure 3.4.3).

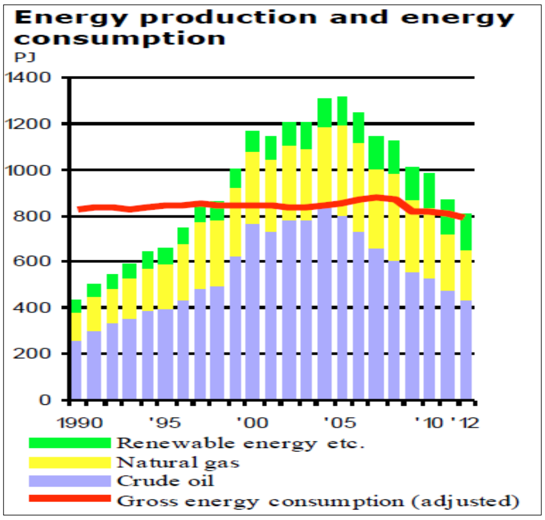


Figure 3.4.2 Energy Production and Energy Consumption [105]

In 1997, for the first time, Denmark produced more energy than it consumed. In 2012, the degree of self-sufficiency in energy was 102% as opposed to 108% the year before and it peaked in 2004 at 156%. Since 1993, Denmark has been more than self-sufficient in oil, resulting in annual net exports. Similarly, the degree of self-sufficiency in oil also peaked in 2004 and it has been declining over the past eight years. [105]

Furthermore, the composition of energy consumption in Denmark has changed greatly as a consequence of energy policy measures to promote the use of renewable energy.[5]Renewable energy today accounts for over 19% of final energy consumption, which has enhanced the security of energy supply and has contributed significantly to fulfilling Denmark's climate goals. From 1990 to 2007, economic activity in Denmark increased by over 45%, while CO_2 emissions were reduced by more than 13%. [104]

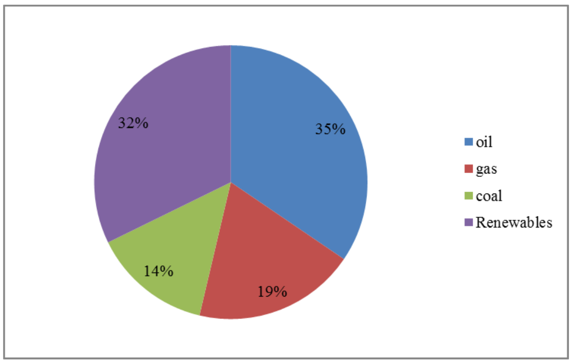


Figure 3.4.3 Denmark Energy Consumption in 2013[22]

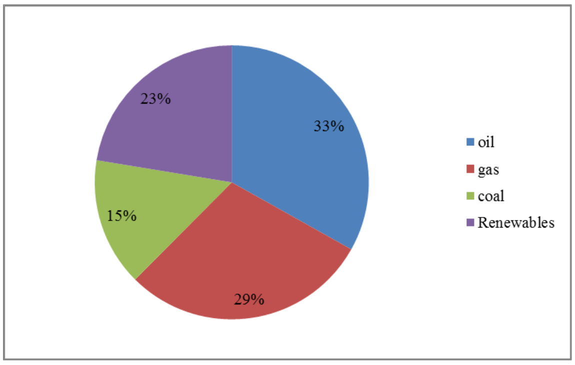


Figure 3.4.4 Denmark Energy Consumption in 2010[22]

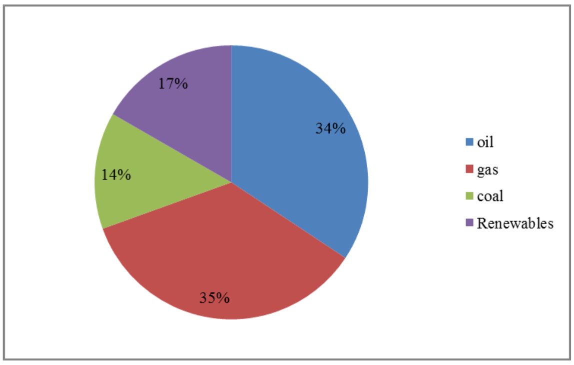


Figure 3.4.5 Denmark Energy Structure In 2005[22]

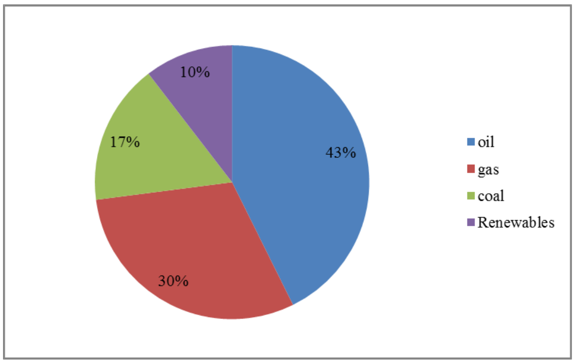


Figure 3.4.6 Denmark Energy Structure in 2000[22]

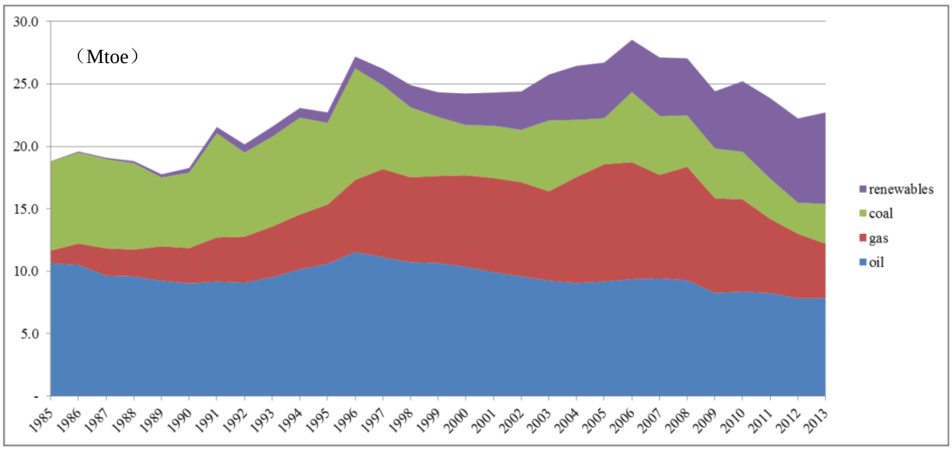


Figure 3.4.7 Energy Consumption Diagram in Denmark, 1985-2013 [22]

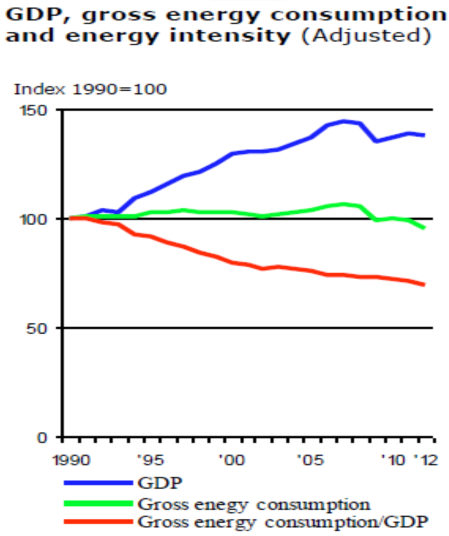


Figure 3.4.8 Energy Consumption, GDP and Energy Intensity [105]

Since 1980, the Danish economy has developed by 78%, with energy consumption remaining more or less constant, and CO_2 emissions reducing. This development reflects an increase in energy and CO_2 efficiency. A number of countries have seen underlying increases in their energy and CO_2 efficiencies, but the Danish increase is among the greatest in the OECD area. [105]

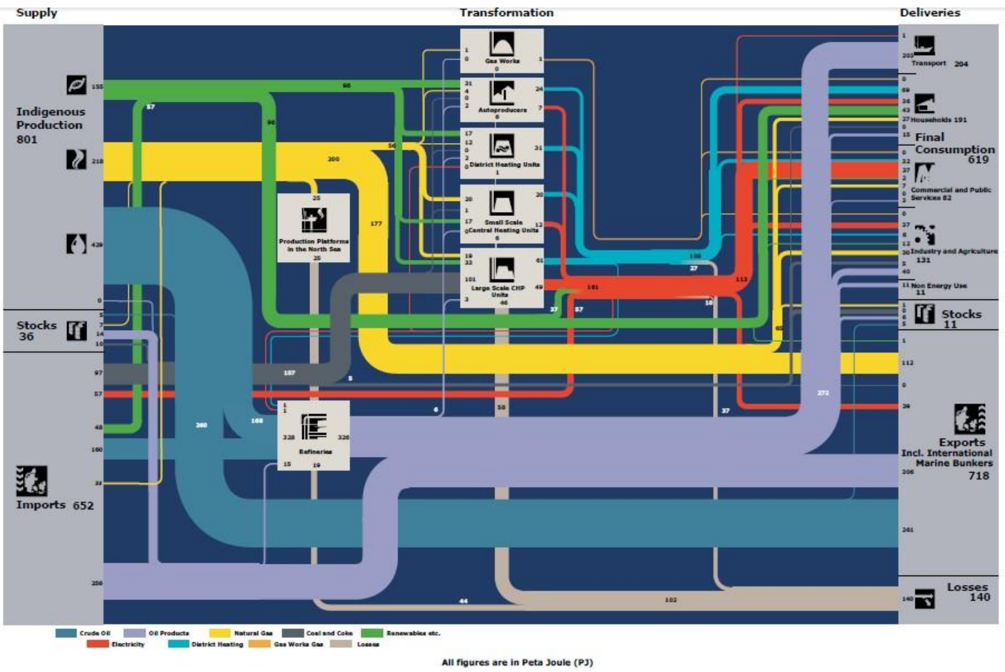
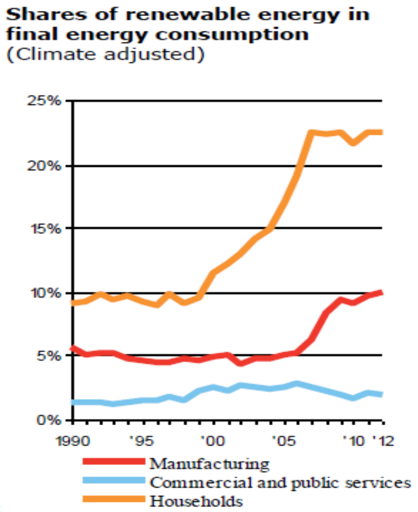


Figure 3.4.9 Denmark Energy Flow Chart [105]

In 2009, the energy production is 801 Mtoe with an importation of 652 Mtoe. The final consumption is 619 Mtoe and the exportation is 718 Mtoe with 140 Mtoe losses. Based on the data from figure 3.4.10, the calculated energy efficiency is 72.08% in Denmark in 2009 which is much higher than the world average level.

3.4.2.2 Renewable Energy

The Denmark government has been focused on renewable energy policies for nearly three decades and has developed a remarkable record of increasing the share of renewable energy in its total primary energy supply (TPES). It .has mainly relied on wind power and biomass for most of its renewable energy and was an early promoter in the wind energy industry. So far, Danish technology is leading the wind power development all over the world. Since 2000, it grew at an average rate of 6.6% per year reaching 19.4% of TPES in 2009. Biomass and waste accounted for the largest, at 17.1% of TPES in 2010, followed by wind, which represented 3.4%, with a negligible contribution from other sources. Sources of biomass include fuel wood and vegetal products such as straw, which accounts to 12% of TPES, followed by waste, which represents around 5% of TPES, with the remainder coming from biofuels.



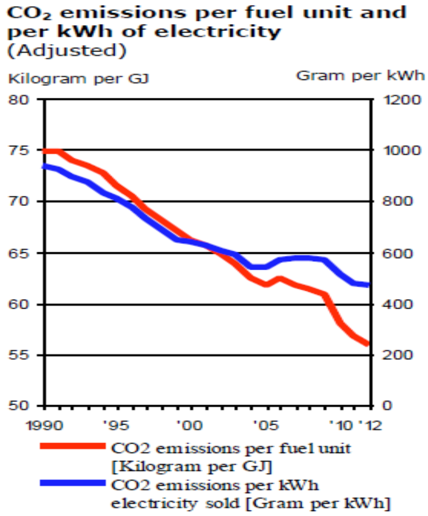


Figure 3.4.10 Share of Renewable Energy Consumption in Denmark[105] Figure 3.4.11 CO_2 Emissions per Fuel Units and per kWh of Electricity in Denmark[105]

Since 1994, renewable energy's share of final energy consumption has seen a rapid growth, from around 8% to nearly 20% in 2007.

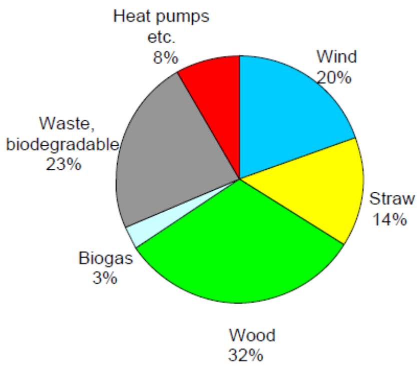


Figure 3.4.12 Renewable Energy's Contribution to Final Energy Consumption [107]

Renewable energy's contribution to final energy consumption is constituted by various types of renewable energy. It can be seen from the figure, various types of biomass contribute the largest share. Of this share, wood accounts for the largest share, followed by biodegradable waste and straw. Wind accounts for 20% of the energy consumption

3.4.2.3 Energy Price

Oil Prices

Taxes and fees charged on the production of oil and gas make a great contribution to government revenues. [9] And the gasoline price for households is DKK 13.17 per liter.

Energy prices for households, 2012	DKK	Euro
Gasoline regular [per litre]	13.17	1.77
Heating gas oil [per litre]	11.58	1.55
Natural gas [per Nm^3]	8.96	1.20
Electricity [per kWh]	2.22	0.30

Figure 3.4.13 Energy Prices for Households in Denmark,2012 [105]

Gas Price

The Danish natural gas market was set free in January 2004. There are no barriers to new users, and all consumers are free to choose their supplier. The households' natural gas price is DKK 8.96 per Nm^3

Electricity Price

Nord Pool spot prices are market-based and reflect changes in consumption, generation and transmission conditions in the Nordic market area. Annual hydropower generation ranges from 150 TWh to 250 TWh and is a key to defining the general spot price level. In wet years, wholesale prices are dominated by cheap hydropower, while in dry years, more expensive thermal power, especially coal-fired power, in Denmark and Finland is generated to make up for low hydropower production in Norway and Sweden. Increased market integration with Central Europe is anticipated to relieve price fluctuation in the Nordic market. [99]

Electricity price for residential units has increased gradually since 1990, reaching around DKK2000/MWh, while for industrial sector, the price has been relatively stable, with minor fluctuation below DKK500/MWh.

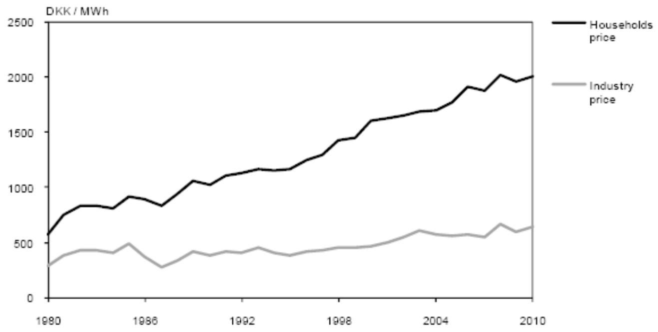


Figure 3.4.14 Electricity Prices For Industry and Households, 1980 to 2010[99]

Electricity prices for industry usage in Denmark are lower than the average of IEA Europe while prices for household customers are among the highest. Taxes, including value-added tax and electricity taxes, account to 56% of the household's end-use price of electricity. [99]

3.4.3 District Energy Development History

In 1903, in order to address the increasingly serious problem of municipal refuse treatment, the Danish built the first combined heat and power plant, by incinerating waste to provide electricity and heat for a new hospital.

During the 1920s and 1930s, to improve energy efficiency, the Danish began to set up a power station which used waste heat as heat source for district heating system. At that time, district heating only accounted for 4% of the total heating supply. Later in 1970s, district heating system had covered 30% of the Danish families. During 1973-1974, in response to the energy crisis and reducing dependence on imported fuel and cost, Denmark began to promote efficient cogeneration from the big cities to middle-sized and small cities.

In 2004, as the cornerstone of the Danish energy policy, district heating covered 60% area in Denmark. In 2011, the volume of Danish district heating reached 132 petajoules, with 76.3% of district heating from the combined heating and power. It saved about 30% of fuel compared with independent heating and power generation system.[108]

3.4.4 District Energy Development Status

District heating is widespread in Denmark, supplying around 60% of domestic housing with heat, corresponding to 45% of the total heat requirement. Danish district heating production takes place partly at combined heat and power plants and partly at units exclusively producing district heating. CHP units produced 72.6%, of which large-scale CHP units contributed 44.4%, small-scale CHP units contributed 14.8%, and CHP units at auto-producers contributed 13.4%.

CHP and district heating units can use diverse types of fuel. In 2012, it reveals that CHP units using coal as the primary fuel accounted for 24.3% of Danish heat supply, while units using natural gas, waste or biomass as primary fuel accounted for 13.0%, 17.5% and 16.8% respectively. For units that exclusively produce district heating, ones primarily firing with biomass contributed 12.2% and natural gas ones contributed 9.3% of total Danish district heating supply.

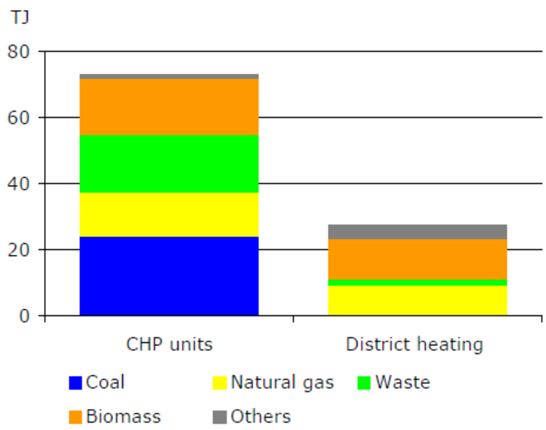


Figure 3.4.18 Heat Supply by Type of Fuel, 2012

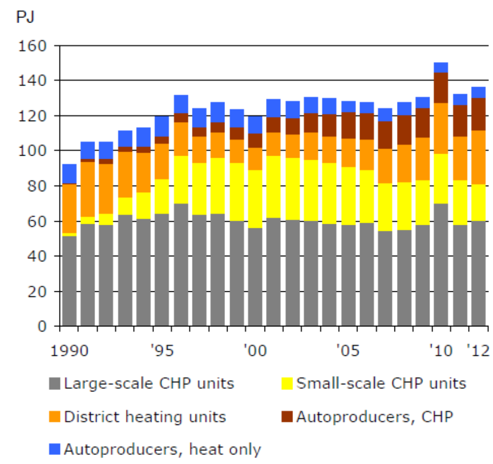


Figure 3.4.19 District heating production by type of production plan

District heating is generated at large-scale CHP units, small-scale CHP units, district heating units and by auto-producers such as in manufacturing, horticulture and waste treatment enterprises. Large-scale CHP accounts for the greatest district heating production as the share of production from small-scale units and auto-producers etc. increased since 1990. However, in recent years, production at small-scale CHP units has declined, while production at district heating plants has gone up again.

Total district heating production was 136.1 PJ in 2012, an increase of 2.8% compared with that in 2011. District heating production has gone up by 13.7% since 2000 and by 47.2% since 1990.

Nearly half of district heat is produced from biomass and organic waste, as shown in figure 14. The Danish Energy Agency's studies have indicated that there is much economic and environmental potential in replacing natural gas with district heat for heating and the DEA has encouraged local authorities to promote projects for the conversion of natural gas to district heating.

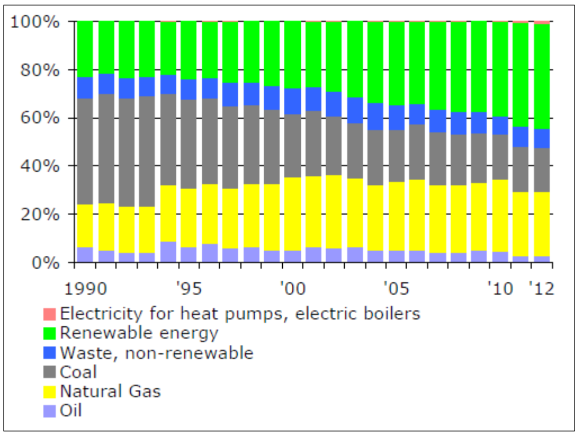


Figure3.4.20 Fuel Consumption for District Heating Production, Percentage Distribution

There was a remarkable change in the fuel types used in the production of district heating in the period 1990 to 2012, with an increased consumption of renewable energy from the share portion of 21.7% in 1990 to 43.7% in 2012 (of which biomass 42% and other renewables 1.7%). On the contrary, coal has decreased dramatically. From 1990 to 2012, the share of coal decreased from 44.2% to 18.3% of total fuel consumption for district heating.

Consumption of natural gas for district heating was 17.4% in 1990, increasing to around 30% up through the 1990s, while in recent years; the share has dropped slightly, reaching 26.7% in 2012. The share of oil was 2.7% in 2012, and electricity for heat pumps and electric boilers was 0.8%.[106]At present, among all the renewables for district heat, biomass is non-taxable. Co-generation and district heating plants are able to use electricity for heat, taking advantage of heating elements with a lower tax. The Green Growth Agreement introduced subsidies for biomass installations and subsidy equality for the sale of biogas to both co - generation plants and the natural gas network. The agreement focuses on breaking down the non-economic barriers for expansion of biomass. The Planning Act will also be amended to allow further penetration of biomass.

A smaller contribution is also expected from solar energy. Over the last few years, large solar installations for district heating have been installed in a number of locations in Denmark. The contribution from solar energy is expected to be 16 ktoe by 2020 compared to 10 ktoe in 2005.

The Municipal District Cooling Act, passed in 2008, allows local authorities that own district heating companies to set up and operate district cooling activities. So far, there is one district cooling project in Copenhagen run by Energy Copenhagen, which will also require a small amount of sea water for district cooling.

3.4.5 District Energy Policy

Since the end of the 1970s, increasing the use of CHP and enlarging the reach of district heating schemes have been part of the Danish energy strategy. The use of renewable energy has been promoted by a number of approaches, including policy support, the tax system and production grants. [99]

Date	Policy	Main content
1977	State subsidies	The state subsidies have promoted the use of waste heat from large electricity plants for district heating. During the 1980s and 1990s, many district heating plants have been converted to combined heat and power generation, mainly fuelled by gas. This development has been enabled by government-led heat planning which sets up the framework for local authorities. The financial incentive to invest in the CHP conversion was promoted by an electricity generation subsidy for small-scale CHP plants.[109]
1977	Taxes on energy	Energy taxes on electricity and oil were established. Since then, the taxes have been grown several times and taxes have also been charged on coal and natural gas in Denmark in 1977.[109]
1979	Municipal heat planning	The planning was divided into several phases. In the first phase, local authorities should prepare reports on their heat requirements, the heating methods used and the amounts of energy consumed as well as to assess heating possibilities. Then the data collected was used by county councils to prepare regional heat supply summaries. In the second phase, local authorities should prepare a draft of future heat supply while the county councils prepared "regional summaries" and then provided a definitive regional heat plan based on this, which became the third phase in overall heat planning. Within the boundaries of the regional plan, and after negotiation with the local energy utilities, the local authorities would then be able to prepare a municipal heat plan. [109]
1981	State subsidies for renewable energy	In 1981, state subsidies for renewable energy, such as for heat pumps and for solar energy for space heating, were established. Because of these subsidies, the share of renewable energy for space heating increased by 8 percent, from 5% in 1980 to 13% in 2001. The subsidy schemes were revised a number of times, but remained in effect until 2001, when the schemes were finally abolished.[109]

1992	CO_2 taxes	Until 1993, Danish industry was exempted from energy and CO_2 taxes, because of export interests. In 1993, a CO_2 tax on energy consumption in industry was set up to encourage the companies to save energy, and in 1996 a new "Green Tax Package" was introduced. This package consisted of three elements: 1) A growing tax on CO_2 emissions from fossil fuels used for industrial processes 2) Enterprises could get a reimbursement of this tax provided that they reached an agreement with the authorities on specific energy savings projects 3) Enterprises could apply for subsidies for the savings projects. The sum set aside for subsidies amounted to DKK 1,800 mill. during the period 1996–1999.[109]
2004、2008、2012	New political agreement	The Agreement comprises a wide range of ambitious initiatives for the period 2012 – 2020, offering Denmark a good step approaching to the target of 100% renewable energy in 2050. By 2020, the Agreement will bring the following main outcomes: 1) Approximately more than 35% renewable energy in final energy consumption; 2) wind power is to supply 50% of electricity consumption; 3) 7.6% reduction in total energy consumption compared to 2010; 4) 34% reduction in greenhouse gas emissions compared to 1990. The Agreement covering the following areas: energy efficiency, renewable energy for electricity production, district heating, combined heat and power production, use of renewable energy in households and industries, smart grids, biogas production, use of electricity and renewable energy for transport, research, development and demonstration and finally financing of the Agreement.[109]

3.4.6 Conclusion

District heating plays a key role in the heat and power supply in Denmark. So far, Denmark has achieved decades of valuable experience with combined heat and power plants and district heating systems. In fact, the first combined heat and power plant in Denmark was built more than 100 years ago in 1904 with the main purpose of providing a large hospital with electricity and heat. Recently, the Danish district heating system provides nearly two thirds of the total heat demand and more than half of all electricity generation in Denmark comes from combined heat and power plants. In addition, six out of ten Danish consumers receive heat from a district heating system or a combined heat and power plant, making district heating essential to the Danish heat and power infrastructure.[110]

Denmark is among the best countries in the development of district energy and can provide references to other countries in this field. In 2012, Denmark's Parliament has passed the most ambitious green economy plan in the world: it will generate 35% of its energy from renewable energy by 2020 and 100% by 2050. Thus, it can be estimated that the energy sources for district energy systems will transform to renewables gradually and the ultimate destination for district energy development will be renewable-based DES.

3.5 District Energy System in United Kingdom

3.5.1 National Overview

3.5.1.1 General Information

Figure 13.5.1 UK Map [111] (source: IEA, 2012)

The Great Britain and Northern Ireland, commonly known as United Kingdom, is a sovereign state located off the northwestern coast of continental Europe. It has an area of 244,000 km^2 (78th largest sovereign state in the world and the 11th largest in Europe) and the island of Great Britain consists of England, Wales and Scotland, while Northern Ireland borders on the Republic of Ireland (see figure 3.5.1). Apart from its land border, it is surrounded by the Atlantic Ocean, with the North Sea in the east and the English Channel in the south. Over the past decade, the UK population has increased by more than 5 million to reach 64.3 million in 2014 [112] which make it the 22nd most populous country. Population is expected to continue to grow, largely as a result of immigration. [111,112,113]

The United Kingdom is a developed country and has the world's sixth-largest economy by nominal GDP, with a total GDP of $2.828 trillion in 2014 and eighth-largest by purchasing power parity (around $2.497 trillion). It was the world's first industrialized country during the 19th and early 20th centuries. [113]

The UK economy have experienced a long boom sine 1992 until the global financial crisis in 2008, when the GDP dropped by 4.4% in 2009. The GDP per capita is slightly higher than the Organization for Economic Co-operation and Development (OECD) average. The economy in UK is dominated by services, representing around 78% of Gross Domestic Product (GDP) in 2010. Banking, insurance and business services are particularly strong and London is a major international financial center. Industry contributed around 22% of GDP and agriculture around 1%. [111]

3.5.1.2 Climate

The United Kingdom has a temperate maritime climate with plentiful rainfall all year round. Average annual rainfall in the north is more than 1,600 mm, while central and southern England receives an average of less than 800 mm. The average annual temperature is around 10 ℃, with three coldest months i.e. December, January and February, ranging between 3 and 6 ℃, and the warmest months of July and August, with a mild temperature between 16 and 21 ℃. The temperature varies with the seasons seldom dropping below −11 °C (12 °F) or rising above 35 °C (95 ℉). Because of the climate features, the district energy supply in Britain is mainly based on heating in winter.[112]

3.5.2 Energy Background

3.5.2.1 Energy structure

Overall

In UK, there are four main primary fuels, i.e. coal, petroleum, natural gas and primary electricity. The primary electricity refers to electricity from renewable energy, nuclear and others. In 2013, the primary supply of fuels was 213.5 million tonnes of oil equivalent (mtoe), among them, natural gas accounts for the most since it exceeded the supply of oil in 1997, with nearly 41.9% of the total primary supply and oil follows, with a percentage of 34% as it has been decreasing over past decades. Because of air pollution reduction requirement set by the EU, the supply of coal has been being decreased, with a share of 15% of the total primary energy supply. The nuclear accounts for 8%, and it is expected to decline as power plants are reaching their operative lives. Biomass and waste represents 3% of the TPES. The supply of wind and hydro are of the lowest level, with 0.4% and 0.2% respectively.

Comparing with other IEA countries, the United Kingdom has a rather high share of fossil fuels in its energy structure and among the lowest share of renewables (Figure 3.5.2)[111]

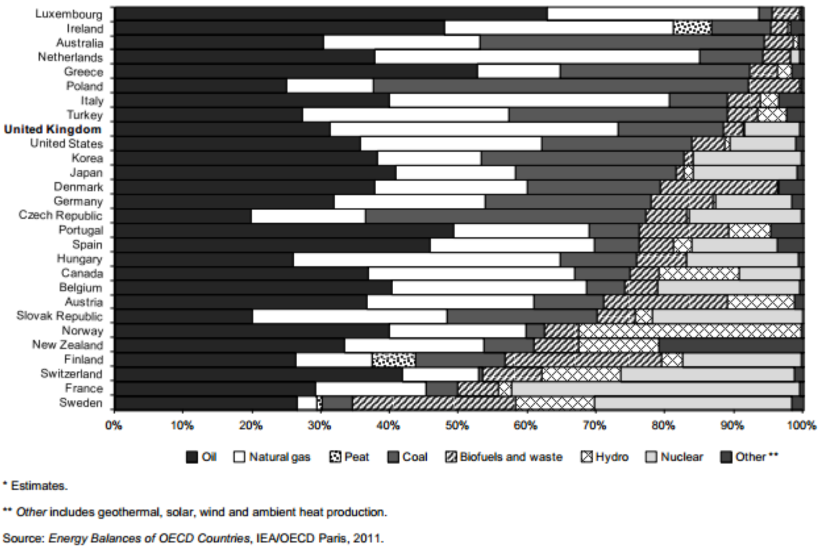
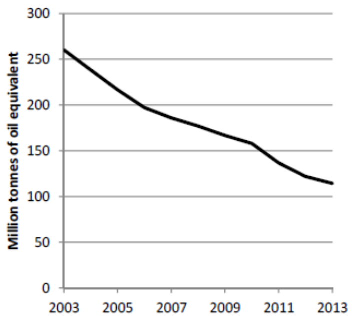


Figure 3.5.2 Total Primary Energy Supply in IEA Countries by Source [111]

During the past decades, the energy production has fallen gradually in each year since 1999 (Figure 3.5.3), due to the longer term decline in UK Continental Shelf (UKCS) output, and has decreased by 62 percent from 2003 to 2013.[114] Since 1973, the production of coal have experienced a gradual decrease while oil, natural gas and nuclear reached their peak during 1997-2003 and then suffers a sharp decline.



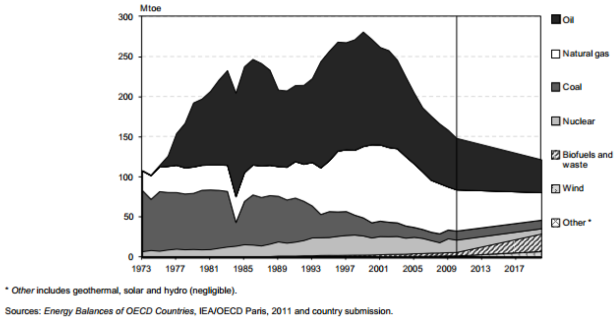
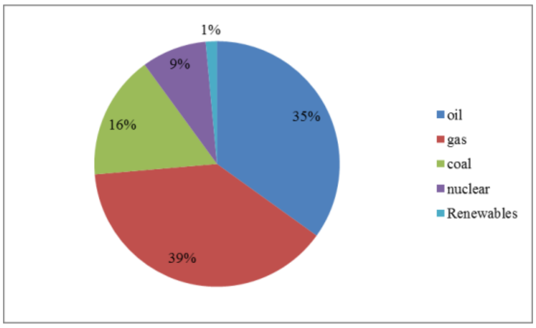


Figure 3.5.3 UK Energy Production Level[114] Figure 3.5.4 Energy Production by Source, 1973 To 2020[111]

The following figures show the energy consumption in UK in 2000, 2005, 2010 and 2013 respectively. In UK, gas consumption proportion is the most, fluctuating between 37% - 40% from 2000 to 2010 and then decreased to 31% in 2013. Oil is the second-largest consumption energy, fluctuating around 35% since 2000. The consumption of coal and nuclear is relatively stable, accounting for 25% in total. Since 2000, the consumption of renewable energy has developed rapidly, from 1% in 2000 to 11% in 2013.



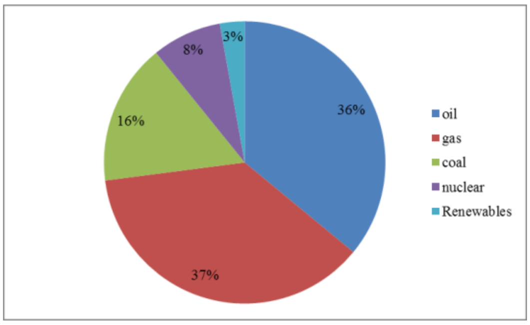
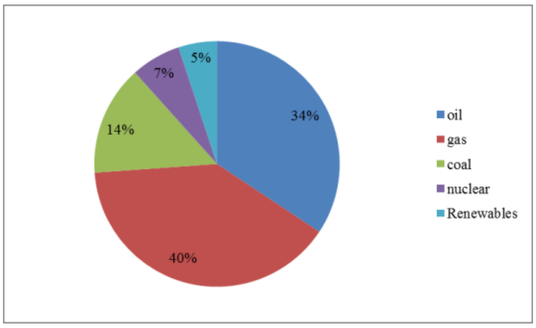


Figure 3.5.5 UK Energy Consumption in 2000[22] Figure 3.5.6 UK Energy Consumption in 2005[22]



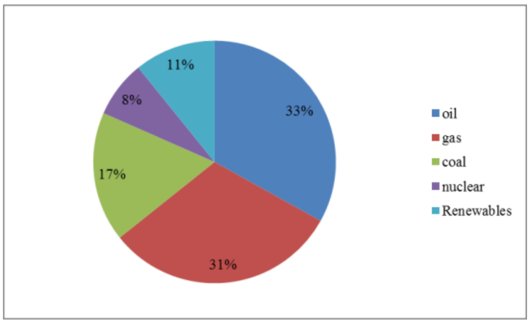


Figure 3.5.7 UK Energy Consumption in 2010[22] Figure 3.5.8 UK Energy Consumption in 2013[22]

It can be seen clearly that from 1985 to 2000, the consumption of natural gas increases gradually while other types of energy supply have experienced a decline trend. While since 2010, all types of energy are estimated to decrease gradually (Figure 3.5.9).

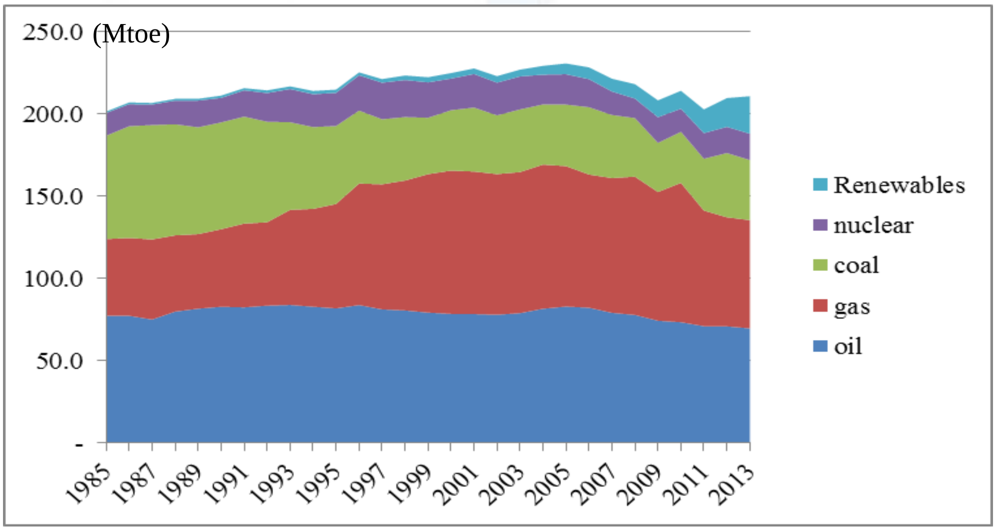
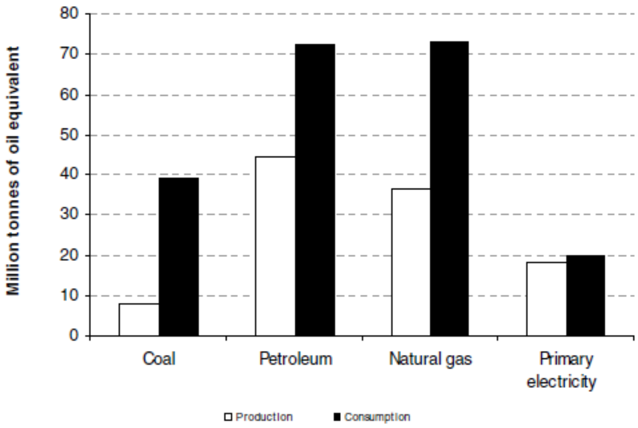


Figure 3.5.9 Total Energy Consumption, 1985 to 2013[22]

UK has experienced a period from net importer (highs in 1970) to net exporter (lows in 1980), and then in 2004, all of the production of the four types of fuels cannot meet the demand need. UK returned to be a net importer of fuel. And later in 2013, the UK became a net importer of petroleum products for the first time since 1973. The imported energy includes coal, oil and natural gas and little primary electricity. Among them, nearly 70% of the coal and 50% of the natural gas rely on importation. This switch from net exporter to importer is largely due to the closure of the Coryton refinery in July 2012. In total, Net imports represented for 47 per cent of energy utilized in the UK in 2013.[114]



Note: Includes non-energy use of petroleum and gas. Differences between consumption and production are made up by foreign trade, marine bunkers and stock changes.

Figure 3.5.10 Production and Consumption of Primary Fuels 2013[114]

The transport sector is the largest end-user. It represents 36% of total final consumption of energy (54 Mtoe). Residential units are the second-largest, with 29% of TFC. Industry accounted for 15% in 2013, and commercial and other sectors for 20%. The total final consumption is expected to decline in the future with a decrease in residential units. [114]

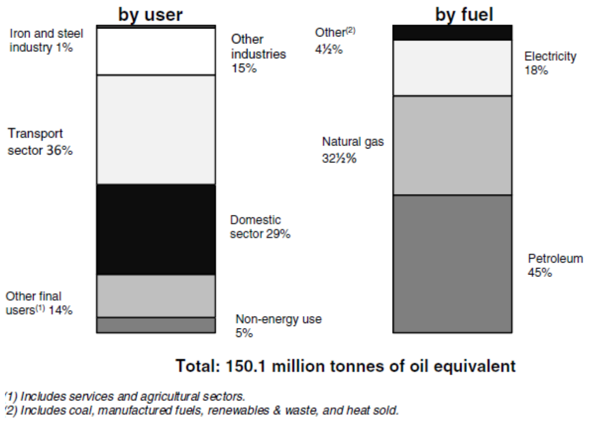


Figure 3.5.11 Final Energy Consumption 2013[114]

From all the types of energy consumption, natural gas and electricity is mainly used for domestic, industry and other final consumers while oil is mainly to support the transport.

In UK, nearly half of the energy is used for heating of one sort or another, and 52% of the total natural gas consumed was used to provide heat for buildings and industry in 2011, while 34% burned in power stations to produce electricity. Heating within the domestic sector currently represents 23% of UK energy demand. Non-domestic buildings represent 17% of total UK energy consumption with over 60% of energy in non-domestic buildings being used for delivering heating and cooling. The heating for the residential units, including space heating, water heating and cooking, accounted for the most heating demand. Industry is the second-largest heating user, involving space heating, high and low temperature process, drying/separation and cooling ventilation.[115]

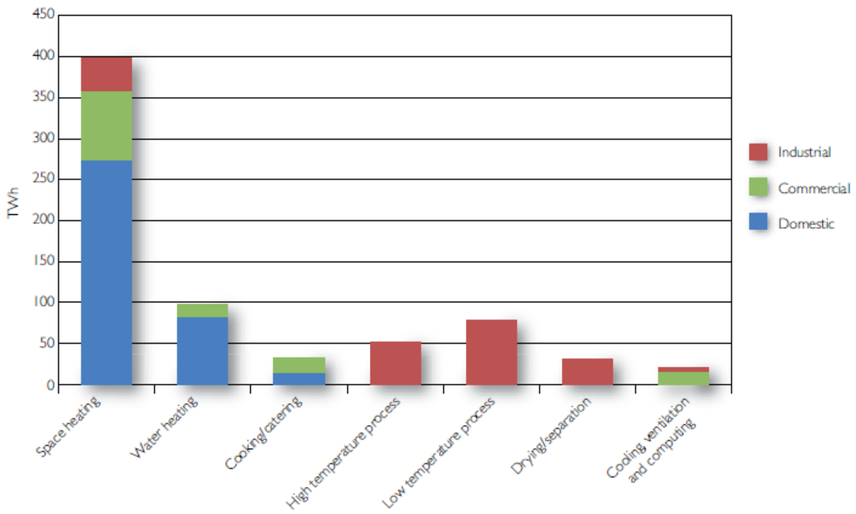


Figure 3.5.12 Energy Consumption for Heating by Sub-Sector and End-Use in Twh (2011) [115]

Over 95% of UK homes are heated by boilers, [116] with the fuel types dependent on location. In UK nearly 23 million households (80%) are connected to the gas grid. The other four million homes that are off the gas grid use other kinds of fuels that relying on whether the household is in a rural or urban setting. In dense urban surroundings, the main fuel for heating off-grid homes is electricity, particularly in housing blocks where there may be limitations on the use of gas for safety reasons. In rural environment, the predominant fuels used for heating are electricity and heating oil, with solid fuels and liquefied petroleum gas (LPG) being used to a lesser extent.

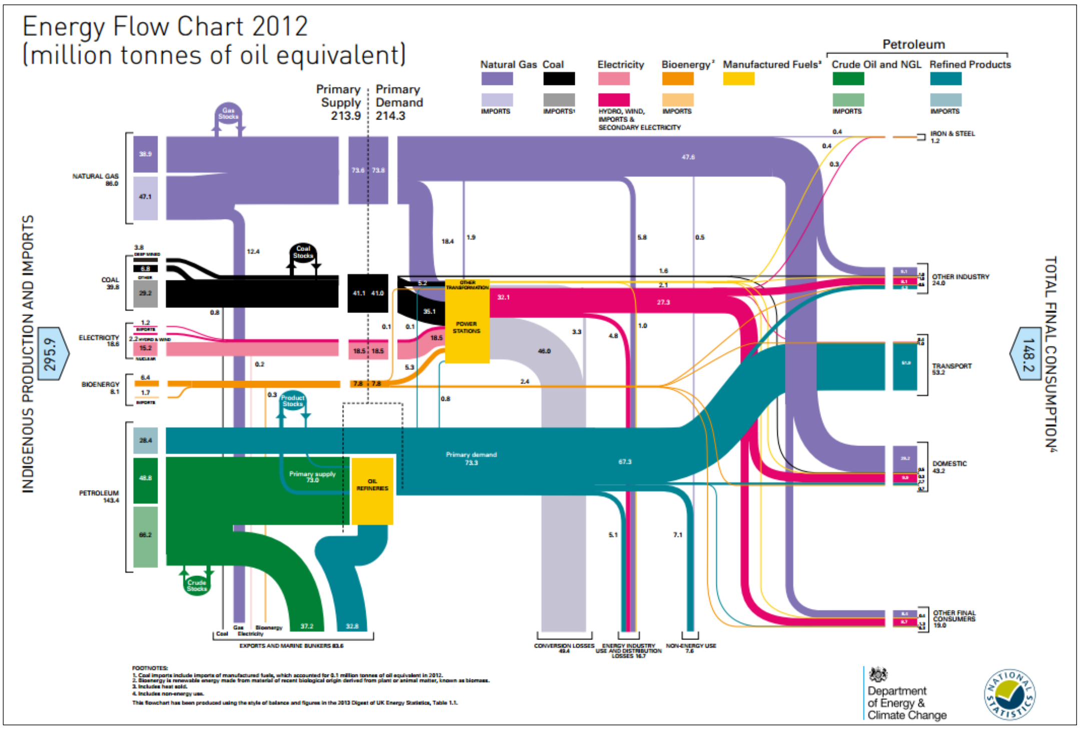


Figure 3.5.13 Energy Flow Chart 2012 [117]

This figure is based on statistics taken from the Digest of United Kingdom Energy Statistics 2013. In 2012 indigenous production and imports totaled 295.9 million tons of oil equivalent. The final consumption is 148.2 million tons of oil equivalent, which accounted for 69% of the primary supply (213.9Mtoe). [117]

3.5.2.2 Renewable Energy

In recent years, the share of renewable energy in the United Kingdom's total primary energy supply (TPES) has increased greatly, from 1.5% in 2003 to 3.7% (7.2million tons of oil equivalent) in 2010. Thus, the United Kingdom ranks fourth-lowest among IEA member countries (see figure 3.5.14) [111]

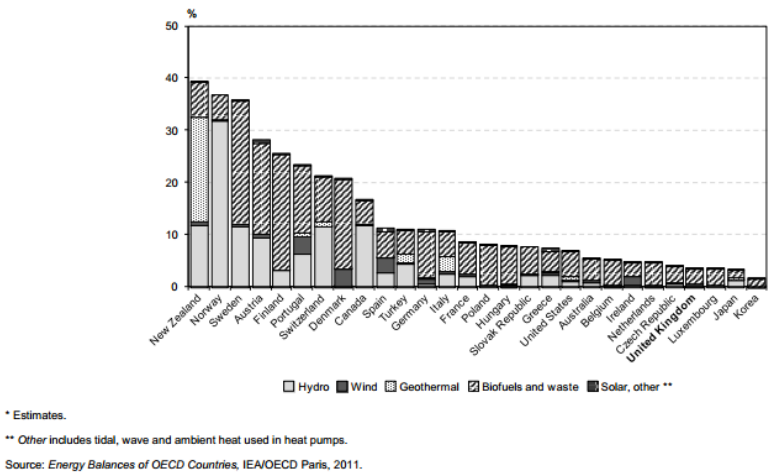


Figure 3.5.14 Renewable Energy in Total Primary Energy Supply in IEA Countries, 2010[111]

Biofuels and waste were the largest renewable energy sources in the United Kingdom, at 5.9 Mtoe, 2.9% of TPES in 2010. Biofuels and waste can be broken down into primary solid biofuels (34%), biogases (30%), liquid biofuels (19%) and industrial and municipal refuses (17%). The share of biogases is particularly high in UK (nearly 1%) compared to most IEA countries (average around 0.3%). In the United Kingdom, 21% of total biofuels and waste are imported (17% of primary solid biofuels and 81% of liquid biodiesel).

The second most important renewable source is wind energy, accounting for 0.4% of TPES in 2010. Other renewable energy sources made a negligible contribution to the total energy mix: hydropower represented 0.2% of TPES and solar energy 0.04% in 2010. The government estimates that renewable energy supply could increase to 16.6% of TPES in 2020, partly compensating the decreasing supply of fossil fuels and nuclear. Biofuels and waste are estimated to increase to 22 Mtoe, 13% of TPES in the decade, and wind power to reach 4% of TPES.[111]

Compared to other IEA countries, electricity generation from renewable energy sources is rather low in the United Kingdom. As a consequence of a high heating demand, a low requirement for cooling, and access to North Sea gas in recent decades, the UK has developed into the world’s number one market for gas boilers. Natural ventilation rather than air conditioning is the main form of cooling in the domestic sector and parts of the commercial sector. |As some countries have been developing heat networks and renewable heating as responses to concerns about price and security of supply of imported fossil fuels, the UK’s very low penetration of these technologies is a direct consequence of ample supplies of low cost natural gas distributed nationally, following the switch from town gas some forty years ago. [118]

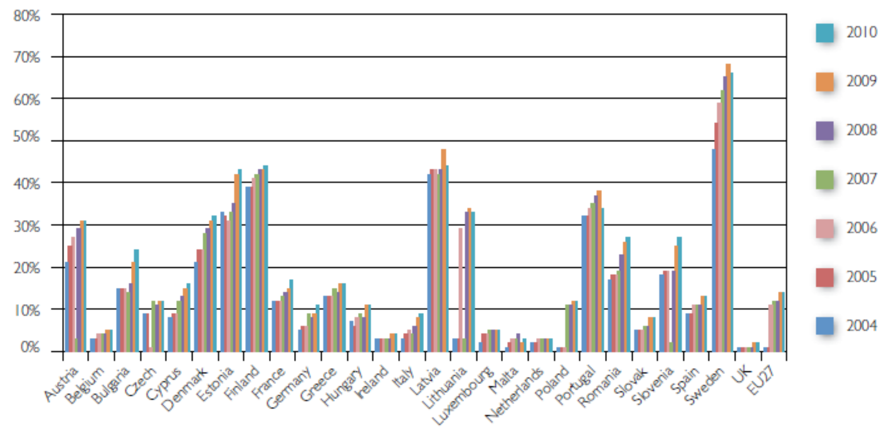


Figure 3.5.15 Percentage of Heating and Cooling From Renewable Resources As A Percentage Of Total Energy Used for That Purpose[118]

According to the data from Eurostat 2010, it can be seen clearly that the penetration of renewable energy in UK is low, almost with the lowest renewable used for heating and cooling.

3.5.2.4 Energy Price

Since 2000, the energy consumption has been decreasing, while the estimated expenditure by users increases to nearly two times in 2013 comparing to 2000. Of the total final expenditure on energy in 2013 (£133 billion), the biggest share, 51 per cent, was consumed by the transport sector. Industry purchased 10 per cent (£14 billion), the domestic sector purchased 27 per cent (£36 billion), with the remaining 11 per cent (£15 billion) consumed by the service sector.[114]

Oil Price

The United Kingdom operates an open and competitive market where the wholesale price of petroleum products is set by market dynamics since 1988/9, allowing customers to switch between different suppliers. The government affects retail prices for consumers only through taxation. Compared with other IEA member countries, unleaded petrol prices in the United Kingdom are close to the median level (Figure 3.5.16); retail automotive diesel prices are among the highest (Figure 3.5.17), while heating oil is relatively cheap. These differences are largely explained by differences in fuel taxation across countries.[111]

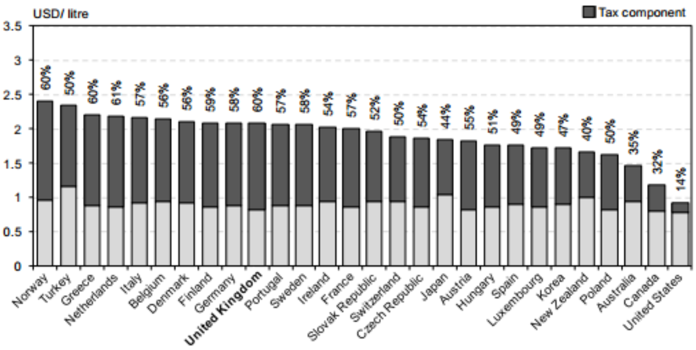


Figure 3.5.16 Unleaded Petrol Prices and Taxes in IEA Countries, 4th Quarter 2011[111]

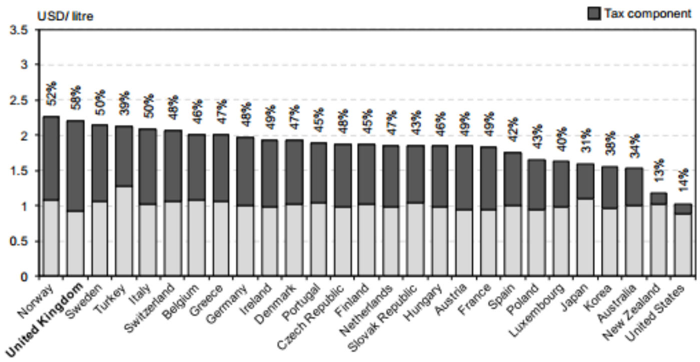


Figure 3.5.17 Automotive Diesel Prices and Taxes in IEA Countries, 4th Quarter 2011[111]

Natural gas price

In UK, the price of gas and electricity is controlled by the market. The wholesale price of nature gas in Great Britain is the National Balancing Point (NBP) price. Established in 1998, the NBP is the largest and most liquid natural gas spot market in Europe and provides a reference as an alternative to oil indexation.[111]

The wholesale gas price has varied considerably over the past ten years (Figure 3.5.18). As the UK moved from a net exporter to a net importer in 2004, NBP prices increased from USD 3 to 4 per MBtu to USD 7 per MBtu. The relationship between the NBP and continental (oil-linked) gas prices then changed, so that the NBP became on average higher than continental prices, although they were still lower during summer times. In particular, NBP prices were showing a significant seasonality at that time, and spot prices peaked at high levels during winter 2005/06 (USD 14 to 15 per MBtu), reflecting shortages on the UK market.[111]

Figure 3.5.18 Natural Gas Wholesale and Retail Prices, 1997 to 2010[111]

After a sharp increase in 2008, similar to European and US gas prices, the NBP prices collapsed in late 2009, due to the economic crisis. It is inevitably that the gas demand is reduced while at the same time, a significant supply was arriving to the market – shale gas in the United States and new LNG. During one year to April 2010, NBP and Henry Hub prices converged at relatively low levels, around USD 4 to 5 per MBtu. Since then, NBP prices rose to almost the level of the continental European prices at around USD 9 to 10 per MBtu, which reflected tightness on global natural gas markets and the fact that the United Kingdom is now acting as a bridge for more supplies to the wider continental markets. However, NBP prices remain at a discount compared with oil-linked gas prices.

The NBP price is the most important component of end-user price. End-user prices are not controlled by the regulator, but set by the suppliers. Ofgem regulates the transmission and distribution components. The NBP prices have increased over the past decade, as well as the end-user gas prices. Industrial gas prices have closely linked with NBP price developments and in 2009 were 2.9 times higher than 2000 levels (1.74 p/kWh versus 0.61 p/kWh). Residential gas prices have increased from 1.58 p/kWh in 2000 to 4.2 p/kWh in 2009. [111] [119]

3.5.3 District Energy Development History

The first attempt to utilize CHP in UK occurred in 1742 when Sir Hugh Plat, a lawyer and horticulturist, used pipes to distribute steam for heating a room. And then, later in 1745, Sir William Cook transferred steam to heat his home in Manchester by a similar means. He also tried to convey heat to a group of buildings from a single source.[120] Subsequently, Mr Hoyle in Halifax obtained a patent for the pipe-based heating system in 1791 and Jacob Perkins and the Marquis de Chambonne utilized hot water as heating medium for a system built in England.[121]

In the UK, CHP started in industry, namely at the Singer factory in Clydebank in 1898. One of the earliest successful large CHP projects was implemented in in 1911 in Bloom Street in Manchester, which supplied steams to neighboring shops, offices and factories. Then, CHP schemes began to install in Dundee and in Stirling during 1920 and 1922 respectively. However, since then, only a little improvement e.g. the Whitehall scheme, the Pimlico DH in London in 1950, Spondon power station scheme in 1960, municipal coal-fire DH scheme in 1965 in Billingham etc. occurred in UK. In 1968, the Nottingham Corporation chose incineration as the future way for refuse disposal. Such scheme is operating and has been the largest of its kind in UK.[122]

In 1970s, the first energy crisis exploded which resulted in the increase of energy policies in UK and in the worldwide government. Apart from this, since 1973, the UK has been a member of the European Union, who has set requirements for the UK and other member countries in a various energy fields, which contributed to the development of energy policies in UK.[111] And then, a political pressure-group advocating CHP was formed in 1975.[123] Only few years later, in 1979, the second oil price shock occurred which led the UK government to set up the Department of Energy and the Organization for Economic Co-operation and Development (OECD) to establish the International Energy Agency. [111] The government' Combined Heat-and-Power Group was optimistic on CHP-DH and recommended the set-up of CHP-DH demonstration schemes and a National Heat Board. However, the two proposal were subsequently rejected by the Department of Energy (DoE).[121,124]

According to the requirements of Marshall Report, the UK government entrusted the Atkins and Partners to assess the feasibility of CHP-HP application in potential locations. In 1980, the cities of Belfast, Glasgow, Liverpool, London, Sheffield and Tyneside were selected for further studies, and in 1981, Edinburgh, Leicester and Manchester were added in the assessment. The study completed in 1982 and funding was recommended to provide CHP-HP scheme in Belfast, Edinburgh and London with the highest rates-of-return.[124] However, the response by the government to the Atkins' report delayed until the DoE, in 1984, invited local consortia, involving both the public and private sectors, to bid for grants towards further detailed studies in up to three of the nine chosen cities and then in 1985, the DoE selected Belfast (Northern Ireland), Edinburgh (Scotland) and Leicester (England) and provided a total grant of £750,000, which was the Lead-City Scheme. For another three rejected cities, namely Sheffield, London and Newcastle continued, in cooperation with private sectors, developing their own project without the government financial support. So, in total, six cities tried to adopt CHP-DH scheme.[121,124]

The first law enacted by the UK government for CHP is in Energy Act (1983), which allows the private generator to (i) buy electricity from the Local Electricity Board (LEB) for its own use or the use of its customers; (ii) sell its privately-generated electricity to the LEB; (iii) use the transmission and distribution network of the LEB for its own use or the use of its customers. Through this policy, the government intended to encourage the Central Electricity Generating Board (CEGB) to invest in CHP programmes and promote the sale of heat by the same means through networks. However, in practice, such law only stimulated the development of industrial and small-scale CHP application.[123]

Unfortunately, the progress of CHP-DH in the three lead-cities, along with the other three privately-supported cities has been disappointing. The barrier, for nearly all the scheme, was that the total expenditure is high before benefits can be seen.[125] While Leicester, since being selected, has spared no efforts to set up a city-wide CHP-DH scheme and the CHP-DH system are supplying heat to thousands of residential units and public buildings, such as schools, children' nurseries, houses and old peoples' homes. In late 1900s, attempts of installing CHP-HP in Leicester and London have been delayed due to lack of financial support.[123,126] Nevertheless, in April 1988, a DH system was implemented in part of Sheffield using municipal waste as the fuel. The scheme consists of 17.5 km underground pipelines and serves 15 main developments, including more than 3500 dwellings and shops with a 30 MW total load, as well as down-town civic and commercial premises with more than a 27 MW of heat demand.[127]

In 1989, the Electricity Act was enacted which resulted in the establishment of (i) two privately-owned major electricity-generating companies, i.e. National Power and PowerGen; (ii) Nuclear Electric; and (iii) twelve regional electricity companies (RECs). The electricity trade between the major generators and the RECs takes place through an electricity pool via a daily competitive-bidding price system. The Office of Electricity Regulation (OFFER) was set up to regulate the activities of the restructured electricity industry. All of these arrangements contributed to the existence of free market and competition for generators and suppliers and hence allow a fair trade for the CHP owners. CHP schemes which meet the requirements: (i) that never produces more than 10 MWe or only provides more than 10 MWe to a single consumer; (ii) for self-generation, where 51% or more of the output of a generating station is provided to a single consumer on the same site as the station. The electricity produced could be sold either through the pool or to local customers could be exempted from the license which is needed prior to joining the electricity-supply business.[128] In addition, OFFER has been able to promote and encourage the development of CHP within the regulatory framework[129]

Because of the lack of direct UK Government initiatives, political hesitancy, too much reliance on short-term monetarist and institutional barriers, the development of CHP-DH has been disappointingly slow compared with other European countries (e.g. Denmark, Germany and Sweden).

3.5.4 District Energy Development Status

In UK, most CHP is used for industry, supplying process steam (93.5% of heat from CHP). A smaller, but proportion of heat supplied by CHP (5.3%) is in the form of ‘Low Temperature Hot Water’ at 75-95 ℃ for space and water heating. This includes heat provided via heat networks. Heat recovered from gas turbine exhaust heat, and supplied as hot air at up to 550 ℃, and hot oil at around 160 ℃ make up the remaining heat supplied by CHP.[118]

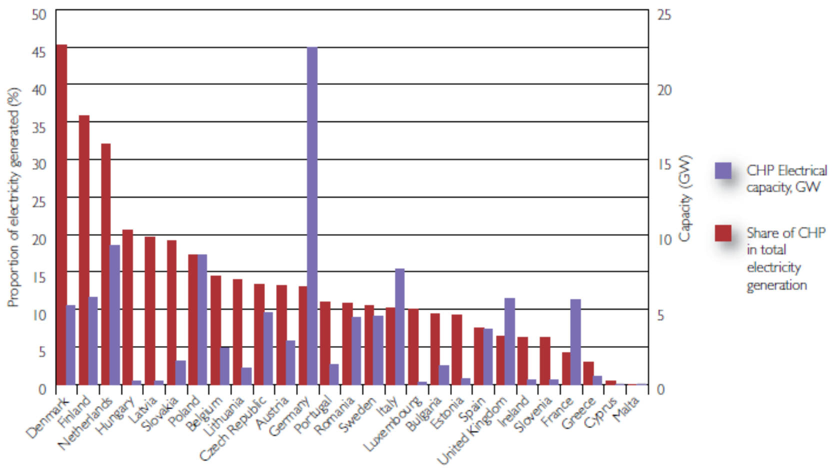


Figure 3.5.19 EU Member States' Total Electricity Generation from CHP [130]

In the UK, Good Quality CHP capacity contributed 6 GW electrical (GWe), 7% of the UK's electrical generating capacity and 10.4 GW of thermal capacity in 2011. Aside from industrial uses, a large number of small CHP schemes, including in commercial premises, local authority buildings, and hospitals, supply heat and power in the non-domestic sector, [118]

Size	No. of schemes	Total capacity	Typical technology	Grade of heat
Fossil fuel CHP				
<10 MWe	1543	852 MWe	Reciprocating engine. Heat, supplied as hot water, recovered from engine cooling system.	75-95°C hot water
10-50 MWe	44	984 MWe	Simple cycle gas turbine. Heat, supplied as steam, recovered from turbine exhaust.	350-450°C steam at up to 60 bar
>50 MWe	25	3947 MWe	Combined cycle gas turbine. Heat, supplied as steam, extracted from steam turbine.	350-450°C steam at up to 60 bar
Renewable CHP				
<10 MWe	220	212 MWe	Bioliquid reciprocating engine. Heat, supplied as hot water, recovered from engine cooling system.	75-95°C hot water
>10 MWe	8	117 MWe	Solid biomass steam turbine. Heat, supplied as steam, extracted from steam turbine.	120-450°C steam at up to 60 bar

Table 3.5.1 UK CHP Capacity, Typical Technologies and Grade of Heat [131]

Table 3.5.1 shows the number and capacity of UK (2011) CHP capacity broken down by size and fuel type, along with typical technologies and heat grade.[118]

3.5.2.3 Heat Networks

The amount of heat supplied to buildings in the UK via heat networks is around 2% of domestic, public sector and commercial heat demand. These nearly 2000 networks serve approximately 210,000 dwellings and 1700 commercial and public buildings across the UK. The largest networks are mainly in the UK's largest cities and on university campuses.[118]

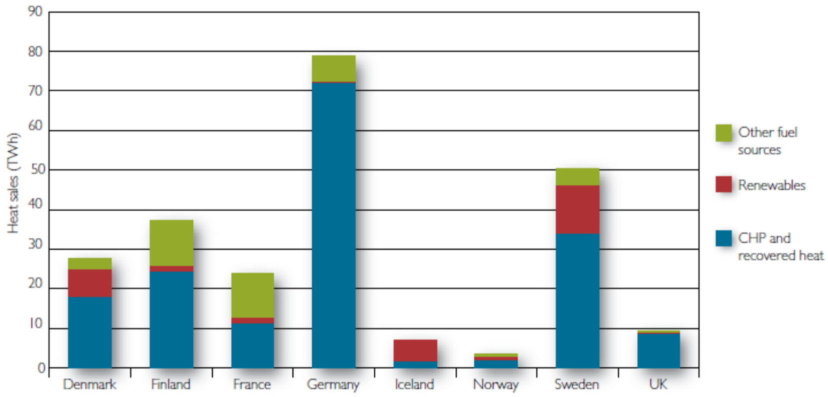


Figure 3.5.20 Heat Sales to Customers via Networks Across Europe[132]

Heat networks are more common in Scandinavia, Eastern Europe, Germany, South Korea and major cities in the USA and Canada. In Denmark, over 61%[133] of customers receive their heat via networks.

Since 1960, there has been a great increase in UK's heat networks. Among all the networks, small networks account for the most, as nearly 80% of the total networks are small ones (Figure 3.5.21).

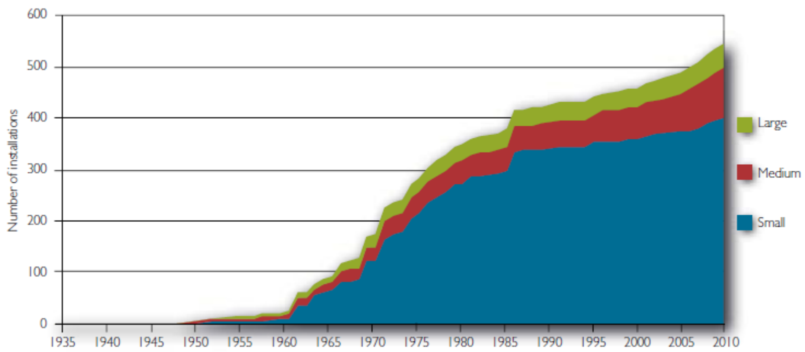


Figure 3.5.21 Growth in Heat Networks in The UK[118]

Large networks :500+ residential properties and/or 10+ non-domestic users;
Medium networks: 101-499 residential properties and/or 3-10 non-domestic users;
Small networks: fewer than 100 residential properties and/or fewer than 3 non-domestic users

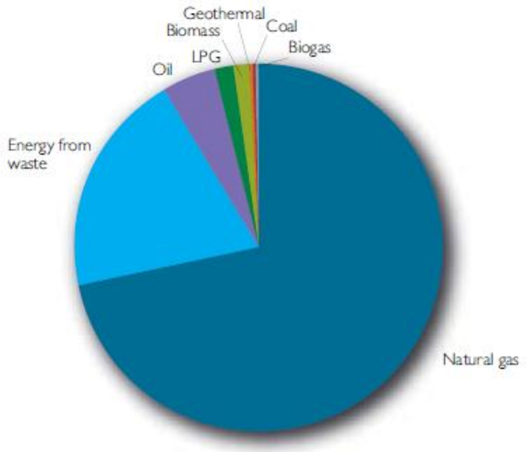


Figure 3.5.22 Fuel Types Supplying Heat Networks in The UK By Twh[118]

A recent survey suggests that UK heat networks are predominantly fuelled by gas CHP (72%). [134]A recent large-scale survey found that a significant minority of homeowners have heard of heat networks (31%). While 83% of homeowners had heard of solar thermal; 47% had heard of ground source heat pumps and biomass boilers; and 32% had heard of air source heat pumps.

3.5.5 District Energy Policy

The UK government has been advanced in various aspects of energy policy. It was the first country to set gas and electricity markets free through privatization, competition and open access to networks. Such successful case has been followed as a model by a number of countries in its path. Ofgem (short for Office of Gas and Electricity Markets), The UK energy regulator, set the standard for qualified, independent regulators which are recognized as essential parts of any competitive market. Moreover, The UK was the first country to formulate a major long-term carbon emission goal of an 80% reduction by 2050 and has been optimistic in bringing climate change to the center of global political discussions. The UK was also one of the first countries to issue a certificates obligation programme for renewable energy and is leading the way with a similar type of programme to support energy efficiency in the household sector. Although there have been defects in some of these initiatives, the overall policy trend is a positive one. [135]

3.5.5.1 Policies and Regulations

On April 1st, 2001, in order to encourage the reduction of GHGs emission, **Climate Change Levy** was introduced under the Finance Act 2000 by HM Revenue & Customs[136], which sets up two rates: the main rates; and the carbon price support (CPS) rates. This rate is applied for fuels such as electricity, gas, solid fuels - like coal, lignite, coke and petroleum coke and industrial, commercial, agricultural and public services. While CHP scheme which is registered under the CHP quality assurance (CHPQA) programme and electricity generated from renewable sources can be exempt from it.[137] CCL on gas is currently levied at 0.182 p/kWh from 1st April 2013 on, encouraging sites to transform to lower carbon heating.[118]

As the EU Emissions Trading Scheme (EU ETS) which sets the limit of Carbon Dioxide emissions issued, the UK government recognized that the renewable energy will play a significant role in the future electricity generation and reduce the GHG emissions, then the government published **Renewable Obligation** in 2002 to support renewable electricity projects. The **Renewables Obligation Certificates (ROCs)** are green certificates promulgated to operators of accredited renewable generating stations for the eligible renewable electricity they generate. Operators can trade ROCs with other parties. ROCs are ultimately used by suppliers to state that they have met their obligation.[138,139]

In response to the IEA in-depth energy policy review (2006) which provide recommendations in general energy policy, energy and climate change, energy efficiency, renewable energy, electricity, fossil fuel and nuclear energy etc.[135], the United Kingdom has defined a strategy to move to a low-carbon economy and to address climate change with a remarkable sense of coherence and commitment.[111] In order to cope with the climate change, the priority is to reduce the GHG emission and the government set the goal that to acquire a GHG emission reduction by 50% in 2027 and 80% in 2050 comparing to 1990 level under the **Climate Change Act 2008** (CCA).[140]

In 2010, the government published the **Environmental Permitting (England and Wales) Regulations** which promote the development of CHP.[141] It requires that developers are required to consider CHP (as a Best Available Technique for energy efficiency) and assess the cost-benefit of CHP opportunities in seeking a permit to operate power plant and industrial installations. Where there are no economic heat supply opportunities at the time of permitting, applicants are required to develop plant as CHP-ready unless they can demonstrate that this is not cost-effective.[118]

According to the **Energy Performance of Buildings Directive** which is issued by EU that requires all new buildings to be nearly Zero Energy Buildings from 2020 (nZEB), as described in Article 2 of the EPBD, the UK government set up **Zero Carbon Policy**, demanding that all new homes built from 2016 to reduce, through multiple measures, all the carbon emissions produced on-site according to the regulated energy use.[142]

At the beginning of 2013, the Energy Companies Obligation (ECO) which is an energy efficiency programme was introduced into Great Britain. It takes places of two previous schemes, the Carbon Emissions Reduction Target (CERT) and the Community Energy Saving Programme (CESP). ECO set legal requirements on the larger energy suppliers to provide energy efficiency measures to domestic energy users. It operates alongside the Green Deal by allowing them to pay the costs through their energy bills rather than upfront. According to the rules of ECO, energy suppliers are required to help promote the energy efficiency of their domestic customers' buildings in three distinct areas: Carbon Emissions Reduction Obligation, Community Obligation, Home Heating Cost Reduction Obligation.[143]

As a revision of the Climate Change Levy, the UK government issued carbon price floor (CPF) which is a tax on fossil fuels used to generate electricity. It came on effect in April, 2013. The CPS rate per tonne of carbon dioxide (tCO_2) will be capped at a maximum of £18 from 2016 to 2017 until 2019 to 2020. This will effectively freeze the CPS rates for each of the individual taxable commodities across this period at around 2015 to 2016 levels.[144]

Most recently, the government set two schemes to improve energy efficiency, i.e. CRC Energy Efficiency Scheme in April 8th, 2014 and Qualification and registration and Combined Heat & Power Quality Assurance Programme in August 1st, 2014. The CRC is designed to improve energy efficiency and cut carbon dioxide (CO_2) emissions in private and public sector organizations that are high energy users.[145] While the CHPQA is to provide a practical, determinate method for assessing all types and sizes of Combined Heat & Power (CHP) schemes throughout the UK. Successful CHPQA certification grants eligibility to a range of benefits, including Renewable Obligation Certificates, Renewable Heat Incentive, Carbon Price Floor (heat) relief, Climate Change Levy exemption (in respect of electricity directly supplied), Enhanced Capital Allowances and preferential Business Rates.[146]

3.5.5.2 Incentives

Moreover, a Feed-in-Tariff (FIT) scheme began in UK in April, 2010. It is designed to promote the uptake of a range of small-scale renewable and low-carbon electricity generation technologies. It requires some of licensed electricity suppliers to make tariff payments on both generation and export of renewable and low carbon electricity. Generation and export tariff rates are index-linked which means that they will increase or decrease with inflation.[147]

In 2011, the UK government set Renewable Heat Incentive (RHI) which is the first long-term financial (20-year) support programme for renewable heating and the main scheme of UK heat strategy. There are two parts of the RHI: (i) Domestic RHI – launched on 9 April 2014 and open to homeowners, private landlords, social landlords and self-builders; (ii) Non-domestic RHI – launched in November 2011 to provide payments to industry, businesses and public sector organizations. It is a financial incentive project which is designed to encourage uptake of renewable heating among domestic and non-domestic consumers. The domestic RHI focuses on, but not limited to, homes off the gas grid. Such incentive will not be open to new-build properties other than self-build. The domestic RHI will pay the following tariffs per unit of heat generated for seven years:[148]

Technology	Tariff
Air-source heat pumps	7.3p/kWh
Ground and water-source heat pumps	18.8p/kWh
Biomass-only boilers and biomass pellet stoves with integrated boilers	12.2p/kWh
Solar thermal panels (flat plate and evacuated tube for hot water only)	19.2 p/kWh

Table 3.5.2 Tariffs Paid by RHI[149]

Later in 2012, the UK government issued The **Enhanced Capital Allowance (ECA)** Scheme which is a key part of government programme to tackle climate change. It provides businesses with enhanced tax relief for investments in equipment that meets published energy-saving criteria.[150]

Also in 2012, in order to encourage the development of energy efficiency, the government provides £3 billion of Government funding to invest in offshore wind, waste, and non-domestic energy efficiency projects which is known as Green Investment Bank (GIB).[118] In addition, in March this year, the government provide a £15m Rural Community Renewable Energy Fund to promote the development of community-scale renewable energy projects in England.[151]

Later in the same year, on October 1st, the UK government launched "Green Deal" scheme to permit loans for energy saving measures for properties in Great Britain. It was officially launched in January, 2013. The scheme allows people to make improvement of energy saving, e.g. insulation, heating, draught-proofing, double glazing, renewable energy generation ect. and the assessor could provide the suitable proposal for you to reduce domestic energy bills.[152]

Regional Growth Fund was also published in late 2012, which the government offers £3.2 billion fund to support eligible programmes which can create economic growth and sustainable employment.[153]

3.5.6 Conclusion

In general, seen from the history, because of the government's uncertainty and hesitancy, the UK experienced losses of opportunities to develop district energy, renewable energy, district heating, CHP etc. Due to its low gas prices and reluctance to change its traditional lifestyle, residents are more apt to continue their tradition like using gas boiler for heating, which barriers the development of district heating and heating networks. However, because of the energy crisis and the deterioration of the environment and climate, the UK government realized these problems and intends to make changes to tackle these cases. Policies related to GHG reduction and encouragement of renewable energy and CHP can be found. What's more, the UK government has set the goal for carbon dioxide reduction, which demonstrated the resolution to mitigate the climate change and air pollution.

From the study of the development of the UK district energy, it can be seen that policy plays a significant role in energy switch, development and utilization. It is important to get the government permission if technologies want to get promoted. Secondly, policies should conform to the demands of markets. A good model is the liberalization of the gas market of UK, which enables the continually adjustment of the gas prices according to the market demand and grasp the development opportunities. Thirdly, the UK government provides incentives as well as obligations for the suppliers and consumers, which furtherance the development of district energy in practice. Moreover, the UK government has been fully conscious of the importance of renewable energy and has set plans to encourage the use of wind energy, waste, etc. Although the UK government lost lots of opportunities in the past, it’s not late to seize the chance to develop district energy from now on.

3.6 District Energy System in China

3.6.1 National Overview

3.6.1.1 General Information

Figure 3.6.1 The Map of China [154]

China locates in the eastern part of the Asia area and the western coast of the Pacific Ocean, with a total area of 9,600,000km^2. The topography in China from west to east is ladder-like distribution with a large area of hilly area and plateau. From east to west, it extends approximately 5,000km and the mainland coastline is as long as 18,000km. The various combinations of temperature and precipitation bring about various climates.

China enjoys diverse geological conditions and adequate mineral resources, accounting to 171 types. Among them, the proved reserves of tungsten, antimony, tombarthite, molybdenum, vanadium and titanium rank the first in the world and that of coal, iron, lead and zinc, copper, argentine, mercury, stannum, nickel, apatite, asbestos is among the largest around the world.

China is the second-largest energy production and consumption country in the world. The constant increase of energy supply, it has provided significant support to the economy society. Also, the rapid increase of energy consumption provides broad space for the development of global energy market. China has been an indispensible part of international energy market and played important and active role in safeguarding global energy security.

Since the 21st century, the district energy industry in China has experienced a rapid development period. The district cooling project in Zhongguancun Software Park and district energy system in Guangzhou University City set a precedent for the district cooling development in China and provide plenty of technology and management experience. So far, the construction of gas-fueled district energy system in China has entered a substantive stage of implementation and development and a number of district energy demonstration projects have put into operation in Beijing, Shanghai and Guangzhou etc. [155]

3.6.1.2 Climate

Because of the vast territory, wide cross latitude, various distances from ocean as well as variance in terrain height and various topography result in a variety of climates. For the climate type, in the east, it enjoys monsoon climate which can be divided into subtropical, medium latitudes and tropical monsoon climate. While for the northwest, it enjoys temperate continental climate and alpine climate of Qinghai Tibet Plateau. Comparing to other regions with the same latitude, China owns a lower winter temperature and a higher summer temperature with a relative bigger yearly temperature variation.

With the lager cross latitude from north to south, which accounts to 49° , the temperature variation between the north and the south is big, and the variation between Mohe Town and Haikou City can reach nearly 50℃. In summer, except Qinghai-Tibetan Plateau, the average temperature in July is above 20℃. In January, the coldest temperature occurs in Mohe Town in Heilongjiang province, with an average temperature of -30.6℃ and the warmest temperature occurs in Xisha Islands, around 22.9℃[155]

3.6.2 Energy Background

3.6.2.1 Energy structure

The primary energy supply in China has increased dramatically since 2001, driven mainly by rapid development, especially in energy consumption by heavy industry. In 2010, the total primary energy supply increased by 8.5% compared with that in 2009, reaching 2299 million tonnes of oil equivalent (Mtoe), including net imports and other. Of all the energy supply, coal was the dominant source, representing 73.1%, followed by oil (19.1%), gas (4.4%) and other (3.5%).[156,157] China's total primary energy supply has been growing at an average annual rate of 2.1% over the past 20 years. This is slower than the average annual growth rate of 5.2% from 1990–2009, which is mainly owing to a projected slowdown in the GDP growth rate and efforts to improve energy efficiency.

Primary energy supply (ktoe)		Final energy consumption (ktoe)		Power generation (GWh)	
Indigenous production	2 087 116	Industry sector	848 602	Total	4 207 160
Net imports and other	333 657	Transport sector	166 547	Thermal	3 331 928
Total PES	2 299 404	Other sectors	340 731	Hydro	722 172
Coal	1 681 031	Total FEC	1 355 881	Nuclear	73 880
Oil	438 085	Coal	541 999	Other	79 180
Gas	100 062	Oil	389 977		
Other	80 225	Gas	66 293		
		Electricity and other	357 612		

Source: EDMC (2012).

Table 3.6.1 Energy Supply and Consumption in China, 2010[156]

In 2010, China's total energy production was 2087 Mtoe, of which coal made up for 81.1%, followed by oil (9.7%), gas (4.2%) and other (5.0%) [156,157]. Since the 1990s, Chinese government has been promoting fuel switching (for instance, from coal to cleaner fuels), introducing energy efficiency initiatives, and optimizing the existing energy structure. In 2011, coal production was 1956 Mtoe, 8.8% higher than that in 2010 and China's domestic crude oil production was 203.6 million tonnes (mt), increasing by 0.3% compared to 2010. [156] Since 2001, gas production in China has grown, on average, 13.0% a year, reaching 102.5 bcm in 2011[156,158].

In terms of China energy history, from 1978 to 2010, the average yearly growth rate of primary energy consumption in China was 5.6% and the average annual growth rate of GDP was 9.9% [159]. Coal has always been the main energy sources for consumption, and oil follows. Especially in the 21st century, the consumption level in China increases significantly and the consumption of primary energy like coal and oil experiences a multiple increase as well as electricity generation and CO_2 emissions. After 2010, it can be seen that although the energy consumption of coal and oil increases gradually, the ratio of them decreases. In addition, the ratio of natural gas and renewables increases, which reflects the constant transformation of energy structure in China. [160]

So far, the energy structure is coal-based and relies too much on import oil, so that the problems relating to energy security and environment protection have been increasingly serious. The Chinese government has been adjusting this energy structure by compressing the ratio of coal in the total energy demand and developing nuclear power, natural gas and renewables as supplementary. For the gross energy consumption in China in 2010, coal accounted to 68%, oil represented 19%, and natural gas, renewables and nuclear followed, accounting to 4%, 8% and 1% respectively. Moreover, it is estimated that in 2003, the ratio of coal to the energy consumption would decrease to 66%, oil, renewables and natural gas represent 18%, 10% and 5% respectively.[160]

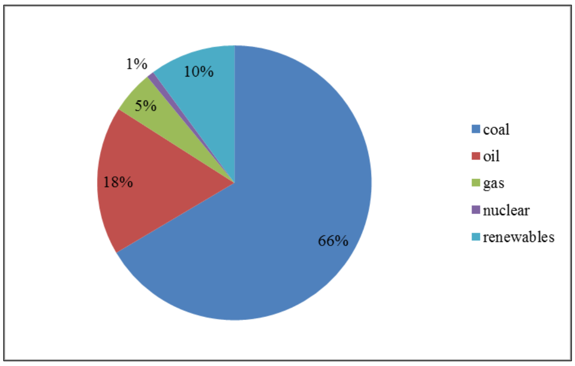


Figure 3.6.2 China Energy Consumption in 2013[22]

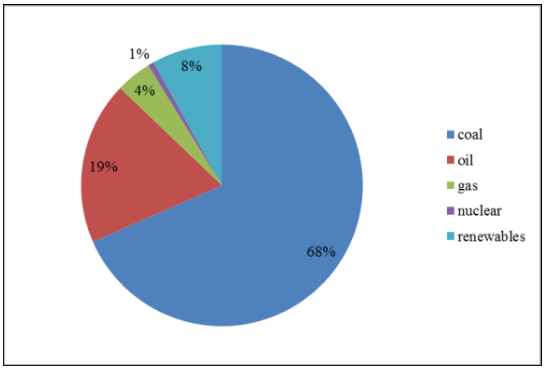


Figure 3.6.3 China Energy Consumption in 2010[22]

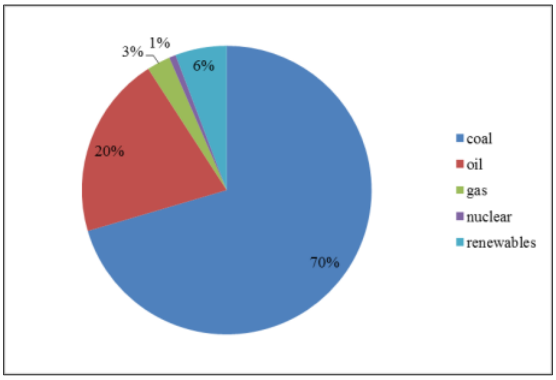


Figure 3.6.4 China Energy Consumption in 2005[22]

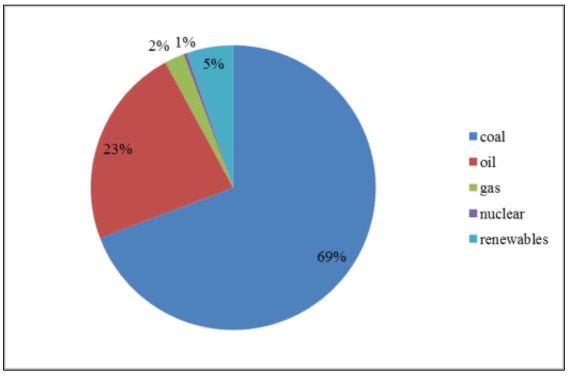


Figure 3.6.5 China Energy Consumption in 2000[22]

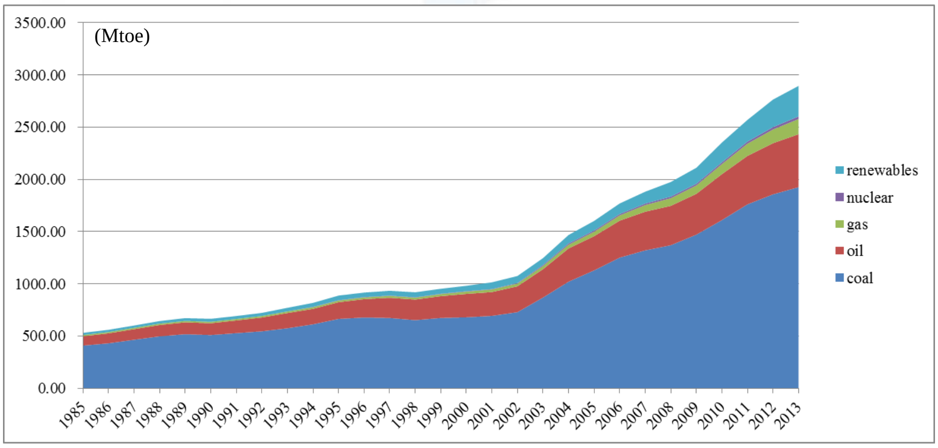


Figure 3.6.6 China Energy Consumption Diagram[22]

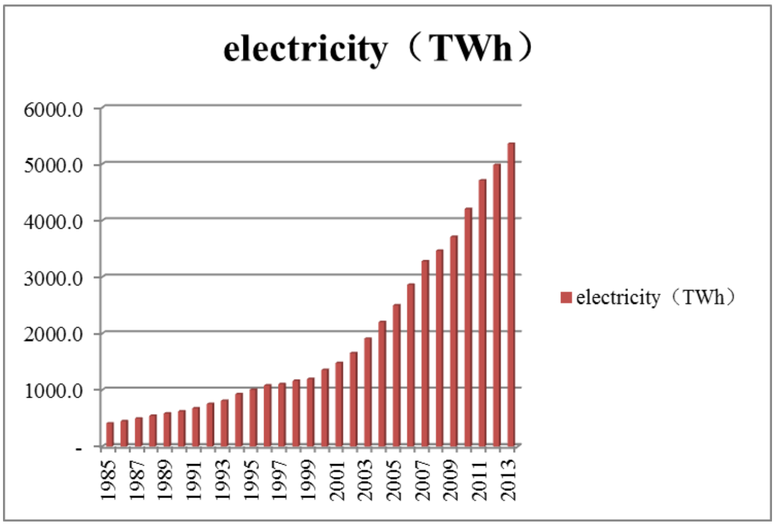


Figure 3.6.7 Electricity Generation（Twh）[22]

The power supply has been becoming more diversified, with rapid increase of wind power and nuclear energy generation. In 2010, China's total power generation reached 4207.16 terawatt hours (TWh). Thermal power generation made up for 79.2% (3331.93 TWh) of total generation, hydropower 17.2% (722.17 TWh), nuclear energy 1.8% (73.88 TWh) and other 1.9% (79.18 TWh) [157]. Since 1985, electricity generation has experienced an increase trend, especial after 2001, it has seen a sharply rise, reaching over 5,000TWh in 2013(Figure 3.6.8).

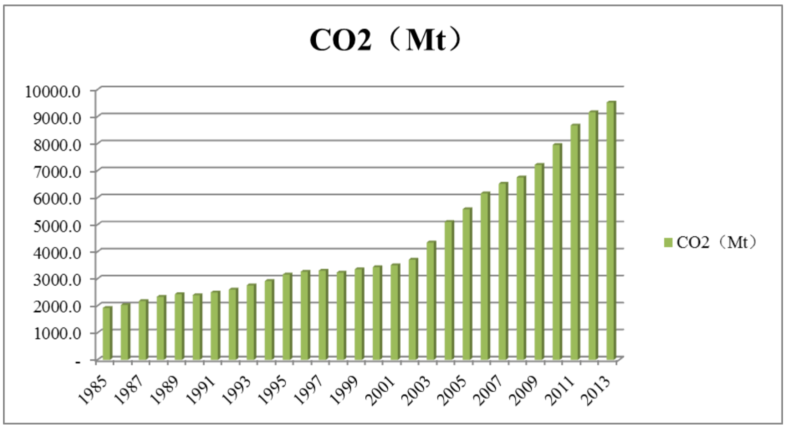


Figure 3.6.8 Carbon Dioxide Emissions (Mt) [22]

Just like the development trend of electricity generation, Carbon dioxide emission has also experienced a gradual increase since 1985 and increased sharply after 2001, reaching 9,000 Mt.

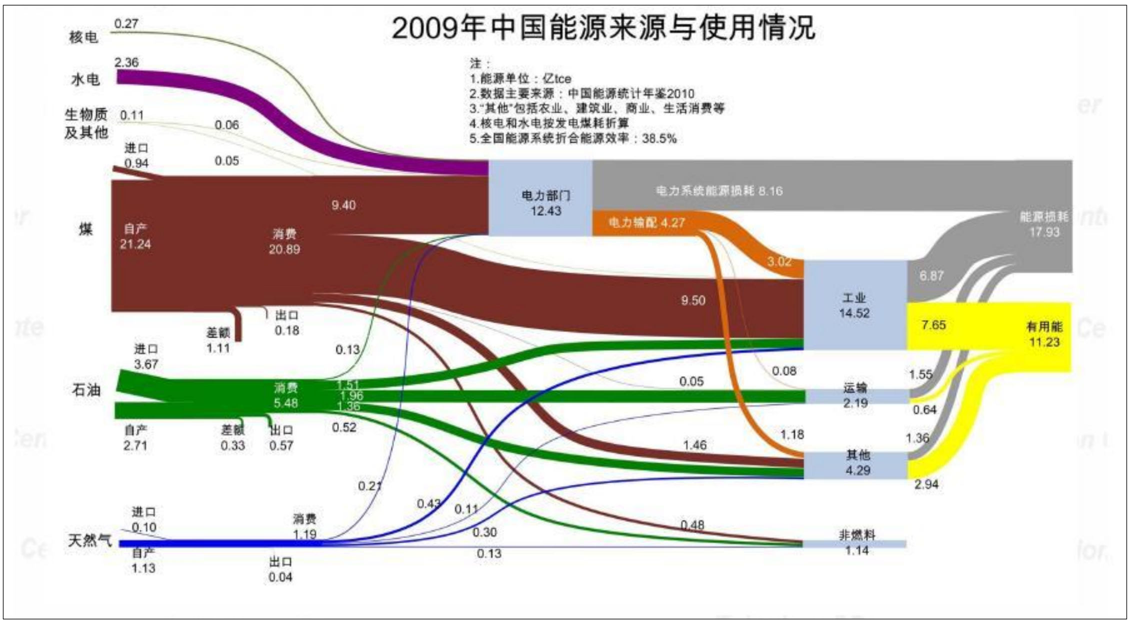


Figure3.6.9 China Energy Flow Chart 2010[161]

From the flow figure above, the energy structure is coal-based and the coal is mainly self-produced. Oil is the second largest energy supply with 40% from importation and 60% from exportation. Coal is mainly used in electricity generation and industrial energy utilization while oil is the main energy for transportation. However, the energy efficiency in electricity generation and industry is low, the energy loss in electricity production is approximately 65.6%, in industry is nearly 47.3% and the overall energy utilization efficiency is only 38.5%, so it's urgent to enhance the energy efficiency.

3.6.2.2 Renewable Energy

In the end of 2006, the total annual renewable energy use accounted to 200 million tons of standard coal equivalent, which accounted for 8% of the total primary energy consumption, a 0.5% rise compared to that in 2005. Among them, hydroelectricity is 150 million tons of standard coal equivalent and solar power, wind power and biomass accounted for 50 Mtce which lays a solid foundation to realize that the use of renewable energy represented 10% of the total primary energy consumption in 2010. So far, the hydroelectricity installed capacity has reached 170 million kW (small hydroelectricity accounts to 50 million kW). The wind power has been over 20 million kW and biomass can contribute to over 2 million kW electricity generation. In addition, there have been 22 million rural household biogas pools to provide clean energy to 80 million peasantries and there are over 1500 large-scale biogas pool to produce methane more than one billion m^3 annually. Moreover, the solar power can produce near 4000MW, and has been the top-level in the world for three consecutive years. The production of solar water heater was 20 million m^2, and accumulated to 145 million m^2. The annual utilization of geothermal is 445 million m^3 and had been introduced to 4000m^2 buildings.[162]

The Chinese government is now taking effective measures to promote the development of renewables. In August, 2009, the government decided to cope with climate change and further defined the guiding ideology, fundamental principle and measures to address climate change as well as the position that China would take active part in international cooperation to cope with climate change. In the United Nations Climate Change Conference in September, 2009, the Chinese president, Mr. Hu, delivered an important speech which indicated that China will unswervingly continue to in an effort to fight climate change from the height of the responsible for their own and the people of the world and in the future China will further cope with climate change into the economic and social development plan and take actions. Moreover, President Hu presented clearly that in 2020, the ratio of non-fossil energy to the total energy consumption reach 15%. Apart from this, also in 2009, the Chinese premier, Mr. Wen, promised that in 2020, the carbon emission per GDP would decrease by 40%-45% compared to the 2005 level.[162]

In the end of 2009, the China's National People's Congress further modified the renewable energy law, deciding to establish national and regional renewable energy exploitation and utilization plan, further defining the application of the system of guaranteeing the purchasing of electricity generated by using renewable energy resources in full amount and making it clear that the national finance should set up renewable energy development fund. In addition, China is formulating industry develop plan of new energy and renewable energy and make necessary adjustments of medium and long term planning objectives for renewables which was set in 2007. It is estimated that the installed hydroelectricity capacity can reach over 300 million kW, with wind power reaching 100-150 million kW and solar power being 20-30 million kW in 2020. Also, the gross collector area of solar water heater can be 300 million m^2 plus biomass energy (30 million kW), annual methane utilization (44 billion m^3), annual biological fuel ethanol and biodiesel use (1.2 million tons) as well as ocean power and geothermal, which account to 600Mtec. These are significant for energy structure adjustment and energy supply security as well as reducing GHG emissions and protecting the environment.[162]

In the following 30 to 50 years, along with the increase of energy demand and adjustment of energy structure, it’s estimated that in 2050, the installed capacity of wind power will be 300-500 million kW, and the exploitation of small-scale hydro power will be finished and reach 100 installed capacity during 2020 and 2030. Also, the solar power will get further and rapid development after 2020 and it’s expected 10% of electricity generation will come from solar power, reaching 200-300 million kW. The area of solar water heater will reach 1.5 billion m^2. The biomass energy supply will play important role in rural energy and transportation energy. At that time, renewable energy will account to 30% or more in total energy consumption.[162]

3.6.2.3 Energy Price[5]

Electricity Price

The electricity price in China is relatively cheap. So far, residential end-use electricity price is approximately ￥0.44-0.75 and the industry and Commerce is about ￥0.44-1.46. The industrial electricity price is around ￥0.37-0.93 and the agricultural electricity price is ￥0.22-0.38.[163]

Coal Price

According to Bohai-Rim Steam-Coal Price Data, the current steam coal price is approximately ￥500/ton.[163]

Oil Price

The current maximum diesel retail price is approximately ￥8000/ton, and the maximum gasoline price is about ￥9000/ton.[163]

Natural Gas Price

The natural gas price fluctuated dramatically. So far, the gas price for residential use is about ￥2.3/m^3 and that for the industry and Commerce is around ￥3.6/m^3. In addition, the price for CNG is about ￥5.0/m^3 and gas prices for electricity and district heating is approximately ￥3.3/m^3.[163]

3.6.3 District Energy Development History

The development of district energy in China began after the founding of the People's Republic of China. Along with the rapid industry development in the three provinces in Northeast China and North China, the problems of heating supply had to be settled urgently. In 1958, Beijing No.1 thermal power plant became the first cogeneration enterprise. Then in 1968, in Northeast China, Shenyang city firstly began to development district heating, but slowly for a long period.[164]

During 1971-1975, because of government policy and other effects, the industrial layout scattered and there were no long-term industrial construction and urban planning, so there is no base to set up development planning for heat and power plant and only short-term plan can be set. But during 1976-1980, although lack of relatively stable long-term plan, the recovery and development of national economy is rapid and there is an increasing trend on the construction of heat and power plant with 975,000 kW heating units going into operation, accounting to 6.8% of newly thermal power installed capacity. Within the units, public heating units were only representing 23%, which means an increase ratio of self-supply CHP.[164]

Since 1981, the government proposed that the city 's industrial and agricultural output would be quadrupled by 2000 and for the energy strategy, equaling conservation and development as well as taking a series of steps and encouraging cogeneration district heating. In addition, the central government and local governments of all levels established energy saving mechanism; the state council set up energy saving meeting system and Planning Commission of the State National Planning Committee establish specialized investment of major energy saving measures to support the construction of cogeneration plants.[164]

On February, 6th, 1986, the promulgation of No. 22 document of the state council boosted the development of district heating industry in northeastern, northwestern and northern area. The district heating developed in 10 cities in 1980 to 81 cities in 1989, with a total heating area of 15.6million m^2. Among 600 cities in 2003, cities with district heating reached 321 with a heating area of 1.89 billion m^2, which is twelve times compared with that in 1989. The hot water network pipes extended 58,000 km and steam pipes were 11,900 km. Until 2010, the total installed capacity of thermal power is 166.55 million kW with an annual heat supply of 2807.60 million GJ. In 2013, the heating area reached 5.72 billion $m^{2,}$ 10.3% more than that in 2012.[165]

3.6.4 District Energy Development Status [166]

3.6.4.1 District Energy Planning Status

The district energy plan in China is in promotion period and the current planning system involves electricity, heat and gas. These three elements exist in isolation and lack of unified consideration no matter from energy demand or energy supply. In the overall planning, the overall energy goal is not divided into each segment.

So far, under the trend that the country promote energy saving and emission reduction, in the planning of new urban area, several new planning goals related to energy saving and emissions reduction have been put forward, like primary energy consumption, energy saving rate, carbon emission and renewable energy efficiency etc. However, these planning goals cannot embody in current planning system so that it's difficult to set up efficient ways to realize and to safeguard.

On the other hand, the application of new energy technology in regional scale itself belong to a type of infrastructure, the scheme depend a great deal on regional load and resource conditions. If overall consideration cannot be done in planning period, it must confront various problems in operating period. So currently, there is an increasing concern to set up district energy planning system.

3.6.4.2 Application Status of District Cooling Technology

District cooling system is aiming at architectural complex within certain regions, producing cold water in central energy power plant and distribute to users after pipelines distribution and heat exchange to fulfill the cooling load. District cooling system is usually combined with cold storage technology.

Recently, there is an increasing trend of the number of cold storage air conditioner in China. Among, a number of district cold storage projects occurred and reaching a scale of hundreds of thousands of square meters or even millions of square meters and is usually applied in areas with high cooling load density and storage cold by using off-peak electricity. From the respect of types of cold storage, ice melting system coil enjoys a maximum share and regional water cooling storage stations are put into operation in recent year. Apart from this, district cooling system is combined with other saving technology like combined cold storage and heat pump. Significant progress has been achieved in district cooling and cold storage technology.

3.6.4.3 Application Status of Combined Cooling, Heating and Power (CCHP) Technology

Combined Cooling Heating & Power is an advanced energy supply technology, which firstly uses fired gas to produce high grade energy and then use the low grade energy (flue gas, steam, hot water etc.) emitted by generating equipment to supply heating and cooling, under which ways, cascade and local use are fulfilled as well as enhancing energy comprehensive use, reducing Transmission and distribution losses and meeting various energy needs of users. In addition, the trigeneration system can be used as emergency power and cooling supply, which increases the energy reliability.

Combined cycle of internal combustion engines and gas turbine is the main form of trigeneration energy supply. The surplus heat from internal combustion engines uses flue gas and the cylinder cooling water as the carrier and the recycling form is single and double effect complex absorption unit and other heat-exchange unit. High temperature flue gas is produced after electricity generation by gas turbine and then producing steam by waste heat boiler. The steam drives a turbine to generate electricity and the surplus heat is recycled by steam lithium bromide absorption unit and other heat-exchange unit to supply heating and cooling. For the small-scale trigeneration system (less than 3～5 MW), the economy of internal combustion engines is better than that of gas turbine. The utilization of electricity generated by trigeneration system plays an important way in operation strategy, economy and system optimization goals.

3.6.4.4 Application Status of Renewables District Energy

Renewable energy is referred to as renewable non-fossil energy sources, including wind power, solar power, geothermal, tidal power, hydroelectricity and biomass etc. Developing renewable energy actively is significant to primary energy conservation and environment protection and is an important way to realize regional ecological goals.

According to “medium and long-term development plan of renewable energy”, in 2020, the renewable energy consumption will account to approximately 15% of the total energy consumption. For the national renewable energy development goals, a large ratio of renewables generates electricity through hydroelectricity, wind power, biomass and photovoltaic power generation and then distributes the electricity to other places. For example, in 2009, renewables represented 8.7% of electricity generation and hydroelectricity accounts to 6.49%, nearly 75% of the renewables. However, district renewable energy should be combined with local resources and utilization ways can be divided into decentralized development, elimination on the spot and concentrated production, elimination in the local area. Because of near the load and no distance distribution, district renewable energy can provide more low-grade thermal energy.

The former application of district renewable energy is usually based on architectural or block level decentralized development and elimination on the spot. Recently, along with the rapid development of renewable energy industry, several districts make full use of local resources to develop regional renewable energy supply system and lots of renewable-based energy plants are established, including heat pump systems that using various low-grade renewable energy (sewage, sea water, surface water, ground tubes etc.), biomass utilization (power generation and gas preparation) and solar energy etc. Renewable energy is research hot spot of the industry and related field. In recent years, a plenty of research outcomes haven been acquired. In the respect of district renewable energy application, the research content includes: district resources and system applicability, district renewables planning, engineering application on district renewable energy system.

3.6.5 Energy Policy

Time	Policy	Administration	Main Content
1997, 2007	"The Energy Conservation Law of the People's Republic of China" formulated in1997, revised in 2007	The standing committee of the National People's Congress	The nation should carry out industrial policy which is beneficial for energy conservation and environment protection and restrict the development of industry with high energy consumption and pollution. The state council and People's governments of provinces, autonomous regions and municipalities directly under the central government should strengthen energy conservation, adjust industrial structure, business structure, product structure and energy consumption structure reasonably, promote enterprise to reduce energy consumption per output unit, eliminate backward productivity, improve energy development, processing, conversion, transmission, storage and supply and enhance energy efficiency.
2004	"China's Long-Term Energy Saving Special Planning"	The national development and Reform Commission	It points out that cogeneration and district heating is the main field for energy saving and listed cogeneration into ten national key energy conservation projects. Also, it develops and promotes advanced and efficient energy conservation and substitution technology, comprehensive utilization technology and new energy and renewables technology. In addition, it should strengthen management, reduce losses and enhance energy efficiency.
2006	"The Renewable Energy Law of The People's Republic of China"	The standing committee of the National People's Congress	The law confirms renewable energy total production (RETP), renewable energy grid power of examination and approval and full acquisition system, renewable energy tariff and cost-sharing system, special funds and taxes on renewable energy and credit incentives.
2006	"Outline of Chinese Energy-Saving Technology Policy	The national development and Reform Commission, Ministry of Science and Technology	It indicates to develop technology of enhancing energy development and utilization efficiency and effectiveness and reducing the effect on environment, containing wasted of energy resources. It should include technologies of optimization of the development and utilization of energy resources, Individual energy saving technology and energy saving technology of system integration, energy-saving production process, High-performance energy-using equipment, directly or indirectly energy consumption reduction of the new material development and application technology and management technology of energy conservation and enhancing energy efficiency etc.

2006	"Management Regulation Related to Renewable Energy Generation" (No. [2006]13)	The national development and Reform Commission	It clearly shows the renewable energy power generation project examination and approval and management style. The renewable energy in the regulation includes wind power, biomass, solar power generation, ocean power and geothermal. This regulation provide enterprises with guiding and operation standard to go into renewable energy generation. Power grid enterprises should carry on association and reform of power grid according to construction and demand of renewable energy power generation projects to ensure full access to the Internet for electricity generated by renewable energy.
2006	"Special Funds Management on Renewable Energy Development"	The ministry of finance	To make the specification of special funds management on renewable energy development set by the ministry of finance and provide key support for power generation by renewable energy and ensure the approaches the funds used is free assistance and preferential loans.
2007	"Medium and Long-Term Development Plan of Renewable Energy"	The national development and Reform Commission	It requires to increase the proportion of renewable energy and to promote the adjustment of energy structure. The proved oil resources and natural gas in China is poor and it's difficult only depending on fossil energy to realize the harmonious development of economy, society and environment. The big potential of hydropower, biomass, wind and solar resources, and the mature or nearly mature technology have the good prospect of large-scale development and utilization. Accelerating the development of hydropower, biomass, wind and solar power, and vigorously promoting the large-scale application of solar energy and geothermal energy in the buildings and reducing the proportion of coal in energy consumption, is the primary goal of Chinese renewable energy development.
2008	"Circular Economy Promotion Law"	The standing committee of the National People's Congress	The government encourages enterprises of all kinds of industrial park to exchange and use waste and cascade energy use. Power grid enterprises should follow the national regulation to acquire eligible electricity generated by waste incineration power plant with full amount.

2010	"Notification Related to Measures to Support The Development of Circular Economy Investment and Financing Policy" (No.[2010]801)	The national development and Reform Commission, People's Bank of China, China Banking Regulatory Commission(CBRC), China Securities Regulatory Commission(CSRC)	Section 1.1: The development of circular economy is an important strategy of national economic and social development; Section 2.2: All localities should put recycling economy project which is "reduction, reuse, resource" as a key investment field; Section 3.1: The banking financial institutions should give priority in credit support to the typical city waste, waste water, and sludge resource utilization projects; Section 3.4: Actively support the enterprises which recycle resources listing and financing.
2011	"Guidance on the Development of Natural Gas Distributed Energy"	The national development and Reform Commission, Ministry of Finance, Ministry of Housing and Urban-Rural Development (MOHURD)	Before 2015 the main equipment development of natural gas distributed energy should be completed. Through the demonstration of engineering application, when the installed capacity reached 5,000,000 kilowatts, the integration of distributed energy system should be solved and the equipment independent rate can reach 60%; when the installed capacity reached 10,000,000 kilowatts, the independent manufacturing of small, micro gas turbine and other core equipment is solved, and self-reliance and equipment rate reaching 90%. By 2020, the use of distributed energy system has been promoted by the national scale and the installed capacity reached 50,000,000 kilowatts, initially realizing of distributed energy equipment industry.
2012	"The Opinion of State Council on Implementation of the Government Work Report Key Work Division" (No. [2012]13)	State Council	Promote energy conservation, emission reduction and ecological environment protection. Strengthen the management of energy use, develop smart grid and distributed energy, implement energy-saving power generation scheduling, energy performance contracting, energy saving and other effective government procurement management mode.
2012	"Natural Gas Utilization Policy"	The national development and Reform Commission	The domestic natural gas use is divided into priority classes, permitted, restricted and prohibited categories: among them, it's pointed out clearly that the preferred class of natural gas utilization, including distributed cogeneration, CCHP users.

2012	"Renewable Energy Electricity Price Subsidies and Cap-And-Trade Scheme"	The national development and Reform Commission, State Electricity Regulatory Commission(SERC)	The scheme emphasize that electricity price for renewable energy power generation projects in the part of local desulfurized coal electricity price is undertaken by the provincial power grid load; the higher part, resolved by the additional electricity price subsidies. The regulation on levied additional renewable energy tariff, quota trading, electricity and subsidies settlement behavior should be enhanced and violations of tariff settlement behavior which are the provisions of this notice should be corrected and punished resolutely to ensure that the additional renewable energy tariff subsidies in place is on time and in full.
2013	"Interim Measures on Distributed Power Generation Management	The national development and Reform Commission	The methods proposed, to encourage enterprises, professional energy service companies and, all kinds of electric power (including individuals) invest, construct and operate distributed generation projects, and to exempt power generation business license for distributed power generation project. In the power grid access, distributed generation power grid enterprises are responsible for external network infrastructure and investment and construction caused by the access part of public power grids, and providing convenient, timely, efficient access to grid services for distributed generation, and signing contract on a grid connection agreement and the sale of electricity with the project units who invest and manage distributed generation facilities (or individual operators, home users). Encourage the construction of smart grid and micro grid combined with distributed generation applications.

3.6.6 Conclusion

The district Energy development in China has been 50 years, but slowly before the twenty-first Century and mainly cogeneration or district heating. After twenty-first Century, with the development of science and technology, the development of district cooling, CCHP and other district energy is rapid, a lot of new district energy projects gradually built up, and the developing level is gradually catch up with the developed countries. However, because of the past extensive development in China, lots of exist district energy projects with much lower efficiency are in urgent need of transformation and the foundation is weak which is also one of the status quo of China's district energy.

China energy structure is dominated by coal with high pollutant treatment cost. At the same time, as a solid fuel coal, the energy efficiency of coal is relatively low. In recent years, the exploitation amount of Chinese natural gas, shale gas increases gradually, gas distribution contact signed with the surroundings increases and the LNG imports also rises steadily, which provides a good foundation for the development of gas district energy system. In 2007, Chinese national development and Reform Commission issued a "medium and long-term development plan of renewable energy", which explicitly proposed: from 2010 to 2020, it should establish a complete system of renewable energy industry, greatly reduce the cost of development and utilization of renewable energy, and lay a good foundation for large-scale development and utilization of renewables. After 2020, it’s expected to make renewable energy technology has obvious market competitiveness, and to make renewable energy become an important energy. Also it’s expected to strive to make renewable energy consumption account for around 10% of the total energy consumption in 2010 and to reach 15% in 2020. [167] The promotion of renewable energy, has brought new impetus to the district energy development.

Along with the progress of science and technology, the Chinese economy develops rapidly and the government pays more attention to district energy. Although compared to other countries district energy started relatively late in China, the development of district energy in China is fast because of the healthy development of Chinese industrial enterprises and abundant talents. With the adjustment of energy structure in China, the increasing people's demands on the environment and the attention paid to the efficiency of energy use, district energy, as one of the optimal method to improve energy efficiency, the development of district energy will be further.

Enlightenment of District Energy Development

District Energy development needs to be based on conservation priority strategy: giving priority to conservation throughout the whole process of energy planning, scientific and rational use of energy, vigorously improving the efficiency of energy utilization, promote the application of district Energy in key areas, reasonably controlling the total energy consumption, developing and supporting the rapid social and economic development with less energy consumption.

District Energy development should keep up with domestic situation and make full use domestic dominant. It should Take advantage of the resource, technology, equipment and personnel, strengthen the exchanges and cooperation with foreign, improve the district energy industrial system, enhance energy security level and maintain energy security in the open pattern.

Through the development of district energy, it can optimize the energy structure and put the development of clean and low carbon energy as the main direction of district energy development. Adhere to the strategy of developing non-fossil fuels, clean energy and fossil energy simultaneously, improve the proportion of the natural gas district energy in all the district energy projects. At the same time, gradually increase the wind power, solar energy, geothermal energy and other renewable energy in the proportion of district energy industry, form scientific and reasonable energy structure which adapt to the situation of our country, greatly reduce the waste of energy, and promote the construction of ecological civilization.

The development of district energy should firstly improve the institutional mechanisms for energy scientific development, given full play to market action. At the same time, set up the mission that the technology can decide and create the future, and promote the development of the industry by raising the overall level of district energy industry technology, gradually reduce district energy technology gap with the world advanced level.

District energy development should be in accordance with safety, green, intensive, efficient principle, through optimizing the economic structure and transforming the energy consumption concept. It should strengthen the industrial, transportation, building energy efficiency and demand side management, pay attention to life saving, strictly control the growth of the total energy consumption, abandon the extensive energy use and guarantee the energy efficiency of district energy utilization.

In order to promote the stable development of district energy industry, it must strictly control excessive growth in energy consumption; effectively change the mode of energy use. For high energy consumption industries and industries with excess capacity, strong constraints should be carried out for the total energy consumption control, other industry constrained by advanced energy efficiency standards. Moreover, the existing energy efficiency should meet the standards within the time limit and the new energy supply projects must meet the domestic advanced standard of energy efficiency.

Encourage a competitive development of new and renewable sources of energy. In accordance with the overall requirement of urban and rural development and the model of new urbanization, the construction of urban and rural energy supply facilities should focus on the local conditions, promote the transformation of energy use in urban and rural area, improve the level and efficiency of urban and rural energy use.

Implement the action plan of new towns, new energy, new life. The government should scientifically establish urban planning, optimize urban spatial layout, promote the depth of integration of informatization and urbanization, low carbonization, and construct low-carbon smart town. In addition, the government should set out urban integrated energy planning, encourage conditional area to develop tri-generation, district heating with diverse energy supply like wind energy, solar energy, biomass energy, geothermal energy etc. as well as improve the utilization level of renewable energy and strengthen overall planning of power supply and power grid, scientifically arrange peak regulation, frequency modulation, energy storage supporting capacity.

The government should encourage large key district energy projects, integrate resources in the construction process, improve the whole industry level through overcoming a variety of problems, encourage the use of advanced technology and the application of independent innovation products, support the development of advanced energy technology and equipment, improve the productivity and level of science and technology of district energy business and form the energy industrial system equipped with international competitiveness.

Formulate national energy technology innovation and energy equipment development strategy. Establish innovation system of which enterprises as the main body, the market as the guidance and the combination of government production and research. Encourage the establishment of a diversified energy technology risk investment fund. Strengthen the construction of energy talent, encourage the introduction of high-end talent, cultivating a number of energy science and technology leading talent.

District energy security measures

1) Deepening the reform of the energy system

Deepen the reform of the energy system and improve the modern energy market system. Establish a modern energy market system that is unified and open, competitive and orderly. Further promote the separation of government and enterprise, separate business of natural monopoly and competitive business, open the competitive field and segments. Implement a unified market access system. Based on the formulation of the negative list, encourage and guide the various types of market players to enter the outside of the negative list equally and by law and promote the diversification of investment. Deepen the reform of state-owned energy enterprises, improve the incentive and evaluation mechanisms, enhance the competitiveness of enterprises. Encourage the use of hedging in the futures market hedging and promote the construction of crude oil futures market.

Reform the energy price. Promote the price reform of petroleum, natural gas, electric power and other fields, orderly open price competitive segment. The natural gas wellhead price and selling price, electricity price and sales price should be managed by the market. Gradually establish a fair access, supply and demand orientation, flexible and reliable electricity and oil and gas transportation network. Accelerate the pace of reform of electric power system, promote the trade between supply and demand sides directly, and construct the competitive power market.

2) Establish and perfect the related laws and regulations of district energy

Improve the energy tax policy. Speed up the resource tax reform, establish and improve the fiscal and taxation system actively, and gradually expand the scope of resource tax valorem. Study on the adjustment of energy consumption tax levy and tax rates, put part of the high energy consumption, high pollution products into the scope of collection. Perfect the tax policy of energy saving and emission reduction, establish and improve the ecological compensation mechanism, speed up the legislative work of the environmental protection tax and explore the establishment of green tax system.

Improve peak regulation and frequency modulation standby compensation policy, implement renewable energy electricity quotas and full protection of the acquisition and the supporting measures. Encourage the banking financial institutions to increase support on energy efficiency, energy saving, comprehensive utilization of energy resources and clean energy projects based on controllable risk, business sustainability principles. Study and formulate the promoting green credit development incentive policy.

Improve the energy consumption policy. Implement differential energy pricing policies. Strengthen energy demand side management, promote energy contract management, cultivate energy-saving services organizations and energy service companies, carry out energy audit system. Perfect the assessment review system of fixed assets investment projects, implement energy efficiency "leader" system.

Further transform government functions and improve the energy regulatory system. Strengthen the formulation and implementation of energy development strategy, planning, policy, standard, accelerate decentralization, continue to cancel and delegate administrative examination and approval items. Strengthen energy regulation, perfect the supervision organization system and regulation system, innovate the way of supervision, improve the efficiency of supervision, maintain fair market order, and create a good environment for the healthy development of district energy industry.

Along with the progress of science and technology, the Chinese economy develops rapidly and the government pays more attention to district energy. Although compared to other countries district energy started relatively late in China, the development of district energy in China is fast because of the healthy development of Chinese industrial enterprises and abundant talents. With the adjustment of energy structure in China, the increasing people's demands on the environment and the attention paid to the efficiency of energy use, district energy, as one of the optimal method to improve energy efficiency, the development of district energy will be further.

4. Conclusion for Case Studies

4.1 District Energy Development History

Seen from the development history of district energy in the selected countries, the United States is the one of the earliest country who established district energy system. In 1853, the first modern district heating network was created at the US Naval Academy in Annapolis, Maryland, which is the beginning of the district energy development in the United States. Along with the arrival of the second industrial revolution and the application of electricity, the demand for living quality has been increased. At the same time, district energy projects in the United States, the United Kingdom and Canada has experienced a rising trend, which is the embryonic form of the district energy supply.

Early in the 20th century, with the technology development and wide application of electricity in the western countries, the thermal power plant began to establish around the city and the surplus heat from power stations became the heat source for the nearby city in winter. These power stations provided electricity and heat for the city simultaneously, which formed the earliest CHP projects. In 1903, Denmark established the first cogeneration system which incinerated waste to provide electricity which created new ideas for the application of district energy. At the meantime, the advancement of mechanical industry made it possible to manufacture large refrigerating compressor equipment. In order to increase thermal comfort in hot summer, in the 1930’s, large cooling systems were built in Rockefeller Centre in New York City and the United States Capitol buildings. Since then, district energy system including the district cooling, heating and power gradually integrated, which create a new era for district energy development.

In the early and medium 20th century, the First and Second World War resulted in stagnation of district energy development. However, the world pattern changed after 1950, technology and economy developed rapidly as well as the district energy. In addition, the advanced technology has been expanded to the world, China and Japan began to establish district energy projects. In China, Beijing established the first thermal power plant in 1958 and started cogenerating and supplying power and heat to the city. Japan started to use district cooling in the Osaka world exposition and nearby central area in 1970. But district energy has been widely used in the United States, the United Kingdom, Denmark and Canada in the same period of time. In 1970s, around 30% Denmark households had adopted district heating.

In the late 20th century, the explosion of the Iran-Iraq war and the Gulf War resulted in the global oil crisis, the oil production suffered a large-scale reduction and oil prices soared, which directly threat the energy safety in a number of countries. Ever since, every country began to think about how to increase the energy efficiency, make comprehensive use of all kinds of energy, reduce dependency on fossil energy and strengthen national energy security. After the energy crisis, the district energy system gets a rapid development due to its high energy efficiency. In the late 20th century, electricity generation from cogeneration in the United States accounted for 8% of the gross generation. In addition, the United Kingdom began to use district energy to provide heating and cooling for cities in a large scale. There have been a large number of investments in district energy system in Denmark, Canada and Japan as well. The Chinese government released investment for major energy saving measures specifically to support the development of cogeneration.

In the 21st century, along with the globalization of economy and technology, as well as the increasing awareness people paid to living quality, district energy gradually become the preferred energy supply means in high load density areas. For example, the current areas heated by district heating account for 60% of the total heating area in Denmark. At the same time, because of improved heat pump technology and the increasing use of renewables, the energy efficiency of district energy get further enhanced. Along with the rapid development of urbanization and the mainstream of energy saving and emission reduction targets, the district energy achieves higher development.

4.2 District Energy Development Status

In the United States, most of the district energy systems are used for colleges, universities and healthcare installations. Most major district energy projects are located in the northern and middle part of American; small ones are normally located in southern and western part. By the end of 2011, the cogeneration capacity was 70 GW in the United States, accounting for 7% of all the installed capacity in the United States. Among them, 25 GW for industrial, l2 GW for commercial and 43 GW for power generation.

There are now nearly 150 district Energy projects in operation in Canada. According to the survey, the Canadian district Energy projects are mainly district heating projects, mainly in large-scale, multi-user areas. And after 2000, it developed rapidly and there was a rapid increase in the number of district energy projects.

District energy in UK is mainly used in industry, and 93.5% of the industry heat supply is from the cogeneration project. In 2011, electricity generation from cogeneration was 6 GW, equivalent to 7% of the UK's electricity supply. Apart from industry, most of the small district energy projects are used for commercial and residential units. Britain's district energy projects are mainly based on less than 50 MW of small-scale projects.

Denmark is among the best countries in the development of district energy, the Danish district heating system provides nearly two thirds of the total heat demand and more than half of all electricity generation in Denmark comes from combined heat and power plants. There was a remarkable change in the fuel types used in the production of district heating in the period 1990 to 2012, with an increased consumption of renewable energy from the share portion of 21.7% in 1990 to 43.7% in 2012 (of which biomass 42% and other renewables 1.7%). On the contrary, coal has decreased dramatically.

Japan's district energy developed rapidly in the past 20 years. Until March 2012, the total installed capacity of cogeneration is 9.5 GW, 3.5% of the electricity supply in Japan. Furthermore, the economic crisis in 2008 affected Japan's industry dramatically, thus affecting the district energy system and reducing Japan's district energy systems in industrial applications. In the present, only 300 MW of district heating is used in Japan. The development of Japan's district energy system is also transformed from small-scale systems to commercial and residential to large-scale industrial applications. Meanwhile, Japan is a world leader in the application of small district energy in residential areas.

The district Energy development history in China is more than 50 years, but slowly before the twenty-first Century and mainly on cogeneration or district heating. After 21st Century, with the progress of science and technologies, district cooling, CCHP and other district energy are developing rapidly; a lot of new district energy projects have been gradually built up, and the standard is gradually catching up with developed countries. However, due to past rapid and intensive development in China, lots of district energy projects with much lower efficiency are in urgent need of renovation.

The district energy systems in the 6 selected countries are all in the stage of rapid development. However, China is still under the transformation from the initial stage to large-scale practice, especially cogeneration project, district cooling system and renewable energy integrated projects still need further development.

4.3 Energy Structure Comparison

In the respect of oil, since the Gulf War in 1990, the third oil crisis occurred and the overall oil consumption decreased annually. Because of its resource scarcity in Japan, the petroleum energy relies mainly on importation and the proportion of oil energy consumption to the gross energy consumption in Japan is the highest compared to other countries. And Denmark follows, just less than that in Japan in 2000 and approaching the level in the occidental world after 2000. The ratio of oil energy consumption to the gross energy consumption in Japan and Denmark has seen an decrease trend gradually, while that in the United States, Canada and the United Kingdom is in a relatively stable state, leveling off at around 30% - 40%. As the oil resource is not adequate in China and the main fuel is coal, so the level of oil consumption is among the lowest in the six countries, fluctuating around 20%.

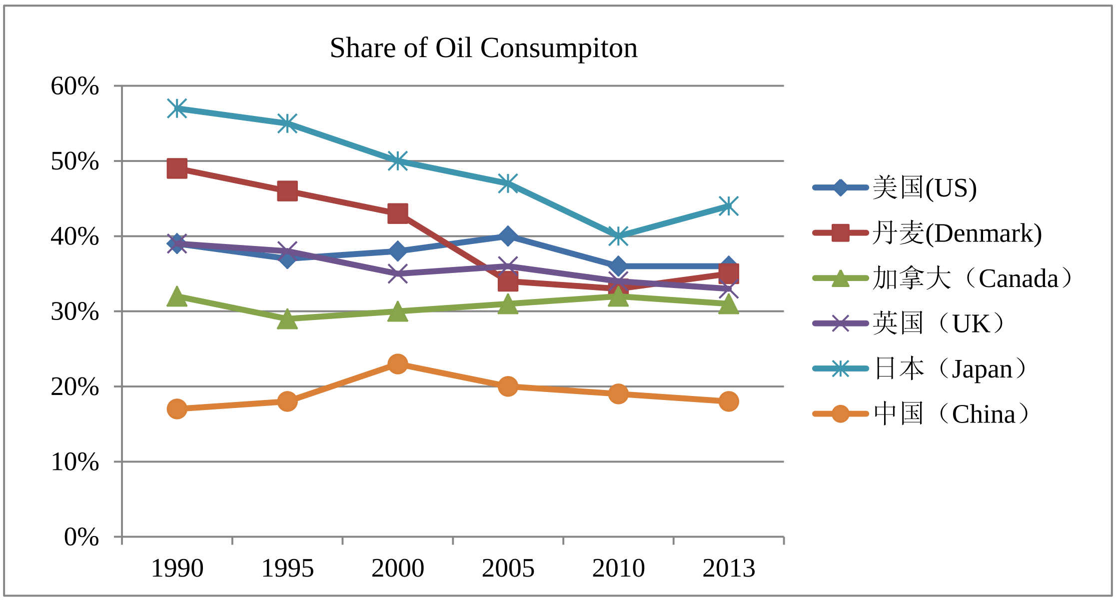


Figure4.1 Share of Oil Consumption to Total Energy Consumption in Different Countries [22]

For coal, China is the country with abundant coal resources and the energy structure is also coal-based. The share of coal consumption to the total energy consumption in China has declined since 1990, from 77% to 66% in 2013, the coal consumption still accounts for over half of the energy consumption. While in the US, Canada, Japan, Denmark and UK, coal represents relatively Low portion of the energy consumption, all less than 30% in last 20 years. As EU countries, Denmark and UK are influenced by the carbon emission reduction goal set by EU and its own development requirement, coal consumption has seen great decrease since 1990 and reduced to below 20% in 2000. While the share of the coal consumption in the United States is relatively stable, just over 20%. In Canada, the coal consumption proportion has been leveling off at 10% and decreased to below 10% in recent years. Unlike these countries, the coal consumption in Japan has experienced a small rise, from 18% in 1990 to 27% in 2013.

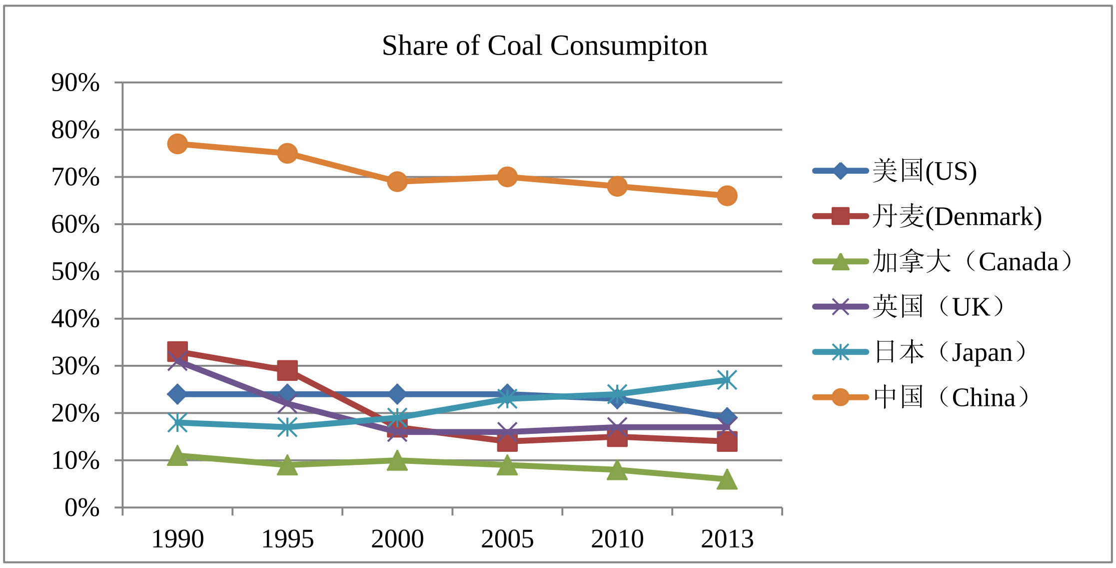


Figure4.2 Share of Coal Consumption to Total Energy Consumption in Different Countries [22]

With adequate coal resource, the coal consumption proportionality is not necessary to cut it off; in other words, increasing gas-fueled distributed energy does not mean giving up coal-fueled district energy system. Instead, coal resource should be used in a most efficiency and environmentally friendly way. According to statistics in 2005, the proportion of washed coal to total coal production is 94.9% in the United Kingdom, 43% in the United States, 98.2% in Japan and 20% in China. The coal-fueled district energy project should enhance the energy efficiency by improving technology and management level in order to reduce the impact on the environment, which is one of the most important aspects for the development of district energy in China.

The natural gas consumption in the United Kingdom accounts for 25% of the gross energy consumption in the early 1990s stabilized around 40% in the early decade in the 21st century, and accounts for the most in the six countries. In the United States and Canada, with abundant natural gas resources, the gas consumption is stabilized at around 25% of the total energy consumption. The gas consumption in Denmark has been increasing in 1990s and reaching 35% in 2005. Along with the vigorously promotion of renewable energy in Denmark, in 2013, the ratio of gas consumption decreased to 19%. Due to resource limitation and technology problems, the application of gas in China and Japan is relatively low, but the ratio increased rapidly in China and

Japan after 2000, from 13% in 2000 to 22% in 2013 in Japan and 2% in 2000 to 5% in 2013 in China.

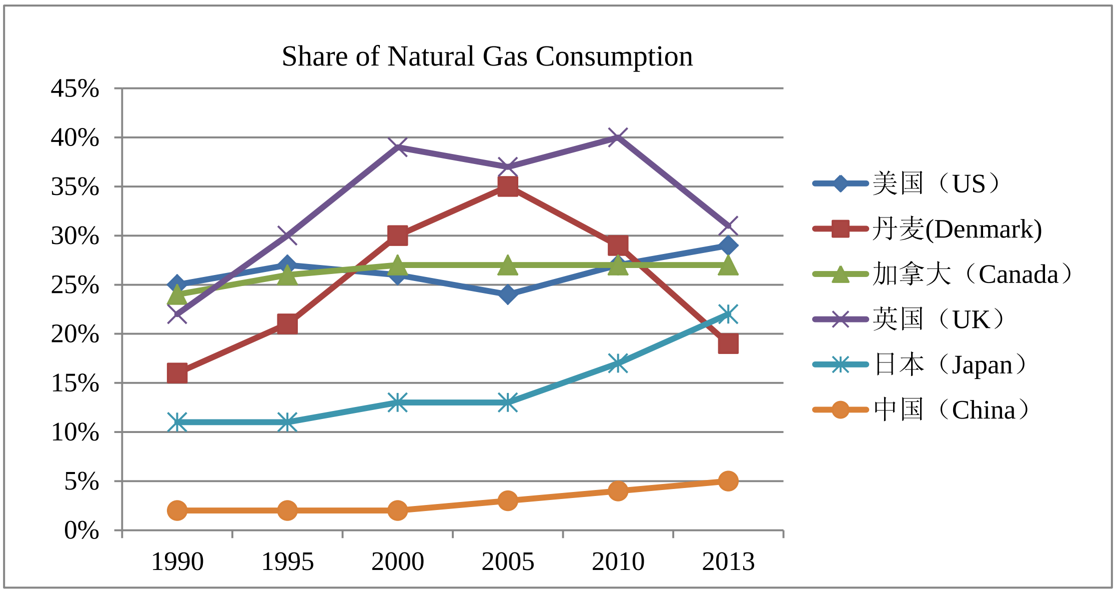


Figure4.3 Share of Natural Gas Consumption to Total Energy Consumption in Different Countries [22]

Along with the explosion of oil crisis, countries around the world began to seek for more secure and stable alternative energy. Renewable energy, as a kind of clean energy, can fulfill the requirement for energy security as well as carbon emission reduction and has been developed rapidly in recent 20 years. The renewable energy development in Denmark has seen a speedy trend, increasing from 2% in 1990 to 32% in 2013, by 16 times. The development of renewables in Canada is at advanced level, the share of renewable is leveling off in the recent 20 years, over 25%. Unlike these two countries, the renewable energy consumption in China is at a lower level, less than 5% in 1990. Among the six countries, the renewable energy ratio in China and UK increased gradually in the recent 10 years, exceeding 10% in 2013 while that in the United States and Japan is relatively stable with little growth.

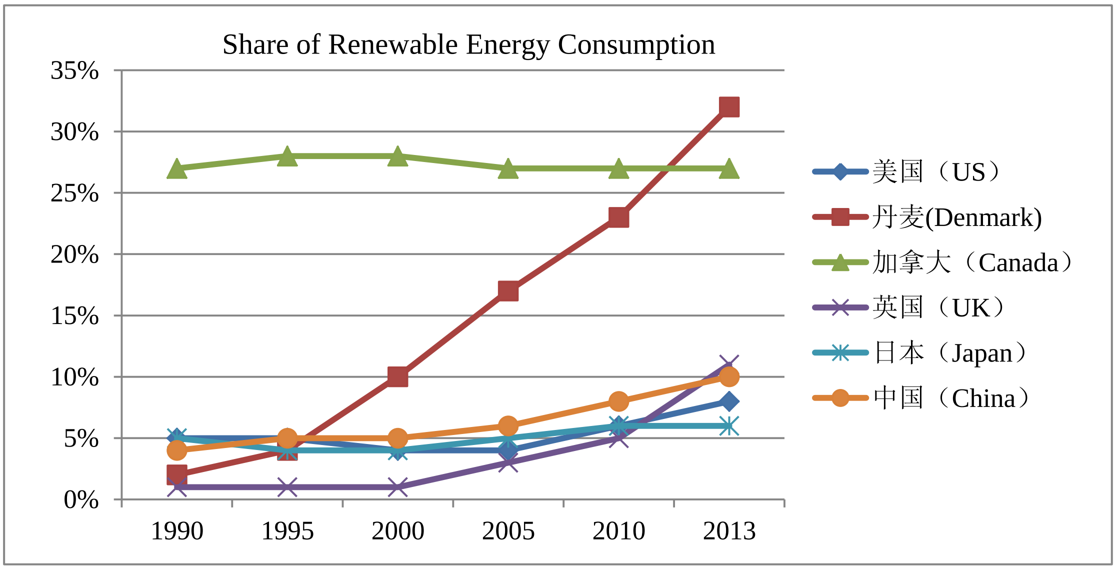


Figure4.4 Share of Renewable Energy Consumption to Total Energy Consumption in Different Countries [22]

4.4 District Energy Policy

Since 1990s, the United States has been working on solving energy problems. The energy problems can be divided into two aspects, one is energy security problems, and the other is carbon emission problems. Unlike other countries, there is no specific policy on carbon emission. Instead, United States emphasizes to achieve the effect of carbon emission by increasing energy efficiency and has successively promulgated a series of measures to promote the application of renewable energy and increase energy efficiency, e.g. Energy Star, Offset Request for Proposals, renewable portfolio standards etc. In 2005, the State federal issued the EP Act, which has been the most comprehensive act since 1992 and set direction for renewable energy utilization. In the same year, the EP Act authorized the Energy Agency to invest 10 billion dollars to increase energy efficiency, renewable energy application and into district energy project. Later, the US federal set up a series of act and incentive mechanism to promote the development of clean energy and district energy.

Because of the particularity of its national institutions and administrative, the Canada federal policy focuses on an overall view without specifics on various aspects. Every state is responsible for its own policy and executive mode. On the state level, Canada federal has paid great attention to environment protection and energy efficiency development since 1990s. The Environment Protection Act issued in 1999 could promote sustainable development and reduce pollution. In 2007, Canada promulgated “Moving Forward on Energy Efficiency in Canada” to provide policy support to enhance energy efficiency and explore energy application potential; Canada also issued “Turning the Corner” in the same year to put forward national carbon emission reduction goal, which indicated that the carbon emission, compared with the level of 2006, will reduce by 20% in 2020 and by 60% -70% in 2050. It presented regulatory requirement on renewable energy use and energy efficiency. In 2010, Canada federal promulgated “Copenhagen Agreement” which further defined emission reduction policy, reducing by 17% in 2020 and by 50% in 2050 compared to 2005.

The United Kingdom has been at advance in carbon emission reduction and enhancing energy efficiency. In 2001, UK government promulgated “Climate Change levy” to set energy taxes and carbon price. Later, with attentions paid on carbon emission reduction and energy utilization by EU, EU set carbon emission reduction and carbon trading mechanism and the UK set Renewable Obligation and began to transform development focus to renewable energy. In addition, Climate Change Act 2008 is a corner stone of the energy development in UK, which define emission reduction target that compared to 1990, reducing carbon emission by 50% in 2020, 80% in 2050. After that, the UK government has given priorities to further improve energy efficiency and reduce carbon emissions. Except policies, UK promulgated a series of tax relief and subsidies policy, e.g. Feed-in-Tariff (FIT) ，Renewable Heat Incentive (RHI) ，Enhanced Capital Allowance (ECA) etc.

Denmark promulgated State Subsidies in 1977, which regulated the utilization of heat surplus from large power plant. During 1980-1990, a number of district heating plants transformed into CHP, fueled by natural gas. In 1979, Denmark promulgated State subsidies for renewable energy. Because of this act, the renewable district energy project increased from 8% in 1980 to 13% in 2001. In 1992, Denmark began to pay attention to carbon emission reduction and set up carbon emission taxes. And then in 2004, 2008, 2012, Denmark issued a series of new political agreement, which will help Denmark to meet the target that renewable energy accounts for 100% of the total energy consumption in 2050. Moreover, Denmark is the earliest and mature country to use district energy.

Since 1970s, Japan began to develop district energy projects. “New Energy Development Plan” is one driving force for DES development in Japan. This plan defines to develop large energy saving technology like renewable energy, heat pump, fuel cell and superconducting electric power etc., to lay a good foundation to the further development of Japan’s district energy. Along with the oil crisis, as energy in Japan relies mainly on importation, the crisis brought a big impact in Japan. In 1993, New Sunshine Plan invested 57 billion Japanese yen on researches in renewable energy technology, fossil fuel application technology, energy transmission and storage technology, systematic technology, fundamental energy saving technology, efficient and innovative energy technologies and environment technology. This plan provide important technology base for district energy development and application in Japan. In 2006, the promulgation of “New National Energy Strategy” definitely put forward that in 2030, the energy efficiency will be increased by 30%, which lay a solid foundation to the development of Japan’s district energy. So far, there are multiple district energy subsidies policy are in operation, the subsidies for some projects cover half of the investment.

The start of district energy in China is relatively late, after the founding of new China. On 6th February1986, the promulgation of No. 22 document of the state council boosted the development of district heating industry in northeastern, northwestern and northern area. In 1997, the national government issued “The energy conservation law of the People's Republic of China” to promote CHP, carry out industry policy which is beneficial to energy saving and environmental protection, restrict the development of high energy consumption, high pollution industries, and develop environmental protection industry. This Act was revised in 2007, greatly improves China’s district energy development and China started to convert from high energy consumption to energy saving model. “The opinion of State Council on the implementation of the government work report key work division” (No. [2012]13), “guidance on the development of natural gas distributed energy” and “Interim measures on distributed power generation management” etc., those regulate to promote energy-saving, emission reduction and ecological environment protection, strengthen energy management, develop smart grid and distributed energy and define tasks, set goals for national gas-fueled district energy development and provide support on policy and economy. Through the policies, China gradually transformed from high energy consumption, high pollution to low consumption, high energy efficiency.

4.5 Inspiration

Sustainable development of national economy requires secure energy supply and smart power system. A huge demand on district energy systems was caused by the pressure from energy efficiency improvement and environment protection. A series of challenges coming with the rapid development of DES includes: investment sources, technical supports, client and market exploitation, policy and regulation, undefined developers, coordination between energy stations, Grid Company and fuel company, which are practical and serious challenges for the DES development.

District energy is the important basic industry and public utilities for national economy, thus multiple ownerships should be allowed to access the DES market. The construction, operation and management need to be operated by market mechanism.

The market exploitation on district energy cannot rely on the government subsidy and compulsory measures. Instead, it should be driven by its own advantages including high energy efficiency and low environment impact, costs reduction on large power grid transmission and peak-load shaving. It is a win-win strategy for environment, government, developer, customer and Energy Company.

District energy development needs abundant capital investment and cannot depend on the investment from the government and taxpayer. The capital operation should follow the market economy to make a virtuous cycle and blossom. In addition, capital and market is gradually developed, but not built in one day.

In order to operating the district energy industry by market mechanism, the government needs to establish relevant policy and regulation and make macro planning and control. In another word, although DES development should follow the market rules and society requirements, the governmental planning is still very import.

5. District Energy Application and Practice Guidelines

5.1 Definition of District Energy

District energy referred to district heating, district cooling, district power supply and energy systems which solve energy demand and their integration. The area can be the administrative division of the city and the urban area, or a residential quarter, or building mix; or it also can be referred to development zones, industrial or business parks etc.

District energy system includes boiler heating system, chiller system, thermal power plant system, CCHP system, heat pump energy supply system or its composite application form etc. The energy for district energy system can be conventional fossil energy, including coal, oil, natural gas, electricity, or renewable which includes solar energy light / heat utilization system (solar energy heat utilization system, photovoltaic power generation system), shallow geothermal resources utilization system (underground water heat pump system, surface water heat pump system, ground source heat pump system), sewage source heat pump system, wind power generation system and biomass energy systems.

Overall, all energy for production and life for human society can be used scientifically, rationally, comprehensively and integrated within certain regions and complete the whole process of energy production, supply, distribution, utilization and emission, which is defined as district energy.

5.2 Object of District Energy Application

The users of district energy include residential units, public buildings, commercial buildings and communities. It can also include industrial users in the urban area.

The promotion and application of district energy involves various departments. It cannot conduct without owners, enterprises (providing related equipment, technology, consultation, service etc.) and attentions, support and promotion from government.

District energy system is applicable to areas with high Floor-area Ratio rates, high energy consumption and high density load rate or industrial users. It’s also applicable to users with constant and stable cooling, heating and electricity loads.

5.3 District Energy Application Process

According to project development sequence, the process of promotion and application of district energy projects can be divided into planning stage, design stage, construction stage and operation stage. Among, it also includes business process and financial process etc.

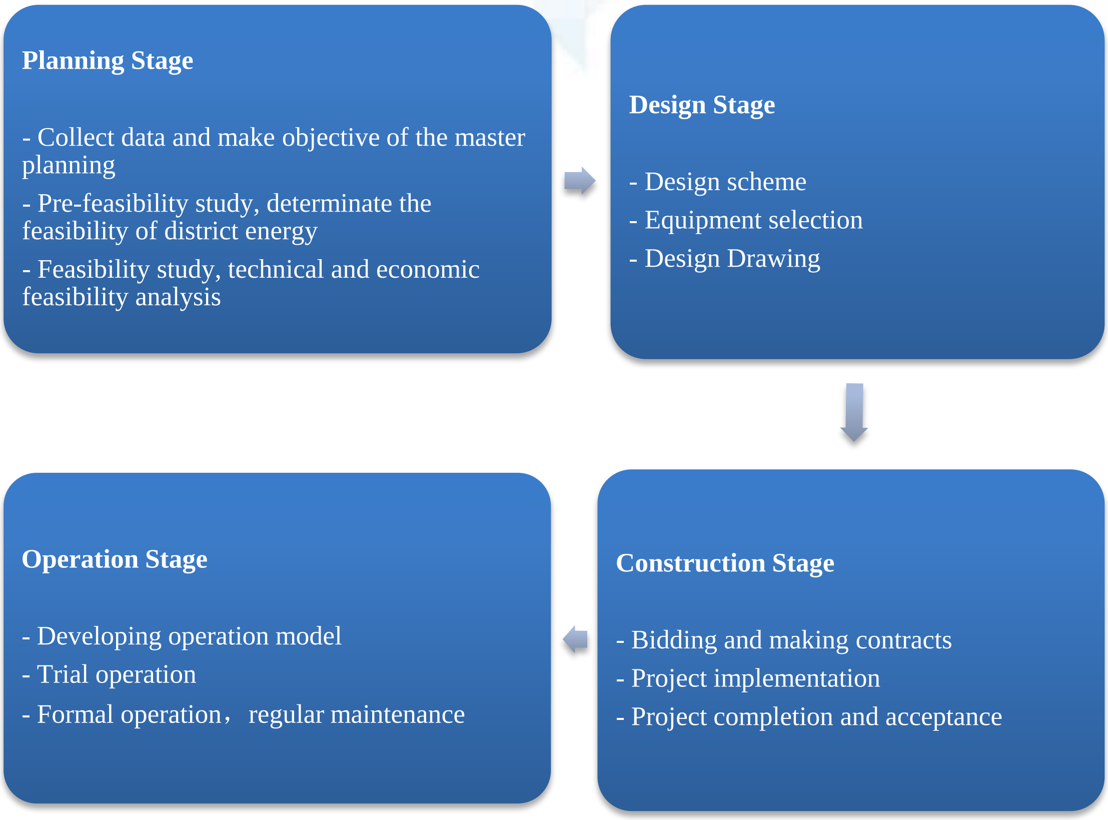


Figure 5.1 Promotion and application process of district energy

5.4 Application Technology of District Energy

The technology form of district energy includes coal-fired cogeneration central heating system, gas-fired central heating system, district cooling system with large-scale heat pump, gas-fired tri-generation system, combined supply system of conventional energy supply system and renewable energy supply system.

District energy system include district heating system, district cooling system, district CCHP system and combined system with renewable energy.

(1) District Heating System (DHS)

Cogeneration central heating is referred to that power generation not only produces electricity, but also uses steam to provide heat to users, namely, process which produce electricity and heat simultaneously. It saves fuels compared with process producing electricity and heat separately. Power plant which runs in the form of cogeneration is called heat and power plant. The steam source for external heating is adjusting steam from steam extraction steam turbine or steam from back type steam turbine, the pressure is usually 0.78～1.28 MPa and 0.12～0.25MPa. The former one provides industry production, and the latter one is for heating supply.

Districted heating is referred to using hot water or steam as heat medium, providing heating to cities, towns or several regions through heat networks through one or several heat sources. So far, it has been one of the most important infrastructures in modern cities and important composition of urban public utilities.

(2) District Cooling System (DCS)

District cooling is installing centralized refrigeration station in an architectural complex to produce air conditioning chilled water and provide cooling to all the buildings through circulation water piping system. Thus, cold source of air conditioning is not needed in every building and cooling power can be avoided everywhere. As the peak of air conditioning load of every building will not occur simultaneously, so the installed capacity of refrigerator will be less than total installed capacity of scattered refrigerator and then decrease the initial investment of refrigerator equipment. Since 1980s, some commercial building complexes in metropolitans in Japan, lots of campuses in United States have also adopted such district cooling. Some typical cases include Tokyo Shinjuku Shintoshin, new airport in Japan Nagoya, many university campuses in the United States. The building floor area served by district cooling is normally more than 500,000m2. The Guangzhou University Town and Beijing Zhongguancun Science Park also adopt such district cooling system, and have put into operation.

(3) Gas-Fired Combined Cooling, Heating And Power (CCHP)

So far, the commonly used form of CCHP system in China can be divided into two types, one is gas-engine based generator unit CCHP system, and the other is gas turbine based generator unit CCHP system.

A. Internal-combustion engine based CCHP system

Natural gas enters gas-fired internal-combustion engine and burned in high compression combustion chamber to generate power, drive the rotor of the generator to generate induction current and output electricity to users. The efficiency of single generation of internal-combustion engine can reach 46%.

Usable waste heat from generation of internal-combustion engine is divided by two aspects, high temperature flue gas and jacket water. The temperature of high temperature flue gas can reach more than 300℃ and is a high grade power. The temperature of jacket water can reach as high as 80℃ and has some value in use. The high temperature flue gas from conventional power plant usually emits directly, which results in energy wastage. While an important composition, waste heat usage system from tri-generation recovers and utilizes such heat surplus. The tri-generation realizes functions that providing cooling or heating to users through a set of absorption refrigeration unit and increase primary energy efficiency dramatically.

The main equipment of heat recovery system is absorption refrigerator, choosing flue gas hot water absorption refrigerating machine docking with internal combustion engine and then realizes the recovery and utilization of flue gas and hot water. In summer and winter, hot water loads can be output simultaneously if needed.

B. Gas-fired turbine cooling, heating and power technology

Natural gas burned in gas turbine combustion chamber, output electricity after working in the turbine and there is one type of usable waste hear, i.e. high temperature flue gas, whose temperature can reach more than 400℃. The gas turbine can dock with waste heat boiler or directly dock with absorption chiller units. When electricity demand is large and cooling and heating demand is relatively small, it considers setting steam turbine after waste heat boiler and using the waste heat to further generate electricity. The generation efficiency of single unit can reach 38% and if combined with waste heat boiler and steam turbine, the power generation efficiency can reach nearly 55%.

The unit power output of simple circulated gas turbine CCHP is less than internal combustion engine system, but waste heat is a form of high temperature flue gas, thus, waste heat system is simpler. In addition, the flue gas temperature is usually higher than that of internal combustion engine. Thus, it’s applicable to users with high heating demand.

Generally speaking, gas engine cogeneration system is applicable for tens to hundreds of thousands of square meters buildings or district energy project. While gas turbine cogeneration system is applicable for hundreds of thousands of square meters district energy project or industrial project.

(4) Integrated district energy system (DES)

New technology form of integrated district energy system includes not only conventional fossil fuel cogeneration and CCHP, but also waste heat resources from city industry, Low grade superficial layer geothermal resources, biomass energy, solar energy and wind power for large scale renewable energy utilization

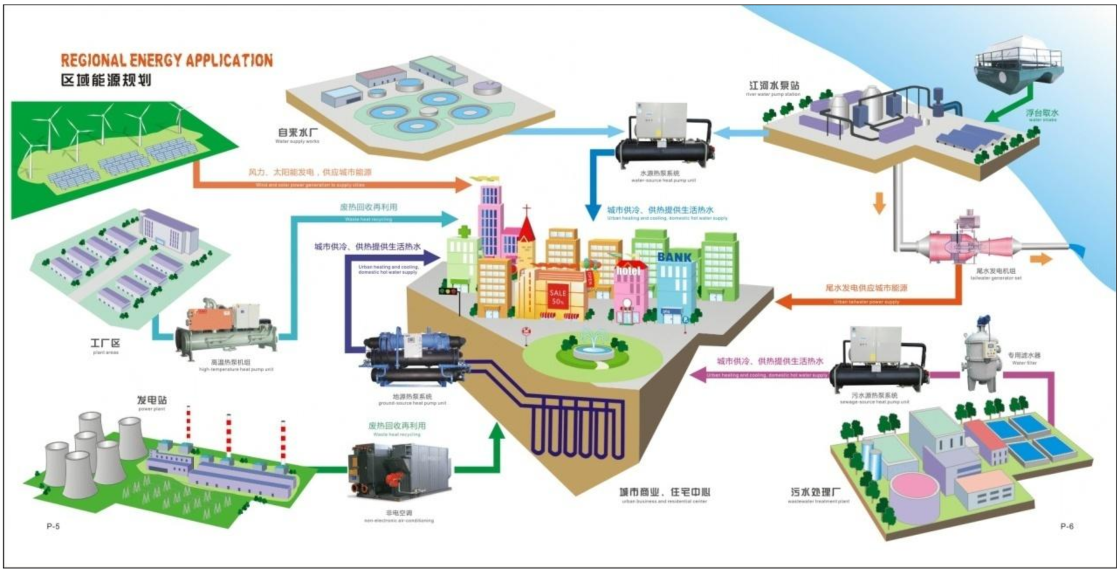


Figure 5.2 Integration Planning Diagram District Energy System

5.5 Development Road Map for District Energy Development

The development of district energy is restricted by fuel utilization technology, equipment development, requirements of energy-saving and environment protection policy etc. The development trend of fuel in district energy is from small-scale, high efficiency with low emissions to large-scale, high efficiency and low emission and from coal to clean energy, from solely using fossil energy to comprehensively using fossil and renewable energy, from independent supply system of cooling, heating and electricity to cogeneration.

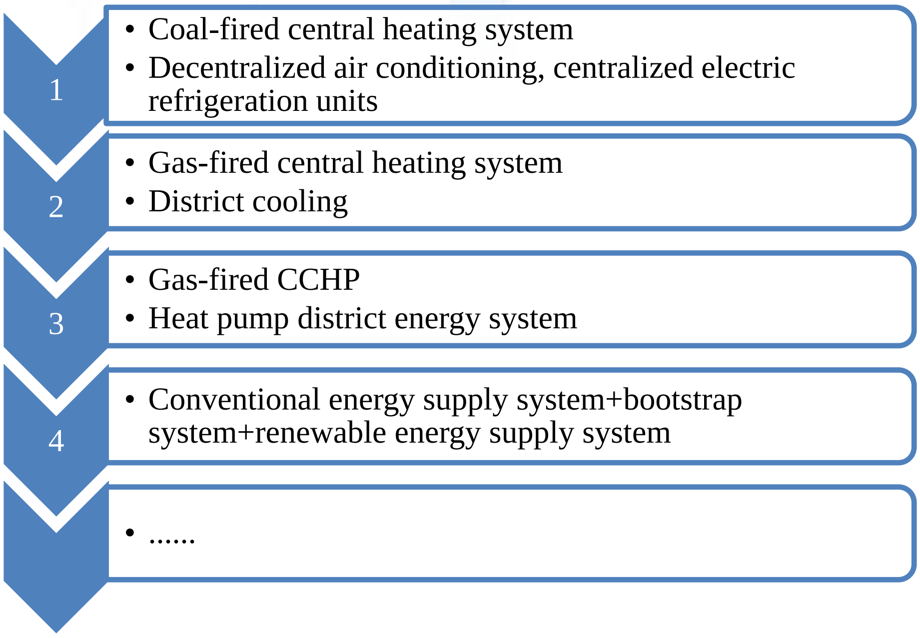


Figure 3 application of district energy system

5.6 Analysis of Promotion and Application Factors of District Energy

Factors affecting the promotion and application of district energy are shown as follows:

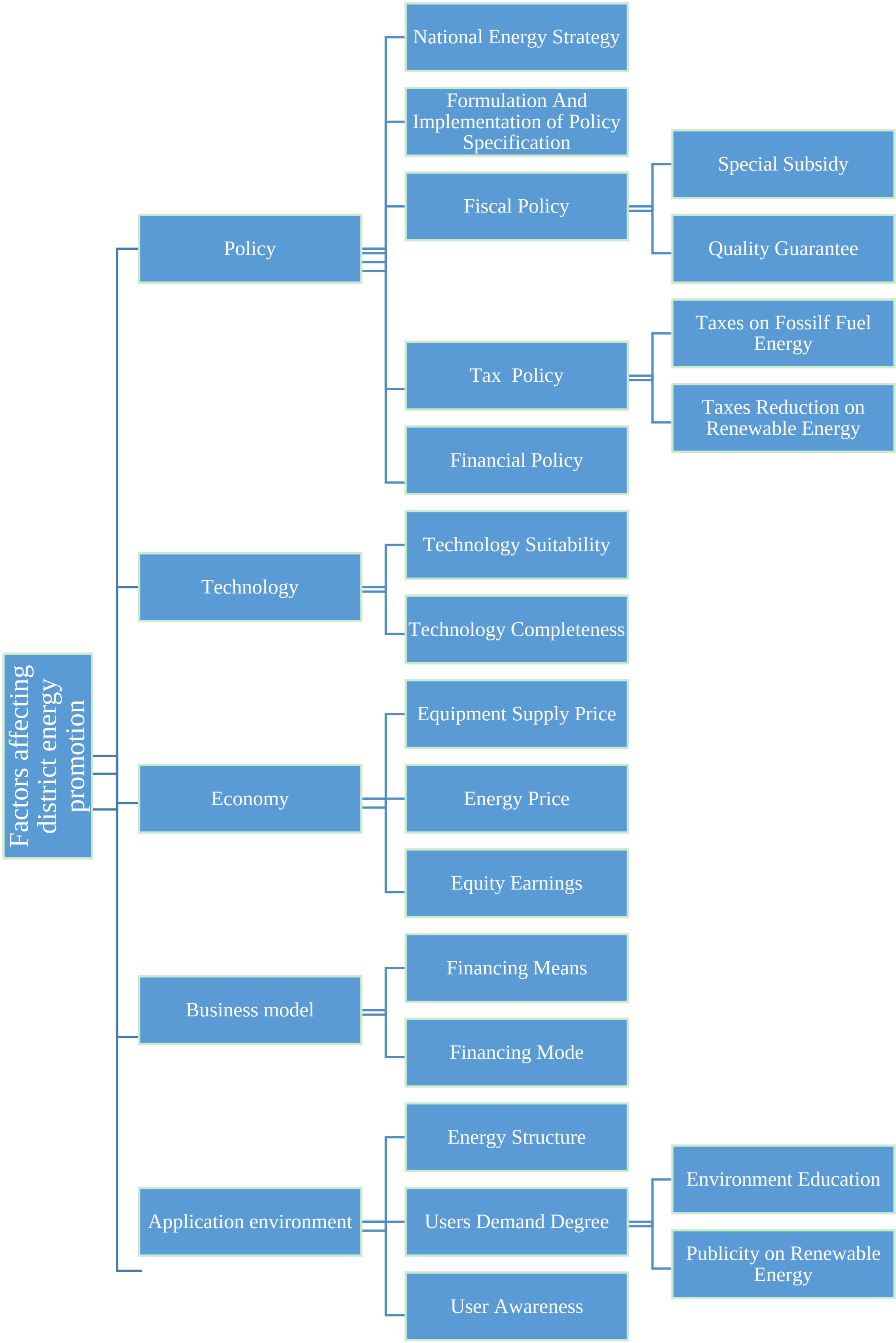


Figure 4 Factors Affecting Promotion and Application of District Energy

5.6.1 Impact Analysis on District Energy Policy

Policies which would affect popularity and application of district energy includes collaboration of national energy strategy, policies and regulations formulation and implement, fiscal policy, tax policy, financial policy. The degree of consistency, improvement and enforcement of the legislation will play an important part in promotion and application of district energy.

5.6.1.1 Influence of the National Energy Policy

So far, China insists energy-saving development national policy. It insists conservation priority, based on the domestic (provide for oneself), multiple development, technology dependence, environment protection, enhance international co-operation, striving to build a stable, economic, clean, safe energy supply system, supporting sustainable development of economy and society by energy sustainable development and providing policy basement for promotion and application of district energy system.

(1) Enhance Energy Saving

Insist on energy development and conservation simultaneously, conservation priority, transform economic development mode actively, adjust industrial structure, encourage energy-saving technology development, popularize energy-saving products, enhance energy management level, perfect energy-saving regulation and standard, increase energy efficiency constantly, provide policy basement for district energy application.

(2) Enhance District Energy Supply Security

Steadily improve domestic energy supply security to meet rising demand of energy market. District energy system with multiple energy supply has better energy security which is conform to technology characteristics of district energy.

(3) Enhance Energy Supply Diversification

Scientifically develop alternative energy, optimize energy structure, realize multi energy complementary and ensure a stable supply of energy through developing local energy resources and vigorously developing renewable energy.

(4) Promote Science and Technology Innovation of District Energy

Enhance independent innovation, improve digestion, absorption and re-innovation ability on introduced technology, breakthrough technical bottleneck of energy development, increase production level of key technology and major equipment, create new paths of energy development and reinforce the development potential.

Build a resource-conserving and environment-friendly society, promote coordinated development of energy and environment and realize sustainable development.

(5) Enhance International Cooperation and National Coordinated Development of District Energy

DES development is based on local condition and shall insists the principle of equality and reciprocity and mutual benefit, enhances international energy cooperation with international energy agencies, perfects cooperation scheme actively, deepen cooperation field, maintains the international energy security and stability, which provide base for international development and cooperation of international district energy technology development.

5.6.1.2 Influence of Formulation and Implementation of Policy and Standard

(1) Strengthen energy conservation legislation, construct ecological civilization and preliminarily form industrial structure, the mode of growth and consumption mode of energy resource conservation and environmental protection. Facing the increasing resource and environmental constraints, crisis awareness should be strengthened and build up green and low carbon development concept, focus on energy conservation and emission reduction, complete sound incentive and constraint mechanism, speed up the construction of resource conservation, environment friendly production mode and consumption pattern, enhance the capability of sustainable development, increase the ecological civilization level and clearly put forward to promoting the popularization and application of the distributed energy system

(2) Strengthen the renewable energy legislation, promote the development and application of renewable energy, increase energy supply, improve energy structure, guarantee energy security, protect environment and realize sustainable development of economy and society.

(3) Strengthen the construction and application of natural gas distributed energy projects. Construct distributed energy demonstration area with various typical characteristics.

(4) Promote the formulation and implementation of regulations of distributed power on-grid technology

(5) Action plan for the air pollution control, put forward to increasing energy efficiency, promoting energy technology and equipment like ground source heat pump, air source heat pump, solar hot water system, building integrated photovoltaic, “heating-electricity-cooling” cogeneration etc.

(6) Promote formulation and implementation of regulations, standards and specifications of district energy projections.

(7) Unified planning and application by government. The national government needs to formulate policy and regulations to encourage, support and protect the cultivation and development of district energy projects and their related industries.

The regulations above provide systematic safeguard for the promotion and application of district energy.

5.6.1.3 Effects of Fiscal Policy

(1) Government Special Subsidy

Energy price plays a decisive role in choosing energy utilization form by users. There are a plenty of renewable energy being in industry development stage and the price is usually higher than conventional energy. Renewable energy should have advantages in price to make users choose it actively. It also can use fiscal subsidies to change the use-cost and when cancel the subsidies when the energy market is mature.

(2) Quality Guarantee

Another applicable policy is government quality guarantee. So far, a number of renewable energy equipment enterprises are unable to provide long-term quality guarantee. If government invested to make a maintenance team to repair renewable energy equipment which is out of guarantee period for free, it can significantly reduce the user's worries for renewable energy equipment, decrease its maintenance cost, encourage citizens to choose renewable energy and then promote the development of renewable-based district energy system.

5.6.1.4 Impact of Tax Policy

Tax policy is also an important policy instrument. It can levy on traditional fossil energy and increase its operational cost and then make renewable energy have advantages on price and increase application ratio of renewable energy in district energy.

(1) Tax on Fossil Energy

Because of the incineration of traditional fossil energy, it will generate a large amount of pollutants like GHGs and SO2. However, the market is failed to reflect the cost caused by fossil fuel incineration to the society, so levying on traditional fossil energy could increase the advantage of renewable price and encourage the utilization of renewables and then promote the popularity and application of district energy.

(2) Tax Relief on Renewable Energy

Reducing taxes on renewable energy production enterprises could decrease the average production cost and cut down the price of renewable products to a certain extent, strengthen competitive advantage of renewable energy and then encourage the promotion and application of district energy.

5.6.2 Impact Analysis of Influence Factors on DES Promotion and Application

District energy system integrates technologies and equipment on the processes of energy production, conversion, recovery and storage. It is a typical systematic engineering and influences from various factors needs to be taken into account. The market suitability, technology maturity and product localization degree of energy system integration technology have significant impacts on its promotion and application.

5.6.3 Impact Analysis of Economic Factors on DES Promotion and Application

The economic factors which affect the promotion of district energy depend on the equipment cost, energy price and investment returns. High equipment and energy price will restrain users' selection and consequently restrain the promotion and application of district energy.

5.6.3.1 Equipment cost

Currently, the high equipment cost is the main impact factor of low economic performance. The cost of waste heat absorption refrigeration machine is higher than waste heat boiler and heat exchanger and other waste heat utilization equipment. It can use high cost and restrains promotion and application of district energy system.

5.6.3.2 Energy Price

The natural gas price rises along with oil price rising. Although the electricity price has increased a little, the overall is relatively stable. The ratio of gas price and electricity price increased rapidly, which greatly affects the promotion of distributed CHP technology. For one aspect, the natural gas price is increasing constantly, while for another aspect, the non-open electricity market make the electricity price low which cannot respect the economy of gas thermal power equipment operation and then restrain the promotion of district energy system.

5.6.3.3 Investment Return

Because of the high equipment cost and system complexity, the frontend investment for DES is higher than the conventional system. The difference of investment return is very large due to multiple factors. The social capital will not sufficient if DES development is lack of professional services, supports and demonstrations.

The profit of DES is mainly from cooling, heating and power. There are two types of price including household price and commercial price. The household price is still determined by the government and the government keeps the operation of the heat company. So the return of the joint supply of cold, heat and electric by natural gas is not satisfied. It limited the distribution of district energy system.

5.6.4 Impact analysis of the business model to DES application

Business model refers to an integrated system for production, service and information flow, which involves all stakeholders and their function within the system, as well as their potential interest and approach. Proper business model can accelerate the promotion of district energy.

Proper business model includes the selection of proper financing tool sand financing mode. Current financing mode includes BOT, TOT and PPP.

We encourage the BOT model in district energy constructions. BOT is short for Build-Operate-Transfer. It refers to the government or a government authorized project owner who authorize an investment enterprise to financing, invest, develop, operate and maintain such project through agreement. The investor will operate the project for a specified period to earn profit, and take risks at meantime. The government or the authorized owner retains supervision rights during that period. By the expiration of the contract the investment company transfers the project to the government. It suits the project that cannot make profit recently but have the potential of future profitability.

TOT is short for Transfer-Operate-Transfer. It refers to the government and the investors make the franchise agreement and then transfer the operation rights to private investors. The owner can raise a lump-sum capital from the project and use them for new infrastructure development. By the end of the franchise agreement, the investor will return the operation right to the government with no charge.

PPP (Public Private Partnership), refer to the cooperation mode of public sectors and private companies. It is a financing mode for public infrastructures.

5.6.5 Impact Analysis on DES Application Environment

The application environment brings comprehensive impacts caused by energy structure, user demand and user recognition. The suitable district energy system is defined through the analysis for certain regions. Thus, the primary energy supply condition, environmental constraints, users' cooling heating and electricity load as well as distribution of space and time etc. are all play an important role in the DES scheme selection.

5.6.5.1 Energy Structure Analysis

Great attention should be paid to the local energy structure. The primary energy supply condition and environmental constraints are all play an important role in the scheme selection of district energy. DES development should consider the condition of primary fossil energy, secondary converted energy, renewable energy, usable low grade energy. It shall to develop DES based on the grade, quantity, usability and selectable technology and equipment.

5.6.5.2 User Demand Analysis

(1) Prediction on users' annual dynamic load. In order to realize energy saving design based on the characteristics of user demand, we should analyze the production and consumption on cooling, heating and power from the stand point of demand side, balance the relationship between demand side and supply side,

(2) Through analysis on customers' energy demand and consumption structure, we can discover the key factor for energy saving by finding out and balance the internal connections among cooling, heating and power demand.

(3) Build up user-side energy saving operation mechanism and provide technical, economical, incentive and administration mechanism for energy demand-side management

5.6.5.3 User Recognition Analysis

(1) Strengthen application environment developing and educational training

The trainings should be enhanced in order to improve public understanding and awareness on district energy technologies and develop application customers.

Publicity on the relations between global climate change and greenhouse gas emissions will help the users to recognize the advantages, restrictions and applicability of DES development.

It should not only include the training on professional knowledge, establishment of professional team for planning, design, operation and maintenance, but also include universal training for basic knowledge and scientific knowledge.

Research and development on system integration and key equipment should be enhanced. The proportion of localized DES project and construction should be increased.

Publicity and trainings will make users to recognize that using the district energy will help protect the environment and reduce harmful emissions, thereby increase users' acceptance on district energy.

(2) Strengthen the publicity of renewable energy

Large-scale application of renewable energy has a certain degree of commercial values. Since the user's awareness of renewable energy is not high, it prevented the promotion of renewable energy.

Use would not be willing to use renewable energy if they cannot receive sufficient information on risks.

But Government can help to increase the user's understanding by media publicizing and increase user's acceptance of renewable energy applications in district energy through the publicity of successful cases of renewable energy.

5.7 Guidelines for the Key Issues during Promotion of DES

Many of the technical problems or critical issues may occur during the promotion of district energy use. However, proper solutions to these problems will be more helpful to enhance the effect in regard of the promotion of dissemination and application of district energy.

This study mainly focuses on the planning, design and operation aspects to analyze the existing problems in promotion district energy use and give further solution guidelines.

5.7.1 Guidelines for the Problems in Project Planning and Feasibility Study

Full demonstration of the local gas prices, hot (cold) prices, electricity prices, environmental carrying capacity should be made during the project planning and feasibility study.

The site of the energy station is near gas stations, city gas networks or other energy center, and meanwhile close to the load center.

5.7.1.1 The analysis of district energy structure, distribution of resources and environmental carrying capacity

In the feasibility study of the planning, district energy system often encounter the following issues, whether the energy structure and resource endowment condition where the district energy project locates is suitable for the application of district energy system.

Problem: the assessment towards designing scheme of district energy system is not comprehensive and evaluation methods are unreasonable, which is likely to cause poor operating results.

Guiding principles: do well in comparing and selecting among different schemes and also in assessing the planning from aspects of energy saving, environmental protection and economic efficiency

If the objective comparing of the program cannot be done, it might have some impacts on the operational phase, which would result in failure to reach the expected operational benefits.

Problem: Inappropriate Energy Structure and Poor Energy Resource Endowment

Guiding principle: The plan in the promotion of district energy should be made on the basis of local fuel resources. Adequate research work on local energy, existing cooling and heating sources should be made to achieve the full use of high efficient cooling and heating source. This will help to increase the utilization ratio of surplus heat and renewable energy under reasonable technical and economic conditions.

Problem: Failure in handling short-term, middle term and long term load problem in the planning period and consider the periodicity characteristics of the development stage of the project will result in poor operational efficiency of the system.

Guiding principle: during the planning stage, we need to set appropriate load index which matches the real demand of the project. Considering the real time implementation of the project, we need to analyze the current status for a short term, mid-term and long term load prediction, so as to achieve a balanced supply and furthermore, to finalize a proper heating and cooling source plan.

This guiding principle can ensure that the heating, cooling and electricity loads of the planned construction are made based on proper basis, the respective load index for new and existing constructions. It also could remind us heating and cooling loads of different type of construction within the district, for example the residential, commercial, office or hotels, etc. The loads of the construction should be made based on either the statistics of the practical research, or the design value of the construction design document. Meanwhile, the peak load adjustment for heating and cooling should also be taken in account.

5.7.1.2 Analysis on the Project Approval Conditions

Problem: District energy project approval conditions.

Guiding principle: The promotion and application of district energy project will encounter restricts like environmental approval, policy approval and technical specifications approval etc.

The implement of district energy project should meet the requirements of relative policy and comply with the requirements of relative technical specifications. The district energy project should strictly implement the requirements of the environmental impact assessment law and meet the local requirements of pollutant emission. For example, the total amount requirements of pollutant emission, water pollutant discharge requirements, requirements of environmental noise emission standards etc. The construction conditions and production layout should meet the requirements of local industry policy and urban planning etc.

5.7.1.3 Prediction Method on the Demand of Cold and Heat load of the users in Different stage

Problem: the accurate prediction on the user's demand load will provide key basis to the project decision

Guiding principle: different load calculation method should be adopted in different stage. The load index per unit area can be used during planning stage together with a set simultaneity factor.

(1) Steady state analysis index can be adopted during design stage to put forward load index of different building types or areas, and calculate district construction load value through Indicator method. Under such basis, it shall define the simultaneity factor of every building type to get district cooling load and additionally, and build up load index model of different types of buildings (residential, hotel, office, commercial buildings).

(2) Dynamic load index can be adopted during initial design stage to get annual load changes of different building types. It is designed not only considering typical working condition but also adopting the working load analysis aided design method to get annual hour-by-hour load value, maximum / minimum value and cumulative value etc.

5.7.1.4 Planning Scheme Analysis

Problem: What is the design principle for gas-fueled distributed CCHP?

(1) When conducting system design for existed buildings, the real cooling, heating and electricity load data should be inspected to draw typical hourly load curve and annual load curve in different seasons according to measured operation data.

(2) When conducting system design for new buildings or existing buildings without measured operation data, estimation should be made according to design load materials and references to measured load data of similar buildings, in order to draw typical hourly load curve and annual load curve in different seasons.

(3) When drawing hourly load curve in different seasons, hourly superposition should be conducted according to types, properties of the load and heating/cooling storage capacity.

(4) When conducting technology and economy analysis on the cogeneration system, calculation of annual cooling, heating and electricity supply should be made according to hourly load curve.

(5) The form, equipment capacity, process flow and operation mode of the cogeneration system should be defined according to gas supply condition and cold, heat, electricity and gas prices after technical and economic comparison. System configuration should be optimized afterwards.

(6) The selection of equipment for cogeneration system should comprehensively consider the change rule of cooling, heating and electricity, make technical and economic comparison for system operation mode, properly allocate power generation equipment, waste heat utilization equipment and supplementary equipment to ensure the full use of heat surplus after generation. The annual average energy comprehensive utilization rate of general project can reach over 70%.

(7) The principle for system configuration is that the generated power is able to be used on-site. In order to guarantee the high operation efficiency of generator units and meet the required hours on an annual basis, the capacity of the generator units should not be too big and also should check the operation status of the generator when load is low. During on-grid operation, if the basic electricity load cannot be defined, the capacity of generator of civil building can select no more than 30% of the maximum designed load of the project and the rest is supplemented by public power grid, under this circumstance, the operation load rate of the generator is high. During isolated grid running, the capacity of generator units should be larger than the maximum electricity load within the region, and the load rate of long-term operation is low.

(8) The equipment capacity of the energy station should be defined according to the designed cooling and heating load of the users. When the heat surplus cannot meet the designed cooling and heating loads, additional supply equipment should be set up to meet the need. The equipment could be cold water absorption units, compression-type water chiller, heat pump and boiler etc., or cooling storage and heat storage devices.

Problem: planning principles of district cooling and heating system

(1) Accurate Prediction on district cooling and heating loads;

(2) Choose energy-saving heat production mode, increase the rate of thermal power plant in district cooling and heating;

(3) Plan supply radius properly and choose the best economic threshold;

(4) Choose HTM types and supply parameters based on system characteristics;

(5) Develop district heating and cooling system with various forms of energy;

(6) A proper design applicable to high plot ratio, high load density and high load rate. Cut down the length of heating and cooling pipes;

(7) Reduce distribution cost, increase transportation temperature variation;

(8) Select system configuration based on load characteristics of different users. The system should be defined after technical and economic comparison.

5.7.1.5 Technical and Economic Evaluation

Problem: feasibility studies should ensure the technical and economic indicators to be scientific and correct.

Guiding principle: if the technical and economic indicators are inappropriate, it would result in incorrect conclusion of the feasibility study, which will cause losses to the project operation later. So the project should be ensured to gain correct evaluation.

In technical economy analysis, more attention should be paid to the analysis of initial investment, annual operation cost, energy conservation rate, primary energy consumption per unit area, total energy consumption, pollutants emissions ect., and make comparison from the aspects of system configuration complexity, operation safety and reliability and cover area etc.

Appropriate reference object should be selected. It is improper to choose a backwards technical scheme as reference object in order to increase the technical and economic indicators of the project. It's encouraged to choose the conventional scheme in the industry.

5.7.2 Guiding Principles in Design Stage

During the design stage, prediction and analysis should be able to be made based on the dynamic load of the users to facilitate the system configuration optimization and equipment selection. Pipelines layout should be designed according to suitable energy supply radius. The energy project involves in coordination of multiple academic majors and departments, so multi-professional cooperation will be needed for comprehensive technology coordination and interface management. It is also needed for the coordination or progress management among power sources, networks and users. This will help us to ensure overall construction safety, quality supervision and progress control.

District energy system is a multi-industry system which integrates natural gas, power distribution and supply, heating supply and cooling supply etc. For infrastructure relating with the system like gas, electricity, heating and cooling etc., the government has formulated well-developed standards and DES project should conform to the provisions of the relevant standards. During the DES implementation process, it also should comply with other relevant mandatory standards.

5.7.2.1 Accurate Prediction and Analysis of Cooling, Heating and Power Load during the Design Phase

Problem: Solutions to the uneven cooling and heating load fluctuation in DES

Guiding principle: As to the inadequate cooling and heating load appeared in the project, the project can be constructed by stages. For uneven distribution of cooling and heating load in all seasons throughout the year, it can conduct the method of analysis on the hourly curve of typical days within each season and select suitable cooling and heating source equipment. For uneven daily load, it can be solved by optimizing the operation plan.

The mistaken estimation on loads will result in uneconomic operation of the whole project. Oversize system configuration will result in low power-to-heat ratio and reduce the time for operation at full load will decreased, which will decline the economic efficiency.

Problem: Method for Load analysis

Guiding principle: the load analysis of distributed energy system is the base of units selection and is the most important input data of the system design. The designer should adopt hourly dynamic load analysis on an annual basis method and based on hourly changed load data. If it's difficult, it can use typical load curve of typical days in every season or every month and to optimize the system and gain the maximum, minimum and average loads.

5.7.2.2 Selection of Energy Station Design Schemes

Problem: Under-developed DES design scheme

Guiding principle: under the prerequisite of considering technical economy, make sure the design scheme adopting advanced and suitable technology. When promoting and applying several advanced energy-saving technologies, it needs to consider the application suitability in specific district energy projects. Avoid the phenomenon that using energy-saving technology during design stage but there is no energy saving in real operation.

The energy supply scheme should not only meet the energy demand for the project area, but also give consideration to energy demand of surrounding areas. In addition, the design should utilize surrounding efficient energy system as much as possible or provide energy for surrounding users.

The DES design should follow the energy use mode as "appropriate temperature, energy cascade utilization, resource Collaboration.

Problem: how to make the optimized selection for design capacity in the distributed energy supply system.

Guiding principle: when choosing system capacity for distributed energy system and CHP, we should conduct detailed simulation and analysis on load variation of electricity, heating, cooling and hot water. Under thermal equilibrium situations, we need to make sure the installed capacity could meet the basic heat load demand and the rest load can be met by peak-load shaving heating boilers and other methods.

Regarding to the system which connects with power grid but not on-grid, the power supply capacity usually should be no more than the users' minimum power load in order to guarantee the operation of the units is not restricted by power load. In order to realize long-time efficient and full operation, the heating supply capacity is usually set as 30% of the maximum heating load. The annual utilization hours should be more than 4,000 hours, the real heating supply quantity should account for more than 50% of the total heating consumption.

Problem: selection method for CCHP generator unit capacity

Guiding principle: the waste heat should be fully utilized and the generator should be operated at full load during all cooling, heating time as much as possible, which will increase the average annual comprehensive utilization rate of generators. It refers to the principle: electrical self-generation and consumption, and waste heat recovery maximization.

If the installed power capacity is larger than the demand load, surplus power needs to be supplied to the public grid, therefore it's applicable to on-grid CCHP projects.

Problem: the requirements for energy station location.

Guiding principle: the location of energy station should be close to cooling and heating source. It should be located in the center area of cooling and heating load which can avoid network loss due to over length pipe networks. At the same time, it can have multiple outlets and reduce pipe diameter of the main networks, which can not only reduce the initial investment on pipelines, but also be beneficial for hydraulic balance adjustment and reduce the power consumption of the transmission and distribution system. It should be close to the main distribution room of the power supply area to avoid over length distribution wire and reduce investment.

5.7.2.3 Pipe Network Design and Network

Problem: what's the design point of different media network?

Guiding principle: the heating radius of steam pipeline is usually within 86km. it should calculate the pipe's pressure drop, temperature drop during design process. If the cooling supply network enters users directly, no refrigeration station is needed. The cooling radius is usually within 1.5km. Heat exchanger is needed for hot water pipelines before entering users, the heating radius is usually within around 10km. booster pump station can be set if the transmission distance is longer than 10km.

For heating networks, the main pipeline network should be one-stage completion according to final capacity. The branch pipeline or pipelines entering users should be designed based on actual building heat load. For domestic hot water supply networks, the average heat load should be introduced to the main pipeline design. If the storage tank capacity is sufficient, the branch pipeline design should adopt average heating load. If with storage tank capacity is not sufficient, the branch pipeline network should adopt maximum heating load to design. If the maximum heat load of users stacked, it should consider simultaneity usage coefficient. The allocation of pipeline should consider the location of heat source, the allocation characteristics of heat load and the characteristics of heat load density. The branch pipeline should go through heat load center.

5.7.2.4 System Matching and Equipment Selection

Problem: configuration principle for CCHP system within DES

Guiding principle: the economic efficiency of CCHP system relies on how to maximize power generation and waste heat recovery efficiency. So the equipment capacity should guarantee long time operation at full load and reach breakeven point for generation capacity and waste heat supply capacity. Moreover, we should make sure gross investment is under reasonable economic range and balance the economical and energy efficiency of the system.

Generally, the equipment capacity of generators and heat recovery equipment could burden the basic load of the whole system. For example, the installed capacity of CHP could account for 30% of the designed load, but the energy supply could account for 70% of the total energy supply. Moreover, the equipment configuration should be closely related with the characteristics of building loads and configure high level automatic system and realize optimization of adjustment function and maximize the benefits of equipment

When possible, it can use heat pump units to absorb heat from low temperature hot water and flue gas condensation water and then further use low temperature waste heat and increase heat utilization efficiency. Heating storage and cooling storage equipment can balance the cooling and heating load, reduce equipment capacity, and increase operation time with full loads.

The exhaust gas temperature of waste heat boiler and heat absorption cold (warm) water machine should not be higher than 120℃. It's better to install flue gas condenser for the heat recovery equipment.

When the waste heat from internal combustion engine cooling water is used for cooling, the outlet temperature of the heat recovery equipment should be less than 85℃. When the waste heat is used for heating supply, the temperature should be less than 65℃.

If the system cannot connect with public grid and the power load is relatively stable, isolated power grid can be adopted. Otherwise, or it must under grid-connected operation.

The waste heat recovery equipment should be determined by generator's waste heat parameters. flue gas with temperature higher than 120℃ and cooling water higher than 85℃ should be utilized.

As for the isolated system, users' electricity load should be monitored by the generator automatically.

For grid-connected system, the power plant shall be automatically synchronized with the public power grid.

Two or more power units should be used if the users request higher reliability on power supply.

5.7.2.5 Coordinated Management for Project Design

Problem: insufficient cooperation in project design management

Because contractors for development of building cooling and heating sources, pipelines networks, and users are different, there is no overall contractor for the whole project, so it's easy to cause issues regarding to benefit. The cooling and heating source is managed by power sectors, the pipeline networks are managed by heat supply unit and the users are managed by property companies or construction developers. It can cause unclear responsibilities among different operation and management departments. The contractor only has control for contracted design company while lack the ability to solve technical problems. The profession segmentation will result in different concerns. The current design standards are lack of definitely requirements of design interface management of project which is easy to cause the misfit of the construction period for heating/cooling source and heat supply network. Incorrect cooling and heating load will cause mismatch between supply network scale and cooling /heating source scale. The heating source for peak-shaving is difficult to put into practice. Water circulating pump selection is not reasonable and operation scheduling scheme is difficult to achieve. All of the above will affect the design quality. All in all, standardized management on project design should be improved.

Guiding principle: this issue can be managed by holding meetings, establishing formal interface documents or specifications and interface code file. Cooperation between design and purchasing on cooling/heating source and networks should be well managed. Meanwhile, design procedure should be specified

If adopting distributed energy system like CCHP, the design of the system has a certain complexity and lots of meticulous works are needed. It should pay attention to cooperate with the power sector or it will cause large deviation between goals and results.

5.7.3 Guidelines for Commissioning and Operation Management

Operation model (self-operation or entrusted operation) and energy-saving operation management should be identified. In order to improve energy saving operation management, professional trainings should be organized for operation and maintenance personnel.

5.7.3.1 Personnel Training

Problem: Training for operation personnel to increase operation quality

As district energy system is complex and involves in multi-discipline and multi-links it need personnel with different professions to cooperated management. The level of operation will play a significant role in operation efficiency and equipment maintenance and management. So strengthening the personnel training will be beneficial to increase the management level and generate actual energy-saving benefits.

5.7.3.2 Energy Saving Operation Management

Problem: Failure to achieve better energy conservation and environmental protection benefit due to underperforming operation

Guiding principle: appropriate operation plan should be developed. If multi-heating sources can be used within a region, it should conduct intelligent scheduling scheme, calculation the economy and running safety of different scheduling schemes, formulate energy-saving scheduling and emission reduction scheme and increase the economical, energy saving and environment protection benefits.

Problem: Operation procedures for gas-fired CCHP system

The system should formulate operating procedures, equipment safety operation procedures, equipment maintenance procedures which approved by manufacturer, and make an operation plan according to the designed operation mode.

It should timely adjust the operation mode according to gas price, electricity price and the regular pattern of users. The system should be switched on and off according to designed operation mode. The switching on and off procedure should be strictly implemented by the operating procedures and manufacturer's requirements. The power supply and distribution should have security measures for normal power supply when generator start-up and shut down.

Before system start-up, steam water system, oil system, flue gas system, gas system, electrical system, ventilation system and management system etc. should be inspected.

The system start-up should as per the following sequence: ventilation system, steam water system, natural gas system, generation system. The system shutdown should be carried out according to the reverse order, while the shutdown of steam water system and ventilation system should be delayed. If the gas equipment stop running for a long time, we should turn off the gas valve.

When the backup power generator stops running, the power supply for generator's starting device, lubricating oil waste heat device, ventilation equipment should not be stopped.

The main equipment should carry out regular inspection and maintenance according to the manufacturer's requirements. The generating units and absorption chilled (warm) water system should be inspected and maintained by the manufacturer.

The protection device of the main equipment, switch of the power distribution system and the automatic regulating valve need to be checked regularly. The inspection of gas concentration alarm system should be no less than once a year. All the measuring meters should be regularly checked in accordance with the requirements.

Problem: Guidelines for operation management of DES heating system

(1) When choosing gas, oil and electric boiler as heating sources, the area of every

(2) Heat / thermal station needs to configure the water treatment device (softening and deoxygenation) to ensure the water quality meeting the current national standard, the dissolved oxygen in water should be no more than 0.1mg/L.

(3) Boiler room, thermal station and building thermal entry should set up heat metering device.

(4) The thermal station should guarantee the proper functioning of heat metering, strictly clean on the pipe network and ancillary equipment, add or improve necessary filtering and decontamination device.

(5) For system with relatively high heat supply quality, it can also install automatic control device in the intake to customers, which can change the total resistance coefficient of the system, such as flow control valve etc. to ensure the constant flow of each customer and not be affected by the condition changes of other customers.

(6) The boiler room should carry out energy-saving operation, reduce flue gas loss, heat loss and that of water supply system, automatic control level of the boiler, increase the level of maintenance, operation and management.

(7) Make full use of various waste heat produced by boiler itself is an important measure to improve the boiler operation efficiency. The utilization of waste heat include: 1) heat recovery from fuel and furnace, 2) heat recovery from disposal sewerage, 3) heat recovery from flue gas.

(8) Heating technology application should fully consider the difference of time, region and temperature. In order to maximize energy saving, it should provide different load control strategy according to different type of users, make the heating supply and heat load of the system consistent, supply heat by time-sharing, zoning, temperature and demand.

(9) Hydraulic balance and adjustment technology: hydraulic imbalance and uneven cooling and heating can solved by hydraulic balance adjustment, and then it can make the actual flow and the designed flow consistent, and achieve the goal of energy saving.

(10) Heat metering and remote charging system: 1) installing heat metering and heat distribution meter to measure the heat is a reliable method. 2) Wireless remote reading can directly transfer the data to a central processor or other data management system through computers, or use data acquisition unit and GPS system to deliver the data to customer service system, and the data can be read online. Or we can connect heating metering and charging system with the gas boiler, to have comprehensive control and balance the flow temperature and the customer heating demand, which can realize an average energy saving rate of 7%-10%.

(11) Use climate compensator: equipment which installs in the location of heat source or heat station to automatically control the outlet water temperature. The equipment could be set according to the variation of outdoor temperature and room temperature as well as automatically adjust water temperature according to parameters of return water temperature to achieve the purpose of regulating the output.

(12) Adopt secondary pumps with variable frequency technology: when the heat source is a hot water boiler, the hot water system should meet the constant requirement for heat boiler circulating water and the variable flow network regulation requirements of the heat source to the heat exchanger. In order to fulfill the target, it can adopt secondary pumps system.

5.8 Conclusion

Attention needs to be paid to the flowing aspects when promoting district energy

(1) Economic efficiency is the vital competitiveness strength of district energy system, in which efficiency is core point and technology decides its performance.

(2) Make accurate prediction of power load, and ensure it matches with the design scale and demand of energy station, so as to avoid the phenomenon *big horse push*es *little car* which reduces the economic efficiency.

(3) Develop well integrated technologies through the comprehensive consideration on customer's orientation, characteristics, demands as well as local resource endowment, energy price, policy conditions etc. Figure out the most suitable technology through quantization method for

investment, energy efficiency, operation cost and cleanness etc.

(4) Manage the progress of investment and project construction based on the load growth regularity. Set up a step-by-step construct projects plan so as to avoid reckless investment and reduce investment risk.

(5) Based on intelligent energy efficiency platform, to build up optimized energy station and realize dynamic matching of demand and supply, and further reduce the operation cost.

The general principles in promotion and application of district energy system:

(1) Meet the requirements of users and comply with national and local design specifications and relevant regulations etc.

(2) To Ensure energy security supply is premise of district energy system

(3) Considering national and local energy policy and price, to make full use of energy saving and emission reduction policies.

(4) Adopt advanced, mature and reliable technology to carry out system design in order to meet the overall needs of the users.

(5) Use electricity, gas, oil etc. to ensure energy supply security and realize the cascade energy utilization.

(6) The district energy system should be used for high load density, high rate of volume, high full load hours and high energy consumption buildings or industrial park with stable load demand characteristics.

(7) Comparison should be made for selection of equipment and scheme according to the predicted load changes. The key factors during scheme selection mainly include annual operation cost saving, energy utilization efficiency, overall investment of systems, system reliability, supply ratio of cooling, heating and electricity, full load hours, equipment utilization rate, the performance of the equipment, system flexibility, equipment downtime hours, degree of dependence of the system on municipal conditions etc. We should consider not only technical and economic factors, but also factors like municipal condition, after sale service of the equipment etc.

(8) Choose high efficient, energy saving and environment protection equipment, optimize the system and increase the comprehensive efficiency of the system.

(9) Properly use distributed energy supply system, carry out multi-energy complementary application form of distributed energy supply system and general cooling and heating sources.

(10) Choose the suitable site as energy center to cut down the district cooling supply radius.

(11) Consider energy storage technology if conditions applicable.

(12) Adopt cooling, heating with large temperature difference to reduce the energy consumption of the transmission and distribution system.

(13) Promote the application of renewable energy in DES in suitable area.

(14) Optimize system configuration and control the investment scale while meeting the demand of the user.

(15) Pay full attention to the requirement of environment protection to reduce the effect on the environment of surroundings.

(16) Pay full attention to the secure protection of energy center and the work staff.

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Appendix 1 Case Study of DES Project in Selected Countries

Case 1 District Energy St. Paul, United States

1. Basic Information

Project Name	St Paul Biomass District Energy System
Location	Downtown St. Paul, United States
Power Generation	25 MW
Heating Capacity	289 MW
Cooling Capacity	N/A
Energy Source	Biomass(wood residue), gas, coal
Owner	Private ownership
Developer	COOEver-Green Energy, LLC
Designer	COOEver-Green Energy, LLC
O&M	Ever-Green Energy

Table 1 basic information of the system

2. Background

(1) Location, Climate and Geography

St. Paul is situated in the east-center of the state of Minnesota and in the northern area of the United States. It is the capital and second-most populous city of the state with a population of 294,873. According to the United States Census Bureau, the city has a total area of 56.18 square miles (145.51 km2), of which 51.98 square miles (134.63 km2) is land and 4.20 square miles (10.88 km2) is water.[2] The city lies mostly on the east bank of the Mississippi River in the area surrounding the point of confluence with the Minnesota River, and borders Minneapolis, the state's largest city. The confluence of the Mississippi and Minnesota Rivers, was carved into the region during the last ice age and formed the defining characteristics of the city.[1]

Saint Paul has a continental climate, with frigid snowy winter and hot humid summer. Because of the typical continental climate, the city suffers one of the greatest ranges of temperature on earth. As its northerly location and lack of large water body to moderate the air, the city is sometimes subjected to cold Arctic air masses, especially in late December, January, and February. The annual average temperature is 45.4 ℉ (7.4 ℃), the lowest average temperature in the continental U.S.

(2) Energy Demand and Supply

District Energy St. Paul Inc. (DESP) currently provides heating to 80 percent of St. Paul’s central business district and adjacent urban areas. The system uses a 65-MWth municipal wood waste combined heat and power plant with an electric capacity of 33 MW, two 44-MW low-sulphur coal-fired boilers, four 25-MW gas-fired boilers, four 106-MW gas and light oil fired boilers, with a total capacity of 106 MW and an emergency, portable 5-MW boiler, for a total capacity of 289 MW.

3. District Energy Plan and System Scheme

(1) Overall

District Energy St. Paul is recognized as a leader in community energy throughout the United States, by providing unparalleled benefits to the customers, the community and the environment. Buildings on the District Energy St. Paul system can get the advantage of reliable service, world-level customer service, and competitive and stable energy rates. District Energy St. Paul provides a superior alternative to on-site gas boilers, by providing highly efficient hot water service to almost 200 buildings, totaling over 31 million square feet of building area.[3]

(2) System Configuration

District heating systems produce hot water, steam, or chilled water at a central plant and then distribute the energy through underground pipes to buildings connected to the system. The system circulates a volume of one million gallons of water per hour, with a supply temperature of 250 ℉ in the winter and 190 ℉ in the off-season. Each district energy customer has its own heat exchanger and control valve, allowing for the thermal energy transferred from the district hot water system to a customer's in-building closed heating loop. The cold water left after the heat exchange returns to the main plant to be reheated and circulated back to customer buildings. Electric centrifugal chillers are used in combination with a hot water absorption chiller to produce the chilled water for the District Cooling system.

The system's reliability has exceeded 99.99 % since service began. The district heating system provides space heat, domestic hot water for restaurants, hotels, laundry and dishwashing facilities, as well as heat for snow melt systems. Once used in customer buildings, the water is returned to the central plant for reheating and then recirculated through the closed-loop piping system.[5]

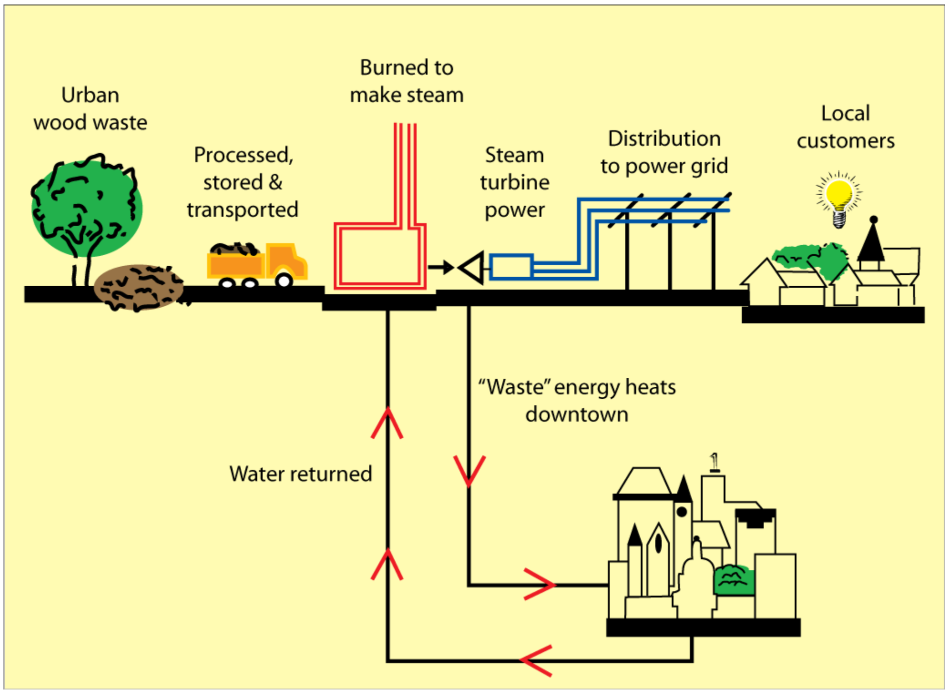

Figure 1 the Configuration of the system (Source: IDEA, 2009)[7]

(3) Timeline of the system

1978	Feasibility study commissioned by the U.S. Department of Energy and the Minnesota Energy Agency.
1979	District Heating Development Company incorporated.
1982	Feasibility studies and marketing complete; financing arranged.
1983	First customers receive service.
1986	Nearby industrial park receives service.
1987	Name changed to District Energy St. Paul Inc. with over 400 customers.
1993	Expands system to include cooling services.
1994	Chilled water storage introduced.
2003	Largest municipal biomass-fueled combined heat and power system becomes operational.
2006	Expansion of the chilled water system.

Table 2 Timeline of the system [6]

4. Environmental and Economic Benefits

(1) General

• The System provides heating to 185 buildings (80 percent of the downtown market); cooling to 95 buildings (60 percent of the downtown market); and 300 single-family homes, and in total, 75 percent of annual energy needs is met by the clean fuel source of the CHP plant.

• Plants are designed without interrupting the historic urban community.

(2) Environmental

• CHP plant uses half of the 600,000 tonnes of wood waste generated in the metro area of St. Paul, which help to decreases the waste and conserves previous resources.

• CHP plant will reduce sulphur-dioxide emissions (SO2) by 60 percent and carbon dioxide emissions (CO2) by 280,000 tons per year comparing to using traditional fossil fuels.

• This system has eliminated the demand for 150 smoke stacks, 50 cooling towers, and 300 chimneys. And the cooling system reduces reliance on chlorofluorocarbon refrigerants (CFCs).

• Closed loop cooling system does not use ground water which avoid ground water contamination.

(3) Economic

• There are a total savings of $7 million for customers in 2005, compared to customers who use natural gas with in-building heating and cooling systems.

• Charges for energy use (includes the energy rate and demand rate charge by DESP) have increased only 0.3 percent on an annual base over a 23-year period, compared to an annual increase of 2.7 percent for natural gas users.[6]

5. Operation and Maintenance Management

Customer buildings on the DESP system gain the advantage of reliable services, world class customer services, and competitive and stable energy rates. The system has offered energy rates below the rate of inflation for the past three decades. The system also saves the customers on capital costs and on-going maintenance and the savings can be invested into buildings and the business itself. Since its plan, District Energy St. Paul has placed a high value on environmental stewardship and paid attention to continual increases in operational efficiency and advanced technology integration. The Ever-Green Energy team working at the plant and on the distribution system makes calculated improvements to optimize the efficiency of the system. This technology integration has taken many forms from the addition of cooling through District Cooling St. Paul to the start-up of the biomass fired combined heat and power plant to the most recent integration of solar thermal capabilities.[3]

With the use of chilled-water storage, as well as advanced maintenance and operational techniques, District Cooling has been able to reduce its customers' collective peak electric demand by as much as 9,000 kilowatts. Additional system improvements, including the operation of a second chilled-water storage tank, significantly increase supply and reduce the ratio between supply and demand. Those economics result in stable rates, with increases averaging just 1.8 percent since service began. [5]

6. Lesson Learned

The customers' recognition of the system can be achieved with a considerate planning and attractive contract

When the project was launched, the investment risk for the scheme was transferred to customers through a long-term agreement. A 30-year contract needed being signed by customers to help underwrite the project. It is not surprising that it is hard to popularize the contract, with only 8 customers totaling 14 MW signing the contracts under the context that natural gas prices were growing rapidly and the old steam-based system was unreliable. Accordingly, the DESP worked closely with the St. Paul Building Owners and Management Association (BOMA) to create a more attractive contract and the results went well. Within a year, customers representing the necessary 135 MW in demand make the project feasible.

A turnkey or package service can contribute to persuade the customers.

For DESP, the cost for converting the existing heating systems can be a great challenge for customers, especially those have their own steam systems. According to this, in the early 1980s, the District Heating Development Company launched an Energy Reinvestment Fund to help offset conversion costs for non-profit building owners. And this continues to work well today.

Early planning, community engagement, public participation and addressing problems as soon as possible can help to facilitate the development process.

In 2003, DESP developed four major infrastructure projects in addition to completing the CHP plant. In order to minimize the interruption to the public, DESP take close incorporation with its affiliate organizations, local officials, building owners and other stakeholders.

Monitor after operation is really important for the maintenance of the system and to increase the competitive power.

DESP can offer cost savings and improve energy efficiency in buildings. The full range of thermal and monitoring services DESP provide can help plant operators compete with local utilities. Developing a range of services can take time and should be part of a long-term growth strategy. Monitoring could tackle problems once they occurred.

Urban areas can be a catalyst for local economic and sustainable development.

With the development of the CHP facilities, innovations were made to ensure the effective operation of the plant – including more than 50 trucks a day bringing the biomass needed to fuel the plant. Solutions included special hoppers that allow two trucks to discharge simultaneously. In St. Paul, most downtown buildings have chosen to link to the DESP. Local developers in St. Paul regard the DESP as an attractive component of marketing affordable commercial and housing development.[6]

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Case 2 Stanford Ice Storage System in United States

1. Basic Information

Project Name	Stanford Ice Storage
Location	Stanford, California
Power Generation	N/A
Heating Capacity	N/A
Cooling Capacity	120,000 Ton-hour
Energy Source	Electricity
Owner	Private ownership
Developer	N/A
Designer	BRYAN power generation
O&M	BRYAN power generatio

Table 1 basic information of the system (Source: BRYAN power generation)[1]

2. Background

(1) Location, Climate and Geography

The Stanford is a census-designated place (CDP) in Santa Clara County, California, United States and is the home to Stanford University. It is an unincorporated area of Santa Clara County and borders the city of Palo Alto.[9] It is located at 37°25′21″N, 122°9′55″W (37.422590, -122.165413) and has a Mediterranean climate (Köppen), with warm summer.[2] The warmest month of the year is July with an average maximum temperature of 78.80 °F, while the coldest month of the year is December with an average minimum temperature of 39.20 °F. Temperature variations during a day tend to be moderate during summer with a difference that can reach 22 °F, and limited during winter days with an average difference of 18 °F. [3]

(2) Energy Demand and Supply

Five 2500 ton electric rotary screw chillers and 120,000 ton hours of ice storage coils were placed in a four-million gallon tank under the Jordan Quad parking lot. Each chiller owns a 2,250 H.P. motor operating at 12,000 volts and uses 3,400 pounds of environmentally friendly anhydrous ammonia as a refrigerant.

Currently, Stanford's average peak electrical demand is 30 megawatts, the equivalent demand of nearly 15,000 single-family homes. The ice storage technology could save Stanford approximately 8 megawatts of peak electrical demand and 6 megawatts of average summer daytime load comparing to a conventional cooling system. The stored cooling could enable 120,000 window air conditioners to operate for 1 hour or provide enough cooling for approximately 2,000 single-family homes on a hot summer day, or 10,000,000 pounds of ice, or 60,000,000 ice cubes.[4]

3. District Energy Plan and System Scheme

(1) Overall

For the Stanford University, the Ice Storage is a significant part of a comprehensive strategy to meet campus chilled water demand. The Ice Plant was constructed in 1999 and provides additional cooling capacity to meet Stanford's summer cooling loads without operating electric chillers during peak loads periods.[4] It could reduce 10 MW of the peak electric demand compared to the level that a conventional chilled water plant could be. Moreover, the temperature of supplied water can be reduced during high demand periods, which enhances the distribution capacity. [5]

(2) System Configuration

The ice is collected on one-inch steel tubing which extended 360 miles. The stacks of tubing are located in a four-million-gallon, 25-foot-deep tank five feet below the Jordan Quad parking lot. The Ice Plant can store 120,000 tons of refrigeration, which equals to 160,000,000 ice cubes. The Stanford's usual peak summer demand is 24,000 tons per hour, or the amount of energy covered 10,000 single-family homes cooling loads.[6]

For the internal melt system, the ice produced around the coils by passing cold glycol inside the tubes during off-peak hours and circulating warm glycol in the tubes could melt ice during peak load. The ice is melted from inward out. In external melt systems, the ice produced around the coils by passing cold refrigerant directly inside the tubes and circulating warm water directly to the tank melts the ice around the tubes. The ice is melted from outward in.[5]

Cooling energy is transferred with a 25% ethylene glycol / water mixture much like the antifreeze used in automobiles. 200,000 gallons are required to fill the system. The Ice Plant is 100% computer controlled and operated remotely. The plant is checked up once every eight hours.[5]

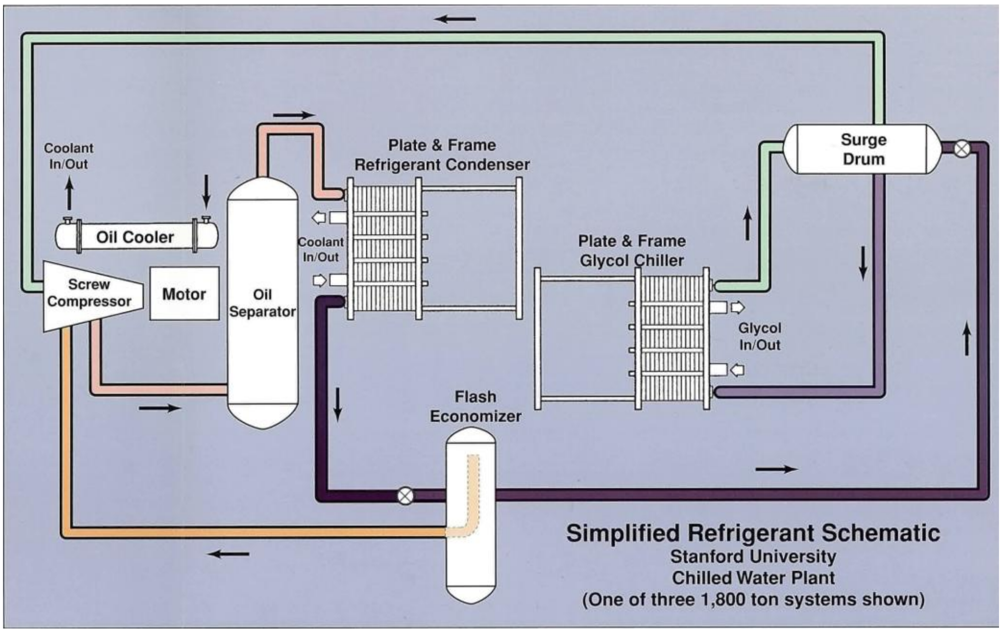

Figure 2 the Configuration of the system [5]

4. Environmental and Economic Benefits

(1) General

• This system provides cooling to the university and adopts ice storage technology to conserve ice during off-peak periods in order to supply cooling to the customers during peak hours.

• Reduce strain on electricity infrastructure and electricity loads.

Provide the residents and staffs of the university with a reliable and costless cooling.

(2) Environmental

• Ammonia is a widely used, environmentally (non-CFC and non-ozone depleting) friendly and cheap refrigerant, so it has a little impact to the environment.

• Once ammonia leaks, it's easily to be detected by one's nose well below acceptable exposure limits. So it's safe to use it.

• It is as safe as the conventional chillers once the operator became comfortable with the system.

• Such ice storage system could reduce the pressure on electricity supply during peak hours and save 8 megawatts of peak electrical demand and 6 megawatts of average summer daytime load

(3) Economic

• Simple CW efficiency drops to 0.62 kW/ton due to screw compressors and multiple heat exchanges

• Ice Build efficiency drops as low as 0.8 kW/ton during final ice build

5. Lesson Learned

The cooling storage system can be well used in a large scale of regions like university campuses or building mixes, which can largely reduce the pressure on electricity infrastructure during the peak hours and save the electricity cost. Also, such systems can be placed underground which will not occupy too much valuable space of the buildings. In addition, such system uses ammonia, which is cleaner and environment-friendly comparing to the conventional air conditioners that use CFCs.

Reference

[1] http://bryan-power.com/inventory/stanford-cef/ice-plant.html, last accessed 2014.11.6

[2] http://en.wikipedia.org/wiki/Stanford,_California, last accessed 2014.11.6

[3] http://www.idcide.com/weather/ca/stanford.htm, last accessed 2014.11.6

[4] http://lbre.stanford.edu/sem/ice, last accessed 2014.11.6

[5] Ice Storage Shifts10 MW off peak demand, Mike Goff Director of Utilities Stanford University, 2009

[6] https://alumni.stanford.edu/get/page/magazine/article/?article_id=32125, last accessed 2014.11.7

Case 3 Deep Lake Water Cooling System (DLWC), Toronto, Canada

1. Basic Information

Project Name	Deep Lake Water Cooling System (DLWC)
Location	Toronto, Canada
Power Generation	11 MW
Heating Capacity	N/A
Cooling Capacity	75,00 tons
Energy Source	deep lake cold water (4℃)
Owner	Public ownership
Developer	Enwave
Designer	Enwave
O&M	Enwave

Table 1 basic information of the system

2. Background

(1) Location, Climate and Geography

Toronto city is located at 43°37'N, 79°23'W, in Southern Ontario of Canada on the northwestern shore of Lake Ontario. It is intersected by three rivers and numerous tributaries: the Humber River in the west end and the Don River at the opposite ends of the Toronto Harbor, and the Rouge River at the city's eastern boundary. The harbor was originally created by sediment from lake currents that shaped the Toronto Islands. There are a number of creeks and rivers cutting from north toward the lake creating large tracts of densely forested ravines, and play an important role in the city's grid plan. [1]

Toronto has a humid continental climate, with four distinct seasons, including warm, humid summers and cold winters. The temperature from day to day varies greatly, particularly during the cold weather seasons. Because of urbanization and its proximity to water, Toronto has a fairly low diurnal temperature variation. Toronto winters sometimes feature cold weather where the temperatures for most days remain below −10 °C (14 °F), which often made to feel colder by wind chill while the summer months features a long stretches of humid weather with a temperature range from 23 to 31 ℃ (73 to 88 ℉). Spring and autumn are transitional seasons with generally mild or cool temperatures and alternating dry and wet periods. [1]

(2) Energy Demand and Supply

The cooling loads for buildings rely on a number of factors, including weather and occupancy etc.. Cooling Degree Days (CDDs), are one such indicator, representing the relative portion of each day spent above a certain outdoor temperature. CDD65 (65 ℉, 18 ℃) of Toronto in 2012 is 394 hours. [2]

The system is designed provide cooling to air conditioning of nearly 3.2 million m^2 of office space, substituting in-building electrically driven chillers. The systems can offer 75,000 tons of connected refrigeration demand. [5]

3. District Energy Plan and System Scheme

(1) Overall

The Deep Lake Water Cooling system is the largest lake-source cooling system around the world.[4] It came into operation in July 2004 and helps keep downtown Toronto buildings cool all the year around as well as enhances the supply of potable water with a clean water source, which contributes to reducing electrical demand and consumption, increasing employment opportunities, and helping businesses and Toronto residents reduce greenhouse gas emissions and improve outdoor air quality.[5]

Enwave, a registered Ontario Business Corporation and the designer and operator of the cooling system, is the largest provider of renewable resource based district cooling in North America. It has two share-holders − the City of Toronto and Ontario Municipal Employees Retirement System (OMERS) − each have a 43% and 57% share of the corporation respectively. The DLWC system is operated by Enwave while the director was appointed by the share-holders.[5]

(2) System Configuration

The system uses the deep lake thermal energy which is solar energy absorbed and stored as heat in the upper layer of the ocean to the customer buildings. It placed three high-density polyethylene (HDPE) intake pipes into Lake Ontario, reaching 5km and bringing cold water (4℃) from 83m below the lake surface to the Toronto’s water filtration plant. The pipes are fixed on the bottom of Lake Ontario by concrete collars. Although they are close to the beachline, they are buried in the beach sand to prevent impact from wind and wave action and ships.

The coldness of the lake water is exchanged through 18 pairs of stainless steel heat exchangers (with over 800 sandwiched plates per heat exchanger) to Enwave’s closed-loop chilled water supply distribution network. The water enters the system at 4℃ and returns at the temperature of no more than 13℃. The returning water is cooled using the deep chilled water from the lake and then by centrifugal polishing chillers to around 3℃. Once it has gone through the heat exchanger, the water drawn from the lake (which is now not more than 13°C) enters the City’s potable water supply system. [5]

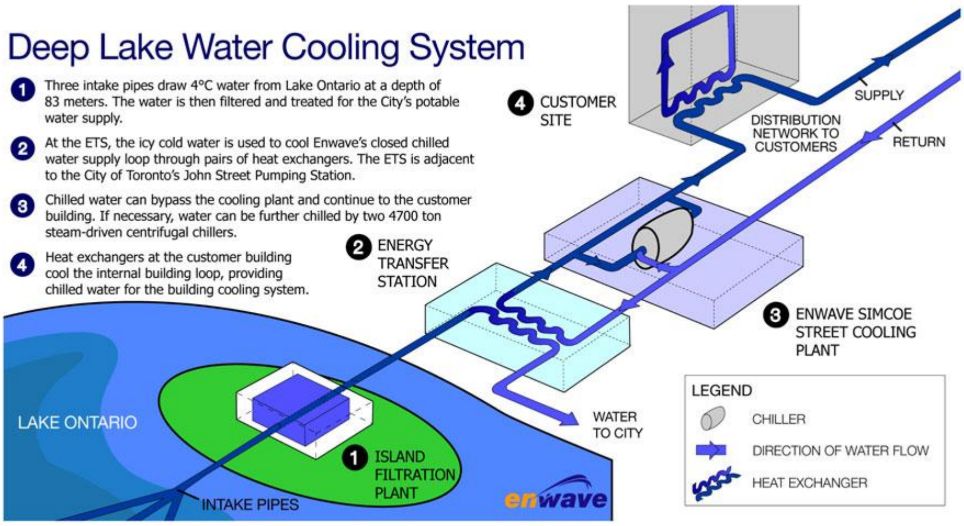

Figure 1 the Configuration of the system [5]

Cold-energy transfer loop dependents on a natural cool energy source, which is extracted using stainless steel heat exchangers. Two 4700-tonne steam driven centrifugal chillers provide additional cooling capacity to increase distribution system capacity.

3) Energy users

The first customers for DLWC system were the Air Canada Centre and the Metro Toronto Convention Centre. The first office complexes were the Oxford Buildings at One University Avenue and the Royal Bank Plaza which came on line in July 2004. The City of Toronto's Metro Hall was the first municipal building to be retrofitted with this system. Apart from this, there are a number of building mixes connected to this system.[4]

4) Timeline of the system

1997	Environmental assessment commences for DLWC; Toronto District Heating Corporation begins financial restructuring.
1998	Environmental assessment completed for DLWC.
1999	Toronto District Housing Corporation becomes Enwave (private corporation co-owned by the City of Toronto and the Borealis Penco Fund, now the Ontario Municipal Employees Retirement System).
2000	Phase II of emerging studies for DLWC begins.
2002	Construction starts.
2003	Intakes placed out in the lake; additional equipment including switch gear, control systems, heat transfers, and pumps constructed.
2004	Enwave begins supplying customers with DLWC.
2007	Growing customer base with nearly 50 buildings signed on and 30 connected (estimated system capacity – 100 office buildings).

Table 2 Timeline of the system

4. Environmental and Economic Benefits

(1) General

• The system provides air-conditioning to a mixes of building types, including residential, commercial, retail, institutional, and government buildings, and major sports facilities.

• A sustainable, clean, and renewable price-competitive service is provided.

• It extends municipal infrastructure and reduces strain on electricity supply and infrastructure, including the transmission grid.

• Provides cleaner and cooler potable water to the residents of Toronto

(2) Environmental

• The system reduces electricity usage by 90 percent compared to a conventional cooling system.

• It sets free up more than 61 MW of electricity for Ontario's and Toronto's electrical grids.

• It reduces approximately 79,000 tonnes of carbon dioxide emitting to the air annually (based on the displacement of coal and at full system build out) - equivalent to taking 15,800 cars off the road.

• Using the lake water thermal energy saves the electricity generation of over 1880 litres per second of lake water cooling demand

• Reduced nitrogen oxide and sulphur dioxide by 145 tonnes and 318 tonnes respectively compared to using the coal-fired electricity.

• Release space for commercial offices and other uses and save about 714 million litres of fresh potable drinking water.

• Buildings which use DLWC can decommission older electrically driven refrigeration systems that contain CFCs and HCFCs.

(3) Economic

• The system uses a renewable energy source which could reduce the potential for rate increases and is free of impact from volatile energy markets and reduce the energy cost for customers.

• Estimated to generate 1,000 person-years of local labor in construction.[5]

5. Operation and Maintenance Management

The system uses 85 million kilowatt-hours per year which is less than traditional cooling systems or roughly equivalent to the amount of power required to supply 6800 homes a year. Moreover, an additional 700 million litres per year water consumption is saved compared to conventional systems. The estimated reduction in GHG emissions (carbon dioxide) is 79000 tonnes a year, which is equal to the emissions by 15800 cars. This estimate is based on displacing coal-fired electricity.

6. Lesson Learned

A life-cycle cost approach to a customer's needs can promote the recognition and evelopment of district energy.

In order to persuade the customers and address the customers' concern, the Enwave developed a sound business case which offered a detailed financial plan over the entire life of the project. The plan indicated that the energy price will be level-off without affecting by the price hikes from electricity and gas. And the maintenance cost will be lower. Also, patient is important when persuading customers as a long-term contract is really challenging.

Lack of technical understanding of new products may increase the difficult to persuade the regulatory authorities, customers and decision makers.

Before a scheme is launched, a detailed plan is significant to persuade the authorities, customers, decision makers and so on. For this system, the Enwave need to convince provincial regulators that the water exacted from the later could be exempted from fees which were charged for industrial uses. And later, the Enwave offered sufficient financial and environmental savings to successfully persuade the regulators. So it is really important to make detailed and considerate plan before systems operation.

Overlooking details can have a cumulative impact on the project. A well-planned scheme should be created after continual development and experience.

Although the company has paid attention as much as they can to details, they still suffered problems. For example, the initial length of intakes is 2.7 km, but after monitoring, Enwave found that with such length, the water temperature will be influence by the shoreline effects. So they extended the length to 5.0km.

Successful project timing starts with a long-range scan of the market place for both potential customers and access to required labor.

Across Canada, large-scale infrastructure projects are creating local shortages for experienced labor, particularly pipefitters, welders, and project managers. At the same time, the cost of product materials is also increasing. Careful consideration should be given to the expected start date of a project and associated increases in material costs, as well as and access to skilled labour, not only for construction, but also for the operation and maintenance of a plant. [5]

Reference

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[2] http://www.degreedays.net/, last accessed 2014.11.3

[3] Energy Efficiency and Beyond Toronto’s Sustainable Energy Plan Staff Background Report, Energy Efficiency Office, Business & Strategic Innovation, Facilities & Real Estate Division, June 2007

[4] http://www.enwave.com/district_cooling_system.html, last accessed 2014.11.4

[5] ENWAVE: DEEP LAKE WATER COOLING: Keeping Toronto cool

Case 4 Markham District Energy System in Canada

1. Basic Information

Project Name	Markham District Energy
Location	Markham Town, Canada
Power Generation	3.5 MW
Heating Capacity	12 MW
Cooling Capacity	4600 tons (two 1100 tons and three 700 tons electrically driven centrifugal chillers and one 300 tons hot water absorption chiller)
Energy Source	Oil, natural gas & Solar energy
Owner	Public ownership
Developer	N/A
Designer	Markham District Energy
O&M	Markham District Energy

Table 1 basic information of the system

2. Background

(1) Location, Climate and Geography

Markham, a city in the Regional Municipality of York, lies in Southern Ontario, Canada.[1] The city is the fourth-largest community within the Greater Toronto Area after Toronto, Mississauga and Brampton. Markham owns an area of 212.47 km2 (82.04 sq mi) and its City Centre is at 43°53'N, 79°15'W. It has an average altitude of 200 m (660 ft) and in general it constitutes of gently rolling hills. The city is cut by two rivers: the Don River and Rouge River, as well as their tributaries.

It borders and shares the same climate with Toronto. On an average day, Markham is generally 1 ℃ (1.8 ℉) cooler than in downtown Toronto. For months, the monthly average temperature can get as low as -5.8℃ in January and from December to March, the daily average temperature is below 0℃.[2]

(2) Energy Demand and Supply

The Markham District Energy currently provides heating and cooling to more than 184,500 m^2 of building mixes, including commercial, institutional, residential and public facilities in Markham Centre. The combined heat and power system (CHP) includes three high-efficiency natural gas-fired boilers with a total capacity of 12.0 MWt and cooling capacity of 4600 tonnes which comprises two 1100 tonnes and three 700 tonnes electrically driven centrifugal chillers and one 300 tonnes hot water absorption chiller. The system can also produce 3.5 MW of electrical power during peak electricity periods, which is sold directly to the grid.[4]

3. District Energy Plan and System Scheme

(1) Overall

The Markham District Energy is launched in 1999 and owned and operated by the Town of

Markham. It is to develop a world-level community based on district energy system that is to encourage local economic development and demonstrate environmental leadership. The first production of energy in Markham Centre was on December 1, 2000, providing a critical IBM software laboratory with chilled water. The system can be isolated from the electricity grid to provide standby power for essential city services and to other customer buildings.[4]

(2) System Configuration

The natural gas fuelled reciprocating engine is operated to generate electricity. And then the exhaust and jacket heat is captured and utilized to produce 3.0 MWt of additional thermal capacity, which is distributed to the district heating network, instead of using the natural gas boilers. The electrical capacity of the plant is under expansion and an additional 5 MW of power will be available to provide a total electricity production of 8.5 MW, and 8.2 MW of thermal energy.

The individual buildings linked to the district heating and cooling loop do not need any on-site hot water boilers or air-conditioning chillers. In their place, each district energy customer has its own heat exchanger, allowing for the transfer of thermal energy from the district heating and cooling water systems to the customer's in-building heating and cooling loops.

Figure1 the first of four Markham Centre energy plants [4]

(3) Energy users

The system serves a number of users, e.g. IBM Laboratory, Motorola Canada Head Office, Honeywell Canada Head Office, Markham's Civic Centre, High school for elite athletics etc.

(4) Timeline of the system

1992	Markham Centre planning begins.
1997	Secondary plan for Markham Centre approved.
1999	MDE established as an a wholly owned subsidiary of Markham Enterprises.
2000	First anchor tenant confirmed; construction of plant begins.
2001	Plant is operational.
2004	Received $5.5 million grant from Federation of Canadian Municipalities to help advance the development of the district energy system.
2007	Awarded electricity generation contract from Ontario Power Authority to add 5 MW of electricity production; second of four plants commences construction.

Table 1 Timeline of the system [4]

4. Environmental and Economic Benefits

(1) General

• MDE so far serves or has signed long term contracts with all new buildings planned to date in the Markham Centre, including two community and school buildings, six commercial buildings, fourteen residential high-rise buildings, and 175 town-homes. And estimated 90 percentage of developed square footage of Markham Center is connected to MDE.

• A complete thermal services package has been provided to commercial and residential customers. And the system is designed to grow with demand.

(2) Environmental

• The fully built-out system will acquire an annual reduction of 99,236 tonnes of CO_2 emissions (50 percent of business-as-usual emissions) and 198 tonnes or 78 percent of nitrogen oxide emissions.

(3) Economic

• MDE contributes to local economic development by attracting high-tech companies and residential developers.

• A competitive and stable long-term price is provided.

• Reduces maintenance costs and increases sellable space for customers by eliminating the need for in-building heating and cooling systems.

5. Operation and Maintenance Management

The system operates well after installation and stabilizes the energy supply of Markham. During 2003, a blackout swept the eastern seaboard of North America, resulting in nearly 10 million people in Ontario without electricity, while the Markham District Energy continued to function. Markham's investment in a cogeneration facility allowed the Town to continue providing heating and cooling to high-tech companies, such as IBM and Motorola. MDE puts customer service first, and has achieved a 100% percent reliability rate on the supply of heating and cooling since the system commenced operations in December 2000.

6. Lesson Learned

It is important to choose the right location which can save not only costs, but time.

By placing the plant on lands belonging to the Municipality, the Town avoided the process of passing an official plan amendment. Even though the siting process still required site plan and building approvals, and noise and emissions dispersion modeling, delays resulting from rezoning applications were avoided.

Operating as a private business with municipal oversight has financial and management advantages. As a private company, MDE can get tax advantages available to the private sector for the construction and operation of plants. In addition, as a wholly owned municipal entity, MDE can leverage sources of capital provided only to Canadian municipalities, such as the Green Municipal Fund.

Rating systems boost the development of district energy market.

The system was certified by Canada’s EcoLogo system, which recognizes technologies that improve buildings’ energy efficiency. Moreover, the system can also apply for rating systems like Commercial Building Improvement Program (CBIP) and the Canada Green Building Rating system which can be marketed to potential businesses and customers.

Experience plays a significant role in planning and makes it easier to forecast future demand.

For MDE, the initial design of phase I focused on meeting the heating and cooling demand of high0tech companies and Motorola and IBM were attracted to Markham Centre by the heating ability of MDE as well as keep server rooms cool. Such experience helped MDE acquire a good reputation as a reliable and cost effective alternative to running and maintaining in-building electric chillers. This is paramount in high-tech industries where technological improvements have decreased the heat produced by electronic equipment, but increases in the use of such equipment. As the electricity cost has been going up and cooling loads continue to rise, developers and owners are looking for strategies to defer capital, control costs, and provide reliable solutions. [4]

Reference

[1] Statistics Canada: 2012

[2] http://en.wikipedia.org/wiki/Markham,_Ontario, last accessed 2014.11.4

[3] The New District Energy: Building Blocks for Sustainable Community Development, On-Line Handbook, January 2008

[4] MARKHAM DISTRICT ENERGY: Putting the Urban in Suburban

Case 5 DHC system for the Shinjuku Area, Tokyo, Japan

1. Basic Information

Project Name	DHC system for the Shinjuku Area
Location	Shinjuku Area, Tokyo，Japan
Power Generation	390MW
Heating Capacity	1.76×10^8 kWh
Cooling Capacity	2.92×10^8 kWh/a
Energy Source	Natural gas
Owner	Tokyo Gas
Developer	Tokyo Gas
Designer	Tokyo Gas
O&M	Tokyo Gas

Table 1 basic information of the system

2. Background

(1) Location, Climate and Geography

This project located in Tokyo where lie in the humid subtropical climate zone with hot humid summers and generally mild winters with cool spells. The region, like much of Japan, experiences a one-month seasonal lag, with the warmest month being August, which averages 27.5 ℃ (81.5 ℉), and the coolest month being January, averaging 6.0 ℃ (42.8 ℉). The record low temperature is −9.2 °C (15.4 °F), and the record high is 39.5 °C (103.1 °F). Annual rainfall averages nearly 1,530 millimetres (60.2 in), with a wetter summer and a drier winter. Snowfall is sporadic, but does occur almost annually. [1]

(2) General Introduction

As a new city center, Shinjuku Tokyo area of Japan consists of high rise buildings with complete planning (mainly in west Shinjuku area). In order to improve the urban environment and save the energy, coal-fired district heating and cooling has been used in early 1970s and later in early 1990s, this area has been expanded to be with advance technology and large scale district cooling and heating projects.

The Shinjuku Shintoshin area started gas-fired district heating and cooling in 1972 and has been operated for nearly 20 years. Later in January, 1988, additional projects began to be installed because of higher energy demand due to the construction of the Tokyo metropolitan government office building (approximately 381,000 m2). This project completed in the end of February, 1990 and began to provide heating and cooling in January, 1991. The cooling capacity of this project is 210,000kW, which is the biggest centralized cooling supply device in the world.

The DHC in Shinjuku is new constructed and some of the devices are shift constructed. The primary machine room is closed next to Park Tower, and is located underground with four stories and a total area of 12927 m2. The electrical control room locates in basement 1, the boiler and gas turbine chamber is in basement 2, the centrifugal chiller room settles in basement 3 while absorption refrigerating machine and pump situates in basement 4. For the aboveground part is the exhibition hall of Tokyo gas company. The cooling tower is cross flow of two layers which is settles in the roof.

3. The system overview [2]

The length of distributed pipes is 8000m and the diameter of the freezing water pipe ranges from 150mm to 1500mm. The diameter of steam pipes is 100-600mm and that of condensate pipes is 50-300mm. It is supplied by four pipes with the supplying water temperature of 4℃(3.5-4.5℃) and returning water temperature of 12 ℃ (10-14 ℃). The vapor pressures are 650-860 kPa.

In order to increase the heat efficiency, after comprehensively considering the effect of energy saving and analyzing heat and electricity load curves, two most suitable sets are selected, one for concentrated cooling supply, the other one is used for Park Tower (each with a capacity of 4000 kW). In order to use the surplus heat from the CHP and consider the steam balance, the DHC adopts the recovery steam of 4 MPa while for the Park Tower; it uses 1 MPa steam as the heat resource.

In order to increase the annual running efficiency of refrigerator, the systems used under base load and peak load should be identified definitively. The high efficiency system combined gas turbine with CHP is used under base load. While for the peak load period, two 25kW gas turbines or centrifugal refrigeration machine from the existing machine room should be added for operation.

The sets of turbine driven centrifugal chiller include: 3×35MW(3×10000rt),3×25MW(3×7000rt), 1×14MW(1×4000rt), 1×7MW(1×2000rt).The absorption refrigerator includes: 2×3.5MW (2×1000rt), all of which provide cooling. The cogeneration gas turbine (2×4MW) provides steam. The water tube boiler accounts to a total of 210 ton/hour.

4. Environmental and Economic Benefits

This project uses gas as the primary energy and adopts steam-driven centrifugal chiller instead of general absorption refrigerator because the former has higher energy efficiency. In this project, the electricity generated by the cogeneration units is not supplied to customers, instead it is used to the distribution system and another two thirds of the electricity demand should be offset from the net grids.

Based on the average overall power generation efficiency of 38% and calorific value of natural gas of 10kWh/m^3, the gas and electricity consumed by this project can be calculated by primary energy of 4.4×108 kWh/a and 0.86×108 kWh/a respectively. Thus, the primary energy efficiency can reach 0.84, which is equal to an electricity efficiency of 2.21. As the heat supply is achieved by steam, instead of heat-exchanger pump, so the electricity consumed by water pump is only used for cooling supply. Supposed that the thermal efficiency of gas-fired boiler is 90%, it will consume a calorific value of the combustible gas7.96×108 kWh to generate 1.76×108 kWh thermal energy, the extra 3.3×108 kWh is the sole energy consumption for cooling by primary energy. So it can be achieved that the primary energy efficiency for cooling of this project if 0.81, which is equal to an electricity efficiency of 2.13. [2]

Reference

[1] http://en.wikipedia.org/wiki/Tokyo, last accessed 2014.11.25

[2] Fan Cunyang, DHC system for the Shinjuku Area in Tokyo, Journal of HV&AC, 1995.5, page 52-55.

Case 6 Tokyo Sky Tree Project, Tokyo, Japan

1. Basic Information

Project Name	Tokyo Sky Tree Project
Location	Tokyo, Japan
Power Generation	0
Heating Capacity	1200RT
Cooling Capacity	8400MJ/h
Energy Source	Nature gas
Owner	Tobu Railway
Developer	Tobu Energy Support Co., Ltd.
Designer	Nikken Design Research Institute
O&M	Tobu Energy Support Co., Ltd.

Table 1 basic information of the system

2. Background

(1) Location, Climate and Geography

Figure1 Picture of Tokyo Sky Tree Project [2]

This project located in Tokyo where lie in the humid subtropical climate zone with hot humid summers and generally mild winters with cool spells. The region, like much of Japan, experiences a one-month seasonal lag, with the warmest month being August, which averages 27.5 ℃ (81.5 ℉), and the coolest month being January, averaging 6.0 ℃ (42.8 ℉). The record low temperature is −9.2 ℃ (15.4 ℉), and the record high is 39.5 ℃ (103.1 ℉). Annual rainfall averages nearly 1,530 millimetres (60.2 in), with a wetter summer and a drier winter. Snowfall is sporadic, but does occur almost annually. [1]

(2) General Information

The initial investment for the sky tree heating device is approximately 4 billion yen and through the grants the government offers, the expected payback period is about more than ten years. The project adopts geothermal pump with storage devices and the machine is only commissioned during the night and shut down in weekends, which can recover the underground temperature rise to the original state at the beginning of the new week. This operation mode is determined after researches on the changes of underground temperature. The administration section monitored the actual temperature to avoid the drop of energy efficiency. The sky tree project is easy to control the operation because of the heat storage tank.

At the beginning of the construction, except of shallow geothermal energy, the design team also explores the heat energy from the river. But if rivers are used as heat source, some problems like lack of water and long distance etc. are existed, so such thought wasn't realized. While with relatively small restricts, projects using the shallow geothermal energy have experienced an increasing trend.

3. The system overview [3]

(1) Cold and heat sources and energy storage system

This project adopts geothermal pump and according to measures and estimates, the underground temperature stabilizes around 15℃−17℃. In summer, the inside temperature is lower than outside, while in winter, it converses. If making good use of such temperature variation, the energy consumption for producing cold water or warm water can be cut down.。

The geothermal pump system inserts 21 into vertical holes underground in the depth of 120m. In addition, 6 heat transfer tubes were installed in the foundation piles. The system uses circulated water in the tubes as medium to extract heat from underground or release heat to the underground.

The gross capacity of the system is approximately 7000t which is equal to seventeen 25m-depth huge heat storage tank. Also, there are another four 16m-depth backup tanks. This set can not only realize energy saving, but also contribute to reducing the peak load during daytime.

In summer, cold water is stored in four tanks while in winter, warm water is stored in three tanks and another tank is used for cold water storage. The surface of the water is covered by polyethylene sphere named "FINE BALL", which covers approximately 90% of the surface to avoid heat radiation as well as inhibit oxygen infiltration and avoid the heat pipe corrosion.

The system uses cold or warm water stored in tanks to distribute to the facilities through the networks for cooling or heating. Therefore, electricity peak load reduction as well as use night cheaper electricity by switching on machine during night to produce cold or warm water and shutting down devices during daytime when the electricity demand is relatively high.

The operation time for the system is from 10:00p.m. to 8:00a.m. the next day, totaling 10 hours. Both in winter and summer, the operation of machine is controlled within 120 days. In order to tackle the unstable power supply after the earthquake, the system completely takes the peak Countermeasures.

Without heat storage tanks, the protocol of electricity consumption is 6,000kW, and now it cuts a half down. In July, 2012, the maximum electricity usage during 1:00 to 4:00 in the afternoon is 346kW, controlled within one tenth of the protocol consumption. Moreover, reducing the protocol of electricity consumption and switching on the system during low price period could decline the cost.

(2) Control and operation mode

The sky tree energy planning adopts Testability Engineering And Maintenance System (TEAMS) for the energy management of the streets. Every residents and building owners can grasp energy information by personal computers through TEAMS whenever and wherever possible. In addition, through Life Cycle Energy Management (LCEM), the energy consumption can be calculated and effectively measures to constrain energy consumption can be discovered. The building owners can provide this as service to provide energy consumption report to the residents. [3]

TOBU Railway CO., LTD. new headquarters B1(energy center 1)		
equipment	number	parameter
Turbine refrigerator	2	Refrigeration capacity：350RT
Hot water boiler	3	
The west block B2 (energy center 2）		
Turbine refrigerator	2	
Heat pump	2	Refrigeration capacity：800RT Heating capacity：7600MJ/h
Water Source Heat Pump	1	Refrigeration capacity：50RT Heating capacity：800MJ/h
Turbine refrigerator (future)	1	
Water thermal Storage	Hot and cold water Thermal Storage	reservoir capacity：4500t
	Cold water Thermal Storage	Storage：2500t

Tabel1 Equipment Table of Cold and Heat Source

4. Environmental and Economic Benefits

a) Annual comprehensive energy utilization efficiency (COP) is over 1.3 (the average COP of DHC in Japan is 0.749); [4]

b) Annual primary energy consumption reduces by 43%;

c) The annual CO_2 emission reduces by 48% (approximately 2271t), which is equal to the absorbing capacity of forest of an area of 688 ha. [2]

Reference

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[2] http://china.nikkeibp.com.cn/news/eco/2810.html?start=1, Nikkei Energy and Ecology, last accessed 2014.11.25

[3] 「東京スカイツリー地区」熱供給(地域冷暖房:ＤＨＣ)事業許可-国内最高水準の省エネ性能・省ＣＯ２化を実現, http://www.rising-east.jp

[4] 「未利用エネルギー面的活用熱供給の実態と次世代に向けた方向性」，経済産業省資源エネルギー庁，２００６年度実績データを基に分析, http://www.rising-east.jp

Case 7 District Heating in Copenhagen, Denmark

1. Basic Information

Project Name	Copenhagen district heating system
Location	Copenhagen, Demark
Power Generation	1497MW
Heating Capacity	3044MW
Cooling Capacity	0
Energy Source	Biomass, coal, fuel oil, gas, waste
Owner	CTR, HOFOR and VEKS
Developer	CTR, HOFOR and VEKS
Designer	CTR, HOFOR and VEKS
O&M	CTR, HOFOR and VEKS

Table 1 basic information of the system

2. Background

(1) Location, Climate and Geography

This project covers the Greater Copenhagen Area where is in the oceanic climate zone. Apart from slightly higher rainfall from July to September, precipitation is moderate. While there can be snow from late December to late April. June is the sunniest month of the year with an average of about eight hours of sunshine a day. July and August are warm with daytime temperatures around 20 ℃ (68 ℉) although rainfall averages 69 mm per month. By contrast, the average hours of sunshine are less than two per day in November and only one and a half per day from December to February.[1]

The temperature in summer is 20℃ /13℃ and winter is 2℃/-2℃, with heating demand of 4000Gwh/year and cooling demand of 75Gwh/year. [4]

(2) General Information

The City's district heating system is part of the regional district heating system, which supplies the metropolitan area with energy efficient, reliable, and affordable heat. Heat is provided from Combined Heat and Power (CHP) plants. As a result of its lack of hydropower resources, Denmark has historically developed the utilization of heat from CHP plants by applying district heating networks, and the Copenhagen system dates to the 1920's. After the energy crisis in the 1970's, a comprehensive heat planning program was launched in Denmark, involving both municipalities and energy companies in an intense planning process. The 1979 Heat Supply Act enabled municipalities to designate certain areas for district heating and make it mandatory for households to connect to district heating. It was considered a successful initiative, leading to significant energy savings and a reduction in overall dependence on imported oil. [2]

Nowadays, Copenhagen's district heating system provides 98% of the city with clean, reliable and affordable heating. This heating supply system uses waste heat from regional refuse incineration plants and combined heat and power plants (CHPs), distributing heat through a pipe system to customers in the city. [2]

3. The System Overview

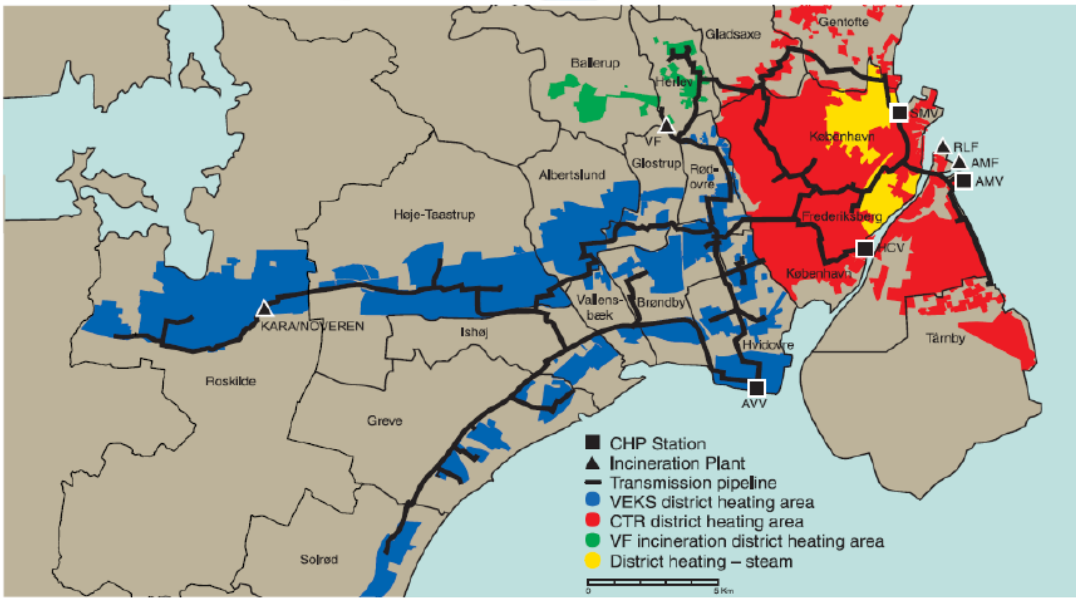
The system is part of the larger metropolitan district heating system that connects four CHP plants, three waste incineration plants, and more than 50 peak load boiler plants with more than 20 distribution companies in one large pool-operated system. Total heat production is approximately 33,000 terajoules per year. [2]

CHP		Fuel	Capacity heat (MJ/s)	Capacity electricity (MW)
Amagerverket	Unit 1	Biomass, coal, fuel oil	250	80
	Unit 3	Coal, fuel oil	331	263
Amagerverket	Unit 1	Coal, fuel oil	330	250
	Unit 2	Coal, biomass, fuel oil	570	570
H.C. Ørsted Værket		Gas	815	185
Svanemølleværket		Gas, fuel oil	355	81
Waste Incineration Plant		**Fuel**	**Capacity heat (MJ/s)**	**Capacity electricity (MW)**
Amagerforbrændingen, AMF		Waste	120	25
Vestforbrændingen, VF		Waste	204	31
KARA		Waste	69	12

Table 2 the information of the system [2]

However, Rome was not built in a day. Long term planning has been the key to developing today's sustainable system. During the 1980s, operators realized the large benefits involved in establishing connections between the various networks, first of all because it would allow utilization of the full capacity of the adjacent large power blocks. This resulted in the establishing of regional transmission networks operated jointly by different municipalities through the companies of CTR (Centralkommunernes Transmissionsselskab I/S), VEKS (Vestegnens Kraftvarmeselskab I/S) and Copenhagen Energy. Since the mid-1980s, the connections and collaboration between the main district heating operators of CTR, VEKS and Copenhagen Energy have been further elaborated. Today, the system is one of the largest worldwide, 160km transmission network supplying approx. 1 million consumers. [4]

The transmission network is the connecting link between the local district heating networks and the production plants. The transmission companies buy heat from heat production units (CHP and Incineration plants), transports it through the network and sells it to the partner municipalities, who are responsible for the supply to the individual consumers. In fact that the transmission companies can choose freely among the various production plants allowing them to optimize the overall system and reduce the number of expensive peak and reserve plants. [4]



The district heating system in the greater Copenhagen area

Figure1 the district heating system in The Greater Copenhagen Area [2]

4. Environmental and Economic Benefits

Currently, the district heating network covers 98% of the total heating needs of Copenhagen – the equivalent to approximately 50 million square meters. Compared to individual heating with boiler units using oil or natural gas, the Greater Copenhagen district heating system significantly reduces CO2 emission: 40% lower CO2 emissions than individual gas boilers and half the CO2 emissions of individual oil boilers. In 2010, renewable energy including waste incineration constituted 35% of the Copenhagen region's heat supply. The content of plastics in incinerated waste has doubled since the nineties, and by 2009 it is assumed that only 60% of the waste is organic; the rest being plastics that produce carbon emissions. Increasing the amount of plastics in the waste incineration process therefore affects the overall carbon emissions of the City. [2]

5. Lesson Learned

The Heat Supply Act of 1979 enabled municipalities to dedicate certain areas to district heating and made it mandatory for households to connect to district heating. As a result costs to consumers were reduced. It was a very successful initiative in terms of energy savings and reducing Copenhagen's dependence on imported oil. The Copenhagen system demonstrates that district heating is a very versatile, adaptable form of heat supply. CHP technology has proven to be successful and over time it has shown to be very flexible since it has been adapted to different fuels and technologies following changing political priorities over the decades. [2]

Reference

[1] wikipedia,http://en.wikipedia.org/wiki/Copenhagen, Retrieved 2014.12.4

[2] New Nork City Global Partners, Best Practice: District Heating System, City: Copenhagen, , report updated: May 25, 2011

[3] Metropolitan Copenhagen Heating Transmission Company (CTR), The Main District Heating Network in Copenhagen.

[4] District Energy Partnership.com, Case Story: Copenhagen, last assessed 2014.12.4

Case 8 Heat Plan Aarhus, Denmark

1. Basic Information

Project Name	Heat Plan Aarhus, Danmark
Location	Aarhus, Danmark
Power Generation	N/A
Heating Capacity	11.5 PJ
Cooling Capacity	N/A
Energy Source	Power plants, waste, coal
Owner	Aarhus Municipal Works and other seven consumer-owned companies, power utility Midtkraft I/S, Utility of Aarhus
Developer	Aarhus Municipal Works and other seven consumer-owned companies
Designer	
O&M	Aarhus Municipality Works

Table 1 basic information of the system

2. Background

1) Location, Climate and Geography

Aarhus is the second-largest city in Denmark and the country's main port. It is located on the east coast of the Jutland peninsula in the geographical center of Denmark187 kilometres (116 mi) northwest of Copenhagen, 39.5 kilometres (24.5 mi) south of Randers, 143 kilometres (89 mi) north of Odense, and 119 kilometres (74 mi) southeast of Aalborg by road.[1] The city has a population of 323,893, with the inner urban area housing 259,754 inhabitants (1 January 2014).[2][3] The land around Aarhus was once covered by forests, remains of which exist as Marselisborg Forest to the south[4] and Riis Skov to the north.[5] Several larger lakes extend west from the Skanderborg railway junction and rise to heights exceeding 152 metres (499 ft) at Himmelbjerget.[6]

Aarhus is in the humid continental climate zone (Köppen: Dfb) [7] and the weather is influenced by low-pressure systems from the Atlantic which result in unstable conditions throughout the year. Temperature varies a great deal across the seasons with a mild spring in May and April, warmer summer months from June to August, frequently rainy and windy fall months in October and September and cooler winter months, often with snow and frost, from December to March. Average temperature over the year is 8.43 ℃ with February being the coldest month (0.1 ℃) and August the warmest (15.9 ℃)[8]

3. District Energy Plan and System Scheme

1) Overall

Aarhus is one of those ten large cities in Denmark which are supplied with district heating from large-scale CHP plants.[9] District heating was introduced in the centre of Aarhus in 1928 and has grown ever since. Today suburbs and villages are supplied as well. Part of the present system is seven cooperatively owned district heating companies. Totally 95 % of the heat market in the municipality with 315,000 inhabitants is covered. Outside the municipality another four cooperatives serve four towns.[10] It is also a key project to help with achieving the CO_2 neutral goal in 2030 in Aarhus.[11] The plan has been fully implemented since year 2000 and is now entering a second phase of increasing the share of renewable energy significantly.[12]

2) System Configuration

The heat supplied is generated at a central CHP plant, Studstrupsværket, and a waste incineration plant (Aarhus North). In 1996 these two base-load plants supplied 98% of all heat delivered to the district heating network. And now it supplied totally 95% of the heat market in the city. The power plant Studstrupværket, MKS is owned by the power utility Midtkraft I/S which in turn is owned by the municipal and co-operative electricity distribution companies in the region. MKS covers the major part of the power demand in Mid-Jutland. MKS consists of four blocks. Blocks 3 and 4 are equipped with district heating supply installations and cover the greater part of the heat demand under Heat Plan Aarhus. And blocks 3 and 4 are equipped with electrofilters and desulphurisations plants to remove fly ash and sulphur dioxide (SO_2) from the flue gas and with low-NOx burners to reduce NOx emissions.[9]

The Aarhus North waste incineration plant is owned by Aarhus Municipal Works, with a capacity of 130,000 tonnes of waste per year. The energy generated from the waste incineration is used to produce power and heat. The heat is supplied to the district heating network which is part of Heat Plan Aarhus. Aarhus North has three boilers, of which two are CHP units with a total electric capacity of 9.4 MW. The total heat capacity of Aarhus North is 47 MW.

The transmission network is owned and operated by Aarhus Municipality Works and covers more than 100 km. Approximately 13 GWh power is used by the pumping plant to circulate nearly 40 million m^3 district heating water per year. The heat loss in the transmission system amounts to about 1.5% of the heat production for the transmission system. Three large oil-fired boilers are connected as peak load and reserve plants, having a maximum heat capacity of 315 MW. The heat is supplied to the distribution networks by means of 45 heat exchanger substations.

Most of the distribution networks are operated at a flow pressure of 4 - 6 bar and a flow temperature of 70 - 80 ℃ depending on the time of year. The power consumption in the distribution networks is very low, but there is a heat loss of up to 20% of the heat production in not very densely built-up areas. Consumers are directly connected to the distribution networks, i.e. without heat exchangers. Some of the distribution networks are supported by central boiler houses as peak load and reserve capacity equipped with small oil-fired boilers. Other networks are connected to small straw or biogas-fuelled boilers, which serve as base load capacity.[9]

3) Energy users

The system covers 95% of the city's housing, and uses surplus heat from electricity production to produce heat

4. Environmental and Economic Benefits

(1) General

- The system fulfills the heat demand of 95% of residential units of the whole city and is one of the key means to achieve Aarhus CO_2 neutral goal in 2030.
- A sustainable, clean, and renewable service is provided.

• Energy efficient energy distribution

(2) Environmental

• It has contributed to an annual carbon dioxide reduction of 210,000 tonnes and recent upgrades contribute to an additional reduction of 60.000 tonnes.[9,11]

• It uses waste incineration to provide heat, not only make good use of refusals, but also reduce the waste into the landfill.

• Some of the plants are equipped with electrofilters and desulphurisations plants to remove fly ash and sulphur dioxide (SO_2) from the flue gas and with low-NO_x burners to reduce NO_x emissions.[9]

(3) Economic

• The system uses the heat surplus from electricity plants as the heat source, which increase the energy efficiency.

Reference

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[11] Aarhus CO2 neutral in 2030 - Tackling climate change in EcoCity Aarhus

[12]http://blog.ramboll.com/urbanenergysolutions/innovation-and-technology/aarhus-and-copenhagen-energy-efficiency-landmarks-for-europe-4.html, last accessed 2014.12.4

Case 9 Sheffield District Energy Network, Sheffield, UK

1. Basic Information

Project Name	Sheffield District Energy Network
Location	Sheffield, UK
Power Generation	60 MW
Heating Capacity	20 MW
Cooling Capacity	N/A
Energy Source	225,000 t/a local municipal waste
Owner	Veolia, Private ownership
Developer	Enwave
Designer	Enwave
O&M	Veolia Environmental Services

Table 1 basic information of the system

2. Background

(1) Location, Climate and Geography

Sheffield, which is the fourth largest metropolitan in England, located in South Yorkshire. It is the greenest city in the UK and homes to almost 550,000 people living in 227,000 households.[1] It is also the main city in the southern part of the Yorkshire and Humber regional economy. The city has a strong and diverse economy, including high-tech manufacturing, business services, creative and digital industries, together with significant public service employment.[2]

Sheffield is located at 53°23′N, 1°28′W, lying directly beside Rotherham, from which it is separated largely by the M1 motorway. Sheffield is a geographically diverse city and it settled in a natural amphitheatre created by several hills and the confluence of five rivers: Don, Sheaf, Rivelin, Loxley and Porter. In this case, the city is mostly built on hillsides which have views of the city center. The lowest point of the city is just 29 meters (95 ft) above sea level near Blackburn Meadows, while some parts of the city are at over 500 meters (1,640 ft), and the highest point being 548 meters (1,798 ft) at High Stones, near Margery Hill. However, 79% of the housing in the city is between 100 and 200 meters (330 and 660 ft) above sea level.[2]

Just like the rest of the United Kingdom, the climate in Sheffield is generally temperate. According to climate data, the Sheffield enjoys an annual average precipitation of 834.6 inches. The hottest temperature occurs in July, with an average maximum temperature of 20.8 ℃ (69.4 ℉) while the coldest month is January and February with an average minimum temperature below 2 ℃.[2]

(2) Energy Demand and Supply

The heat energy for the district energy network is supplied by bled steam from the turbine via the two heat exchangers. It provides heat for more than 140 customers who connect with it. Moreover, it has a total electricity capacity of 21MW and a total heat capacity of 40 MW. The system which is mainly based on steam turbine can produce 115 GWh electricity and 113 GWh heat annually.[3]

3. District Energy Plan and System Scheme

(1) Overall

Sheffield has an award winning City Centre District Heating Scheme which was established in 1988 and is so far one of the largest in the UK. It was established in 1988 and is still expanding today. The system is operated by Veolia Environmental Services under contract, on behalf of Sheffield City Council. It saves an equivalent 21,000 plus tonnes of CO2 each year comparing to conventional sources of energy – electricity delivered from the national grid and heat generated by individual boilers.[4] Apart from this, buildings which connect to the network reduces the reliance on fossil fuels and improves local air quality. [5]

The City Centre District Heating Scheme allows businesses to avoid the Climate Change Levy and the connections between the customers and system helps the buildings achieve an excellent BREEAM rating. The carbon dioxide emission is only 0.059 kg/kWh, which enables them to achieve a high credit score.[5]

(2) System Configuration

The system produces electricity and heat through the combustion of household waste in incinerators and the heat is delivered through more than 45km underground pipes to provide over 140 buildings across the city center with all the needs of heating and hot water. [5] The system transfers a staggering 225,000 tonnes of waste into energy through boilers, producing up to 60 MWe of thermal energy and up to 19 MWe of electrical energy. This makes good use of the waste material that would otherwise have gone to landfill and benefit for the community society and economy. The city now sends less than 15% of its waste to landfill (the second lowest level in the UK).[5]

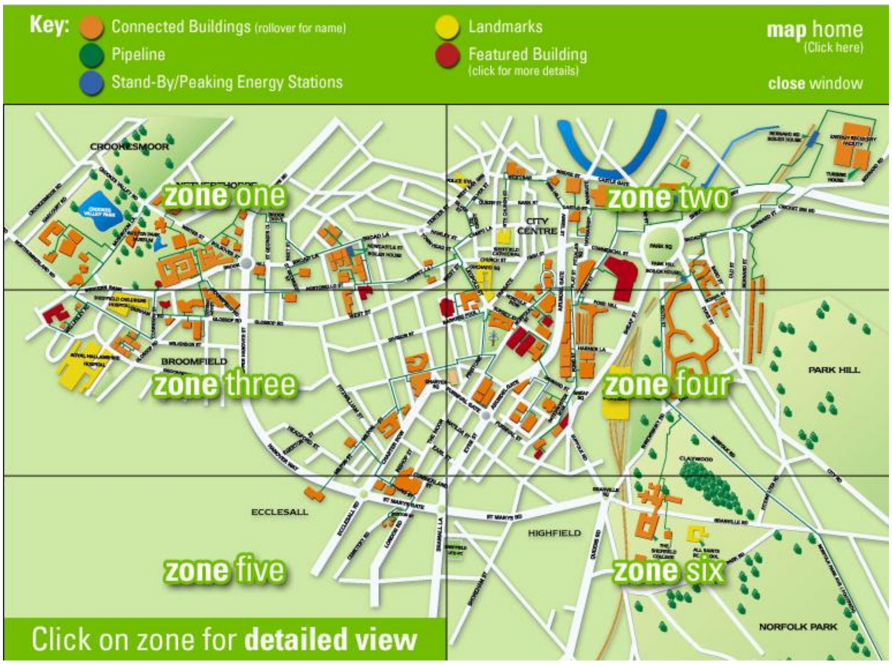

Figure 1 the heating map in Sheffield

(3) Energy users

There are recently 146 buildings which connect to the district heating network and benefit from such a low carbon energy providing project, generating electricity and heat from Sheffield's own residual waste. These customers include landmarks such as the Sheffield City Hall, the Lyceum Theatre and two universities, as well as a building mix such as hospitals, flats, shops, offices and leisure facilities. Nearly 2,800 residential households, mainly in flats, benefit from connection to the system across Sheffield. In a typical year, around 120,000 Megawatt hours (MWh) of heat is delivered to customers.[5]

(4) Timeline of the system

1960's	Park Hill and Hyde Park flats are connected by a pipeline to form the basis of a large scale District Energy Network (DEN) using a central oil fired boiler system.
1970's	The original Energy Recovery Facility (ERF) is connected to the Park Hill and Hyde Park DEN so that 'waste heat' can replace the oil fired boilers and investment and development of 'community' scale schemes in Council owned housing stock.
1980's	The DEN is extended to the Norfolk Park area and other blocks of flats are connected. Sheffield Heat & Power Ltd formed to own, develop, manage and operate the DEN.
1990's	The DEN is extended into the city centre and then out to Weston Park. Both Universities are connected and a large number of private sector buildings are connected. A steam turbine is added to the ERF.
2000's	The District Energy business is transferred to Veolia Environmental Services as part of one of the largest integrated waste management contracts in the UK. More private sector buildings are connected.
2006	A new state of the art ERF is handed over to Veolia, reducing the reliance on fossil fuel back up and providing more energy for further expansion of the DEN
Present	–Aspiration to expand, decarbonise and add resilience to existing network. Integrating with new networks planned in the Don Valley

Table 2 Timeline of the system [6]

4. Environmental and Economic Benefits

(1) General

• Providing heat to the cities buildings mix, including the government, universities, hospitals, hotels etc.
• Providing a price-competitive service, which is sustainable, clean, and renewable.
• System is designed to grow with demand and is expected to expand in the near future.
• The system is monitored by skilled engineers 24 hours a day. Backup heat supplies can be introduced via hi-tech control systems at a moment's notice
• Experienced Service Engineers are on call 24 hours a day for assistance.

(2) Environmental

• This system contributes to an improved local air quality.
• Instead of using fossil fuels, the system use household waste, which not only reduce the waste into the landfill but also conserve previous resources.
• The carbon emissions of District Energy is calculated as 0.044kg of CO2 per kWh, which is great lower than the traditional energy consumption.
• There are no harmful emissions produced by the heat exchanger so that a flue or chimney is not required. The heat exchanger can be connected with various control systems allowing individual management

(3) Economic

• Savings can be made on connection, operation and maintenance costs. Moreover, businesses can also avoid the Climate Change Levy and save money.
• The equipment used to transfer the heat from the network takes up less than one quarter of the space of a conventional boiler plant, sparing valuable space to be put to other uses.
• Due to the high efficiency of the heat exchanger, more useful energy is produced with less fuel input.[7]

5. **Operation and Maintenance Management**

The system is operated and maintained by Veolia Environmental Services and is monitored by computer systems. Also, there are skilled engineers who will monitor the scheme 24 hours a day and once failure occurs, backup heat supplies can be used immediately. Apart from this, service engineers are on call the whole days to tackle problems

6. Lesson Learned

The system serves a large scale of areas which could make full use of the district heating and enhance the economic efficiency. Because of the government and policies support, businesses who linked to the system could avoid the Climate Change Levy, which promote the utilization of the system. Also, it can be seen that pre-planning is really important for district energy system application, as how the pipelines goes, what the capacity is ect. should be carefully considered.

Reference

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Case 10 Olympic Park Energy Centre, London, United Kingdom

1. Basic Information

Project Name	Olympic Park Energy Centre
Location	London, United Kingdom
Power Generation	30MW
Heating Capacity	200MW
Cooling Capacity	65MW
Energy Source	natural gas & sustainable biomass
Owner	Olympic Delivery Authority and Straford City Development
Developer	Cofely
Designer	GDF SUEZ
O&M	Cofely District Energy

Table 1 basic information of the system

2. Background

(1) Location, Climate and Geography

London is the capital of the United Kingdom and the most populous city in the UK, with a metropolitan area of 1,583 square kilometers (611 sq mi), settling over 13 million inhabitants. London is a leading global city, with strengths in the arts, commerce, education, entertainment, fashion, finance, healthcare, media, professional services, research and development, tourism and transport fields. It is one of the leading financial centers around the world and has the world's fifth-or sixth-largest metropolitan area GDP according to measurement.

Modern London is located at the Thames, its primary geographical feature, a navigable river which crosses the city from the south-west to the east.[1]

London has a temperate oceanic climate (Köppen: Cfb), with warm summers, similar to all of southern Britain. Despite its famous for being a rainy city, London receives less precipitation (with 601 mm (24 in) in a year), comparing to Rome, Bordeaux and Toulouse etc. The average annual temperature is 11.3 ℃ (52.3 ℉), and the highest temperature occurs in summer, from June to August, with an average monthly temperature ranging from 16.4 ℃ (61.5 ℉) to 18.7 ℃ (65.7 ℉). Rain generally occurs on around two out of 10 summer days.[1]

(2) Energy Demand and Supply

Before the plan and construction of the system, the Energy Statement conducted studies to assess a range of renewable energies that were potentially suitable for the park site, including large-scale wind, biomass heating, biomass CHP, small scale wind, hydro power, tidal energy, ground energy, solar photovoltaic and solar thermal water heating. For each potential source, a measurement of £/kg CO2 reduction metric was conducted (capital and whole life cost), in addition to the total potential carbon reduction, based on spatial and other constraints. The results indicated that the best carbon savings were from infrastructure scale technologies, for example, large scale wind, biomass heating and biomass CHP.

Moreover, Demand side assessments were based on a review of all potential energy efficiency measures and the use of community heating and cooling networks, which were supplied by an efficient CCHP plant. The modeling was based on estimated floor areas and grade of use, and was constrained by the mixed-up about legacy use. Subsequently, the change of the master plan for the Olympic Park added difficulties to the calculations of total energy consumption and the demand profile of the Park in legacy. [2]

The plant's current installed capacity is 46.6 MW heating, 18 MW cooling and up to 6.68 MW of electrical power, depending on loads. When all the plant is in place the energy center will have the potential to generate up to 122.5 MW heating, 25 MW cooling and 10.02 MW of electrical power.[3]

3. District Energy Plan and System Scheme

(1) Overall

The scheme is the largest energy center project to be built so far in the UK and it was first put forward in October 2010, by the Olympic Delivery Authority (ODA). It was used to provide an efficient low-carbon heating and cooling system across the site for the Games and the new communities and buildings that developed after 2012 and helped to reduce the carbon emissions of the Olympic Park. The Energy Centre is able to meet the heating and cooling demands of venues and buildings across the Olympic Park. [1]

The design and construction of energy centers was in a modular format to enable plant to be added in the future, once the legacy loads are known. The utility had two years from the start of construction to build the two energy centers and the site wide network of 16km heating and cooling pipework [3]

(2) System Configuration

The centers are large, brown rectangular boxes, which were wrapped in a mesh of pre-rusted, perforated cladding panels. And a 45m tower settles at one end housing the boiler flues. In order to enable future plant to be installed, the building's cladding sections have been designed to be easily removed.

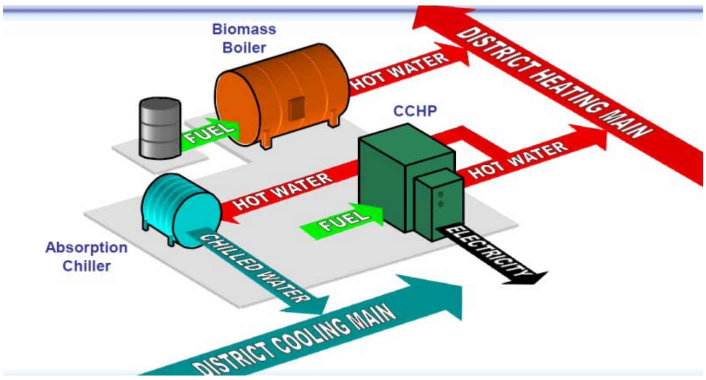

Figure 1 the Configuration of the system

In summer, when the demand for heating is less, heat produced from the CHP units can be utilized to drive a 4 MW absorption chiller. Even if the absorption chiller is out of operation, cooling can still be supplied by two 7 MW ammonia-based chillers.

To ensure cooling can be supplied efficiently, even under light load conditions, the chilled water circuit includes a giant cylindrical chilled water buffer vessel. The vessel increases the capacity of the chilled water system by 4.7 MWh, which enables the ammonia or absorption chillers to run uninterrupted when loads are low. Similarly, for the hot water circuit, a 27.5 MWh capacity buffer vessel was designed to the uninterrupted operation of the CHP engine and the system's giant boilers. A third tank contains treated make-up water for the hot and chilled water system. The enormous tanks are located outside the building, adjacent to the plant's eastern façade.

Some redundancy has been built into the center's total capacity to enable the systems to run uninterrupted even while items of plant are off-line for maintenance. There is an agreement to achieve a reduction in carbon emissions of 20% in 2012 as a result of the CHP services, rising to 30% in 2013. When fully operational, the scheme has the potential to save up to 12,000 tonnes of CO2 a year, compared with conventional energy supplies.[3]

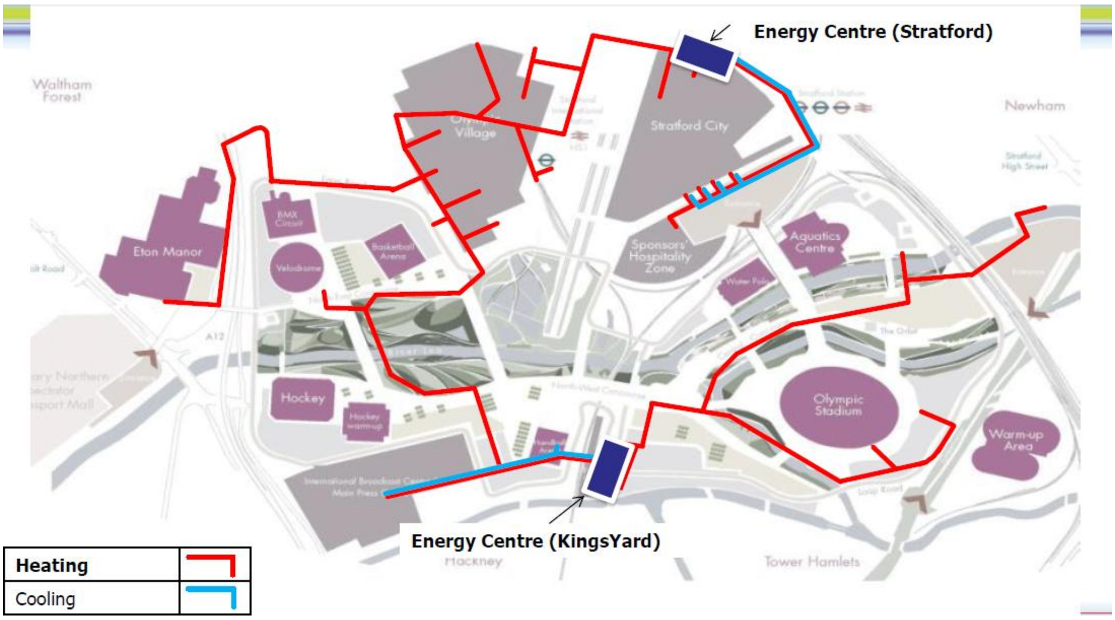

Figure 2 the Configuration of the system

4. Environmental and Economic Benefits

The energy center is a sustainable facility and an annual reduction of 1000t of carbon emissions can be achieved after the operation boilers and CCHP units and it also has a potential reduction of 12,000 tonnes of CO2 emissions. In addition, the CCHP utilizes wastewater treated at the site to cool the facility which saves lots of water. Moreover, the energy center plays a significant role in meeting the ODA's target to reduce carbon emissions of the Olympic Park by 50%. [4]

The system focuses on large-scale energy supply and increases the energy supply and economic efficiency of this park. Also, because of its modular approach, it spares enough space for future development which reduces the cost for future change. Moreover, this system could provide a number of local labors in construction.

5. Operation and Maintenance Management

Based on the modular approach, the center is planned to be developed in the future according to the change of loads, which increases the resilience and sustainability of the system. Next to the two huge 20 MW dual-fuel gas/oil fired boilers is the space for three additional boilers. All the pipework and flues are in place so that boilers can be added in the future with the minimum of disturbance,. Similarly, adjacent to the 3.3 MW gas-fired combined heat and power (CHP) engine, pipework connections are already in place in four empty bays for further units, if required.

6. Lesson Learned

A pre-design and modular approach can play an important role in the later development of the system.

Because of modular approach, designers can make full measurement and consider energy sources and energy supply before construction as well as the future development of the system based on loads change. The system designers spare enough space for other devices to add in which not only reduce the development cost, but also increase the transformation efficiency.

A large-scale district energy system could contribute to achieve the goal of the local environmental requirements.

As reducing the emission of carbon dioxide has been a priority in energy utilization in the United Kingdom and the large-scale district energy system could reduce carbon dioxide emissions as well as increase resilience and security of energy supply.

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Case 11 Olympic Village Recycled Water Heat Pump System, Beijing, China

1. Basic Information

Project Name	Olympic Village Recycled Water Heat Pump System
Location	Beijing, China
Power Generation	0
Heating Capacity	21 MW（winter）
Cooling Capacity	28.2MW（summer）
Energy Source	recycled water 12.5 ℃（winter）, 25.9 ℃（summer）
Owner	Public ownership
Developer	Beijing Institute of Geo-exploration Technology
Designer	Beijing Institute of Geo-exploration Technology
O&M	Beijing Institute of Geo-exploration Technology

Table 1 basic information of the system

2. Background

Beijing has a rather dry, monsoon-influenced humid continental climate (Köppen climate classification Dwa), characterized by hot, humid summers due to the East Asian monsoon, and generally cold, windy, dry winters that reflect the influence of the vast Siberian anticyclone.[1] Spring can bear witness to sandstorms blowing in from the Gobi Desert across the Mongolian steppe, accompanied by rapidly warming, but generally dry, conditions. Autumn, like spring, sees little rain, but is crisp and short. The monthly daily average temperature in January is −3.7 °C (25.3 °F), while in July it is 26.2 °C (79.2 °F). Precipitation averages around 570 mm (22.4 in) annually, with close to three-fourths of that total falling from June to August. With monthly percent possible sunshine ranging from 47% in July to 65% in January and February, the city receives 2,671 hours of bright sunshine annually. Extremes have ranged from −27.4 °C (−17 °F) on 22 February 1966 to 42.6 °C (109 °F) on 15 June 1942. [1]

3. District Energy Plan and System Scheme [3]

The Olympic village is located in Olympic Park in Chaoyang District in Beijing. It is the main residence for players during tournament and high-grade residential quarters after the game. The total construction area is about 517,000 m^2 and the ground floor area is 410,500 m^2, including 42 houses or apartments for athletes (6-layer and 9-layer respectively), two public buildings. The apartment building area is 380,000 m^2, with a construction area of 30,500 m^2 (2750 m^2 were added after the Games)

The reclaimed water cold and heat source heat pump project in Olympic village is to meet the heating and air conditioning needs in Olympic Village during the match, mainly including: water intaking, returning, heat transfer and heat exchange water delivery system and also the cold and hot water preparation and delivery system for the Olympic village.

Figure 1 Olympic village

A. Reclaimed water condition

The reclaimed water is from the Qinghe sewage treatment plant, with a daily disposal capacity of 400kt, discharging to Qinghe through culvert. The minimum water temperature in Qinghe is 12.5℃ in winter and the highest water temperature is 25.9℃ in summer.

(2) Terminal Mode

1) Summer: air conditioning adopts fan coil system (without fresh air supply system), the cold water supply and return water temperature is 7℃/12℃, with a temperature variation of 5℃.
2) Winter: for the low-temperature radiant floor heating system, hot water supply and return water temperature is 44℃/38℃, with a temperature variation of 6℃.
3) Public part: according to the central air conditioning design, fan coil unit plus fresh air system or all-air air conditioning system.

(3) Cooling and heating source equipment

Performance Parameters of Energy Center Unit		
The centrifugal heat pump units	number	4
	heating capacity	5250KW
	supply and return water temperature of hot water	44.5℃/38.5℃
	water source temperature	5℃/10℃
	cooling capacity	5330KW
	supply and return water temperature of cold water	5℃/12℃
The centrifugal heat pump units	number	4
	cooling capacity	1856KW
	supply and return water temperature of cold water	5℃/12℃
COP	3.285	
AnnualCO_2 emission	7200t	

(4) Heat circulation pipe design

The circulating water of the heat transfer is 3120 m^3/h. The supply and return water temperature is 5.5℃/10.5℃ to 5℃/10℃ in winter (negative) while in summer, the supply and return water temperature is 29℃/39℃ to 28.5℃/38.50℃(positive). The distance between heat exchange station and the Olympic village center is approximately 3.0km.

Water temperature changes: 2m deep pipeline, winter soil temperature of 6℃, the temperature drop <0.073℃； summer soil temperature 17℃, water temperature drop <0.02 C. The temperature changes can be neglected.

The water temperature changes of water pipe network in the scheme design considered as 0.5℃, namely: temperature drop in winter is 0.5℃, summer temperature drop is disregarded as a safety factor.

The pipeline is designed as the DN800 glass steel, water pressure of the heat transfer station is approximately 0.65MPa, and the working pressure of raceway is 1.0MPa pipes. When the buried depth is more than 1.5m, two tubes is larger than 0.5m, no thermal insulation is needed. When the depth is less than or equal to 1.5m or distance between two tubes is less than or equal to 0.5m, thermal insulation pipe is used. The project depth is around 2~4m.

(5) Hot and cold water conveying system

This project uses third-grade pump hot and cold water systems, namely: The primary pump is constant flow operation, the second pump is constant pressure and frequency conversion control, the third pump is proportional differential pressure frequency conversion control.

The primary pump, secondary pump station is in the center, and the secondary pump is set into three groups according to area. The supply and return water temperature is 5℃/12℃ with a temperature variation of 7℃; the third pump is set into 7 sub-station and is arranged by region. There is a third pump in each floor (with a prepared), the temperature of the supply and return water is 7℃/12℃,with a temperature variation of 5℃, mixing, by way of. Under this circumstance, the total flow of the secondary pump can be reduced by 28.6%, which means the energy consumption through transportation can be saved by 28.6% (pipe diameter of the second pipeline is DN600-DN500). In addition, the third pump unit adopts proportional differential pressure control mode, energy consumption being saved nearly 22% more than second pump system annually.

The system is divided into seven sub-stations according to regions, three in the eastern area and four in the western area. A set of thirdly pump water mixing system is provided in each floor (total 45 building)

The secondary water supply and return temperature is 5℃/12℃, the third water is 7℃/12℃, controlling the mixing water amount according to the three water temperature and adopting thirdly pump frequency variation speed control according to the supply and return water pressure constant (ratio adjustment). If the floor heating system in winter were not installing temperature automatic adjustment measures, the thirdly pump adopts climate compensation (the return water temperature, room temperature, climate temperature) to change the water pump frequency control scheme.

Characteristics of third pump system:

1) water supply can be changed by timely frequency conversion according to load changes of each floor, reducing the secondary hydraulic pipe network disorder degree, relieving the phenomenon of hot in near distance and cold in far distance (winter);

2) The water temperature difference of the secondary water pipe network is7℃, saving the initial investment (secondly network DN600 to DN500, secondly pump flow 28.6% down) and transportation costs by 28.6%.

3) The three water pipe network (users network) have a small temperature difference of 5℃, which is beneficial to increasing a thermal stability to the building system and improving household comfort.

4) The investment of the thirdly pump and thirdly pipe network increased and the saving energy is in the economic recovery period.

5) The thirdly pump system increases the operation and management work, but the secondly network adjustment (initial adjustment after completion, debugging during and after match, debugging every season) has become easier.

Figure 2 Network plan

4 Environmental and Economic Benefits [2]

The reclaimed water cold and heat source heat pump system in Olympic village is mainly composed of 4 parts, namely recycled water intake, return water pipeline, heat exchange station, central apparatus room and the terminal radiator. The heart of the system is the heat pump and a refrigerant R134a is circulated in the heat pump unit internal which would not destroy the atmospheric ozone layer and is an environment-friendly refrigerants. The unique of this system project is to use the reclaimed water heat pump system as the cold and heat source to replace the traditional air conditioning system, use reclaimed water from Qinghe sewage treatment plant as recycled water, replacing cooling tower cooling by recycled water. In the process of refrigeration and heating, water without quality change and recycled water be discharged into Qinghe at last. As no noise and no cooling tower water mist pollution, refrigeration is fulfilled quietly, creating a quiet, comfortable environment for the Olympic village.

After the completion of the reclaimed water heat pump cold heat source project in Olympic village, compared with the conventional cooling methods, electricity can be saved by more than 20% in summer, the extraction energy from reclaimed water in winter on an annual basis is equivalent to standard coal of about 3600 tons, which is equivalent to about 270m^3 natural gas. It can also emit 8600 tons of carbon dioxide, 48 tons of sulfur dioxide, 80 tons of dust less than coal-fired heating. Also, it adopts radiation floor heating in winter heating, saving energy by 30%.compared with the traditional convection radiator. [2]

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Case 12 Guangzhou University Town District Energy Project, Guangzhou, China

1. Basic Information

Project Name	Guangzhou University Town District Energy Project,
Location	Guangzhou, China
Power Generation	166 MW
Heating Capacity	444,450GJ/y
Cooling Capacity	77 thousand ton of refrigeration
Energy Source	Nature gas
Owner	Public ownership
Developer	Guangzhou University Town Energy development co., LTD
Designer	South China University of Technology
O&M	Guangzhou University Town Energy development co., LTD

Table 1 basic information of the system

2. Background

(1) Location, Climate and Geography

Guangzhou University Town, which is also called Guangzhou Higher Education Mega Center or Guangzhou University City, is an area featured by higher education institutions, located on Xiaoguwei Island in Panyu District, Guangzhou, China. It was opened in 2004. With an area of approximately 17.9 km2 and 3.53 millions square meters of indoor space, the complex is capable of accommodating 350 to 400 thousand people. [1]

Located just in south of the Tropic of Cancer, Guangzhou has a humid subtropical climate influenced by the East Asian monsoon. Summers are wet with high temperatures, high humidity, and a high heat index. Winters are mild and comparatively dry. Guangzhou has a lengthy monsoon season, spanning from April through September. Monthly averages range from 13.6 ℃ (56.5 ℉) in January to 28.6 ℃ (83.5 ℉) in July, while the annual mean is 22.6 ℃ (72.7 ℉), the relative humidity is approximately 68 percent, whereas annual rainfall in the metropolitan area is over 1,700 mm (67 in).With monthly percent possible sunshine ranging from 17 percent in March and April to 52 percent in November, the city receives 1,628 hours of bright sunshine annually, considerably less than nearby Shenzhen and Hong Kong.[2] Thus, this region has very high demands on cooling.

(2) General Information

In January, 2003, in accordance with the modern city planning, construction and management philosophy, Guangdong Provincial Government built a high standard university town with a covers area of 18 km^2 and could hold 250 thousand students. As more than 98% of coal and oil in Guangzhou needs importing from outside the province, and the electricity relies mainly on the provincial network, the load rate of air-conditioning in summer can reach as high as over 40%, with a shortfall of peak power around 1,000,000 kW. The coal-dominated energy structure has made acid-controlled area reach 63%, with a direct economic loss of ￥4 billion/year. "Ecosystems are in the sub-health condition, energy structure, water environment etc. have a certain distance from ecological city". In view of this, the Guangzhou University City Construction Headquarters entrusted the South China University of Technology and other units, formulated the "Guangzhou University Town Energy Planning", which includes 8 million m2 energy-saving buildings design, distributed energy system based on combined cooling heating and power (DES/ CCHP), the application scheme of renewable energy, energy system construction and operation mechanism and so on. The DES/CCHP and DCS scheme have passed the authoritative expert review in June and in July, 2003 successively, and put into effort. [3]

Figure 1: Rendering of Guangzhou University Town

3. District Energy Plan and System Scheme [4]

A. District Energy Plan

1) Optimize energy saving design of main buildings.

Guangzhou University Town formulated the "construction of energy-efficient design standards of Guangzhou University Town", which requires that through adopting a reasonable building design, strengthening the natural ventilation and cooling function, improving the performance of envelope insulation and the energy efficiency ratio of air conditioning equipment and other energy-saving measures, the annual air conditioning energy consumption should be reduced by 65% compared with baseline building under the prerequisite of ensuring the same indoor thermal environment.

2) Distributed energy supply system plan.

Using gas - steam combined circulation trigeneration technology, the installed capacity of power generation is about 126MW. The system uses natural gas as fuel gas and generates electricity through 100MW turbine units, and then the exhaust from the combustion engine enters into the waste heat boiler, producing 4.0MPa medium pressure steam into the extraction condensing turbine unit to generate power. The low pressure steam extracted from gas turbine is used to provide steam supply for the users and for refrigeration station absorption chiller. The waste heat from boiler is used for heat source of domestic hot water; electricity generated from energy station is used for electric compression refrigeration air conditioning system and as a part of daily use of the electric power. The energy efficiency of the whole system can reach over 80%. Through the regulation of working conditions of the gas turbine, waste heat boiler and steam turbine, the system can meet load demand under different seasons climate, cold, heat, steam, and has a high flexibility.

Researches have been done on the utilization of solar energy (lighting in outdoor public area, water-heating air conditioning), power generation by waste incineration, wind power utilization, energy utilization of low enthalpy value (Pearl River water, ground source heat pump) scheme have been studied. Goals have been put forward that new energy and renewable energy would account for 8%-10% in 2010 in the University Town.

4) The operation mechanism of energy supply system.

Investment, construction and operation management are done in accordance with the socialization, market-oriented mechanism. It is suggested that government-regulated (Guangzhou University Town Management Committee) Energy Service Companies operated under franchise mode. Such company should allow foreign investment, encourage user participation, and ownership diversified and is fully in accordance with the market mechanism. It achieved "four wins" goal through government, Energy Service Companies, user, grid law protocols, relied on scientific management.

B. Energy system

1) Distributed energy station

Distributed energy station is the core of the system in Guangzhou University Town. The energy station uses natural gas as fuel, plans and constructs four sets of 78MW class gas - steam combined cycle unit. The first 2 sets of generating units was put into operation in October, 2009. According to the design, its function can meet the heat, cold and other energy demand of the University Town (including 10 University and central business district). But due to the system and other objective reasons, the current energy station failed to achieve power supply to the University Town area directly, its power is from the 110kV cable access network.

The flue gas waste heat of the heat boiler from energy station is used for the preparation of producing domestic hot water and 1# cold station and energy station air-conditioning produce air-conditioning chilled water. The primary natural gas from the energy station got cascade comprehensive utilization. The system energy efficiency can reach as high as 80%, fulfilling energy saving, energy structure optimization, pollution control, environmental improvement purpose.

2) The district cooling system

The district cooling system in the University Town adopts advanced ice storage technology, plans a total installed capacity of 106,000 ton of refrigeration, containing four independent freezing station and corresponding freezing water branch network, terminal heat exchanger. So far, it has built and run 2#, 3#, 4# cold station and corresponding network, with an installed capacity of 77000 tons of refrigeration. Users include ten university, Guangdong Science Center, North Pavilion Plaza, digital home and digital TV research incubator base, Southern International Conference center. The cooling is delivered to end-use air conditioning system through terminal heat exchanger. The terminal room has built more than 300.

3) Centralized hot water system

The centralized hot water system in Guangzhou University Town is comprised of hot water production station, a primary hot trunk pipeline network, decentralized (pressurized) station, secondary hot water pipe network and single hot water system, which is open cycle system. Hot water preparation station mainly produces 60℃ hot water to distributed energy station. The terminal water users use prepaid IC card water meter metering while minority groups use mechanical water meter metering user table.

4. Environmental and Economic Benefits [3]

1) Because of the use of centralized cold supply, installed refrigeration capacity could save by about 45%-50%compared with the ordinary refrigeration mode.

2) Adopt a part of lithium bromide absorption refrigeration units, with a saving of installed power by 50MW, reducing the installed power capacity of 120MW.

3) It can save nearly ￥0.86 billion by use centralized cooling system compared with common cooling way.

4) It can increase energy efficiency dramatically and the energy utilization rate is close to 80%.

5) The total energy consumption is reduced by 25%, with annual electricity saving of 129 million kWh.

6) Reduce CO_2 emission of 240,000 t/a, SO_2 6000t/a. NO_x emission is 80% less than that from conventional coal-fired power plants, 36% less than the national standard for gas fired power plant.

7) Because the units mainly concentrate in the engine room, the noise during operation has been greatly reduced.

5. Lesson Learned [3][4]

There are some significant results on studies on energy planning of Guangzhou University Town. There are lots of problems existed in the construction and operation management. The following experience and lessons can be learnt according to the conditions of the project.

1) The function and the position of the overall planning and district energy planning are inseparable. The district energy planning of Guangzhou University Town is accurate in its university function and as ecological sensitive area of Guangzhou city in its special development pattern. So it clearly puts forward the guiding ideology of energy planning, namely, energy saving, high efficient, ecological and environmental protection and establishing energy management and operation system which is compatible with the market economy.

2) It is important parts of district energy planning to grasp the characteristics of district energy load and to predict energy load accurately. Guangzhou University Town as the University Park, the main energy consumption groups are college students, therefore, the characteristics of energy load is that the peak valley difference is big and there was a seasonal (summer and winter vacation) and day and night imbalance. In view of these load characteristics, energy station turbine equipment should select aeroderivative machine, which is fast response and comprised of four

combustion engines. And it can be single or multiple operation, obtains higher operation efficiency under different loads, better meets the heating load demand of University Town. The district cooling system uses ice storage technology, realizes the peak load shifting. For the load forecasting, it adopts the classification of building integrated power index to calculate of power load and for others such as retention of other village, it adopts per capita comprehensive power consumption index for load forecasting. Prediction of air conditioning load is through surveys ton the air conditioning requirements of different types of buildings, based on the hourly load analysis, adopting the hourly cooling load calculation software, determine the different functional area reasonable use air conditioning and coefficient based on mastering certain statistical regularity,. But the operating data of a few years show that, there are still some gap between the real load and forecasting load of air conditioning.

3) Analyze district geographical environment, ecological environment and meteorological conditions specifically, choose district cooling and heating and other energy products supply mode according to local conditions.

4) District energy plan cannot operate without the support from national energy policy, laws and regulations. In March, 2010, Guangdong Provincial Price Bureau approved on University Town Investment Management Co., Ltd. and other two companies to try out ice storage price, making the operation of ice storage of district cooling of the University Town economic and reasonable. The construction and planning of distributed energy station in Guangzhou University Town has achieved attention and support from the province, City Hall. In order to solve market positioning of energy station, the provincial government has repeatedly organized and coordinated. It is considered that the construction of energy station is an active exploration and attempt to solve efficiency, structure, safety, environment problems faced by Guangdong Province and even the country. In 2006, the provincial government approved the "Guangzhou University Town distribution energy station power supply reform pilot scheme", the blackout caused by southern snow disaster in 2008 has made a person with breadth of vision urgently feel that distributed energy is an effective way to solve the reliability of district energy supply directly. Considering environmental benefits and other social benefits brought about by the district cooling and distributed energy, if the government could give appropriate preferential treatment in natural gas prices, and properly guide user to use the distributed energy system, it will be a strong support for the distributed energy. Therefore, energy planning are more looking forward to breakthrough from national policies, laws and regulations.

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