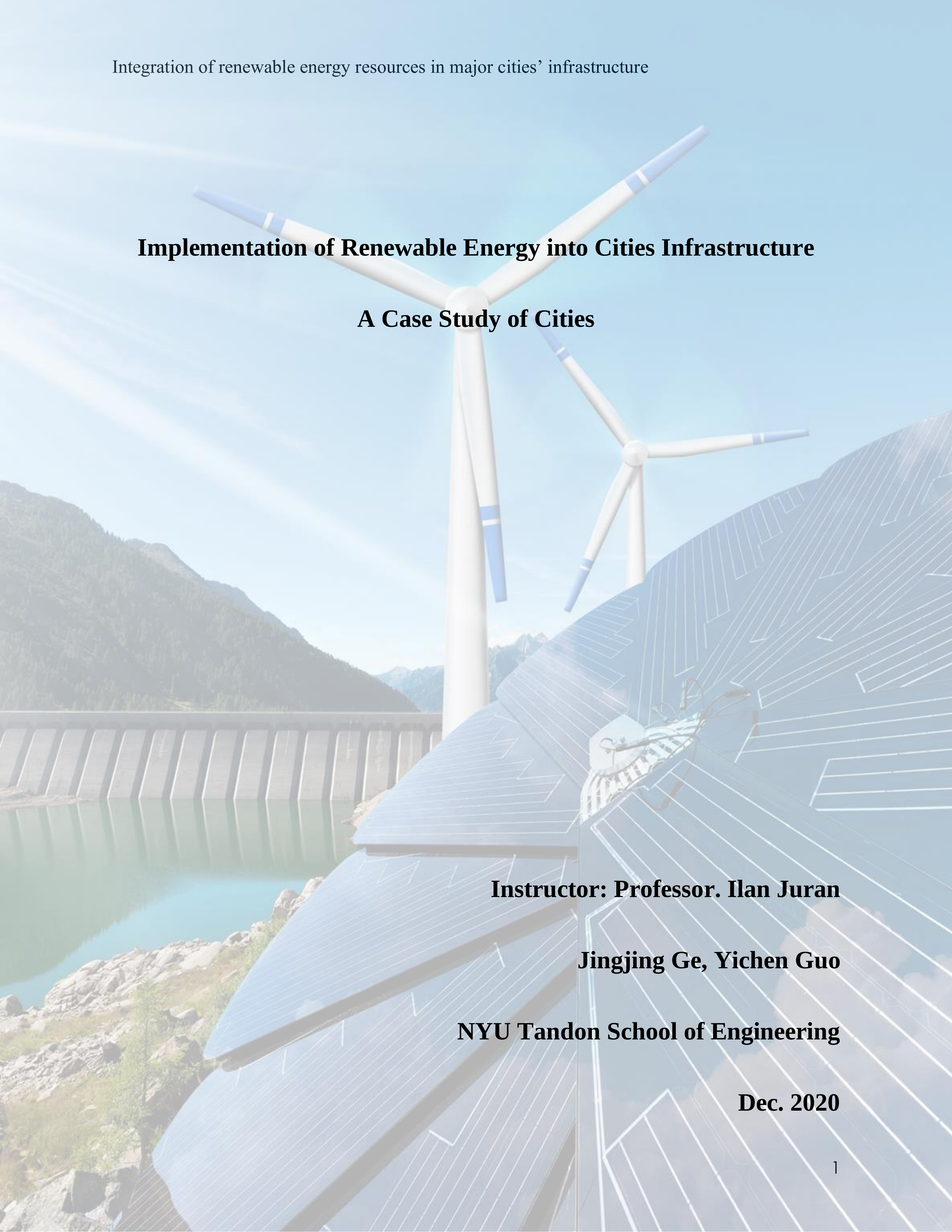

Implementation of Renewable Energy into Cities Infrastructure

A Case Study of Cities

Instructor: Professor. Ilan Juran

Jingjing Ge, Yichen Guo

NYU Tandon School of Engineering

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CONTENT

Introduction

Renewable energy resources prove their importance with the ever-increasing severe effects from climatic change majorly brought by fossil fuels. With increased urbanization and population in major cities worldwide, climatic conditions take a turn for the worse with greenhouse gas emissions (GHG). Therefore, using renewable energy instead of traditional fossil fuels is a vast game-changer with low carbon and GHG emission levels. Renewable energy resources are essential in changing the course of climate change, there being growing importance attached to their integration in the infrastructure of cities around the world. Measures taken to replace fossil fuels with renewable energy resources have effectively reduced GHG emission rates as countries strive to mitigate the effects wrought by climate change and enhance climate security.

Integrating renewable energy resources in cities' current infrastructure plays a massive role in securing the environment and atmosphere even for generations to come. By integrating renewable energy resources, government authorities worldwide serve to protect the environment by having alternatives to harmful fuel oils and ensuring energy security. Catastrophic climatic conditions have been experienced in different parts of the world, showing the extent of damage to the atmosphere from burning fossil fuels. Rising sea levels, too high temperatures with heatwaves and wildfires, and rampant flooding are evidence of the danger posed by the alarming pollutions levels witnessed in the world. The greatest extent of the damage is from industrial processes due to pushing for economic growth and development. However, with the rising pollution levels, countries started acknowledging the degrading effects that fossil fuels have on the environment and started taking towards cleaner energy. Renewable energy resources are perfect alternatives, saving on energy consumption as well as promoting energy efficiency.

Integration of renewable energy resources in major cities' infrastructure

The paper will analyze three cities in the world where there are efforts to integrate renewable energy resources into their infrastructure. The cities under review are Boston, the capital of Massachusetts, the United States of America, Beijing, the capital city of China, and Shanghai, a megacity also in China. The contextual background of each city will be given together with the stakeholders concerning renewable energy resources. Additionally, there will be a review of the city's objectives on using renewable energy, the implemented strategies, and their impacts. Finally, a conclusion will be given, assessing the implementation of integrative strategy in the three cities and comparing Beijing and Shanghai. The comparisons will be based on the similar cultures the two cities enjoy. The three cities have similar factors in that they have strategies to integrate renewable energy resources into their infrastructure. The cities have also previously experienced extreme weather conditions from climate change. The cities came up with plans to mitigate the effects and focus on the strategies planned on how to integrate renewable energy resources into their operations from the climatic changes.

The plans for some cities such as Boston date as far as 2000 with the mayor's efforts to curb climate change. Boston from then saw the Climate Action Plan's inception in 2005, where it is always updated every three years. The Plan is based upon previous climate agreements like the Kyoto agreement. The use of clean energy is a top priority in the city's Plan of fully being a green city by 2050. The document also reviews the implemented strategies and the impact the initiatives and programs have.

Beijing and Shanghai are in China; they have similar plans for integrating renewable energy into their infrastructure. The strategies are mostly documented in the Five Year Plans (FYP) of the country. The paper will analyze plans listed in the 11th FYP through the 13th FYP. The implemented strategies in each city will be investigated, and the impacts in both Beijing and

Shanghai. The implementation of strategy in the two towns will be assessed from China and have the same culture.

City 1: Boston

Urban and historical context

Boston, a city in the United States, is the capital of the state of Massachusetts. The climatic conditions range from warm to hot summers and frigid winters. It also snows a lot during the winters in Boston. However, Boston's weather has been shifting, owing to the climatic changes in the recent past. Extreme weather is evidenced by the rising sea levels witnessed in the city. The drastic climatic changes are a threat to Boston, with the city taking initiatives to mitigate the effects felt by changing weather patterns. Initial initiatives include the construction of the first municipal green building in 2002. The municipal green building is a conservation center named the George Robert White Environmental Conservation Center (City of Boston, 2008). The center often incorporates renewable technologies such as geothermal heat pumps. Other technologies include; solar hot water systems and photovoltaic shingles. Further strides toward integrating renewable energy resources in Boston's infrastructure involve installing solar panels at institutions, a move made in 2004 and 2005. Three schools in the city had solar panels being installed by the city.

Over the years, Boston has made efforts to curb the production of greenhouse gases from manufacturers, with the former mayor of Boston in 2007 signing an order that saw the reduction in greenhouse gas emissions. The mayor's mandate included incorporating initiatives focusing on clean and renewable energy (City of Boston, 2008). Implementation of renewable energy types has been taking place over the years, such as wind power starting to be used in the city for energy supply in 2007. By 2017, Boston had several renewable energy resources in use, such as solar energy, wind power, landfill gas, hydropower, and wind power, which has continued to be the city's largest renewable energy source.

As a driver to change in ensuring more use of renewable energy in Boston, the city came up with a building energy report in 2013. The initiative saw the Building Energy Reporting and Disclosure Ordinance (BERDO) (City of Boston, 2008). Through this initiative, the city can track energy use from all commercial and residential buildings for efficient planning on integrating renewable energy use. The building covered in this initiative is one with more than 35 units apart from energy consumption and is also expected to report water consumption (City of Boston, 2008). Boston's city can then advise property owners on cleaner energy and cut their energy consumption rates from the data acquired. Buildings are also expected to show how they have reduced their energy emissions rates every five years as an initiative to cut on carbon emissions. It is an initiative

Figure: Boston Resilient Harbor

that seeks to integrate renewable energy as well as enhancing climate change preparedness. Boston's climate has been undergoing considerable changes, with new records of climatic conditions in recent years. July in 2019 was marked as the hottest month since 1872 when the city started keeping records (Boston government, 2020). The winter in 2015 had the most significant snowfall since record-keeping unchanged in 1872. The city has also received severe weather with a bomb cyclone in 2018 that caused icy flooding causing the highest water levels witnessed in Boston Harbor (Boston Government, 2020). The Resilient Boston Harbor was then developed to enhance climate change preparedness (Boston Government, 2020). This program has seen the city developing green infrastructure policies and district energy to integrate renewable energy resources.

With the current climatic conditions, the city has drawn strategies to integrate renewable energy resources to mitigate the extreme climatic conditions and their impacts. Carbon neutrality has been on the forefront as a significant city initiative to deal with climatic change. There have also been over 24 megawatts in solar power from the increased solar panels installation in buildings across the city (Boston Government, 2020). The city also encourages the shift from fuel oils in a household to cheaper natural gas, which has lower carbon emissions levels. Strategies in integrating renewable energy resources touch on solar power, cutting on fuel oils and promoting natural gas, cutting on the carbon emissions, and enhancing energy economy with saving on the energy consumed in commercial and residential buildings. Most of the strategies aid out is documented in Boston's Climate Action Plan through 2007 to the most recent one in 2019. There are updates every three years, reviewing the implemented strategies as well as the impact they have.

Government and stakeholders

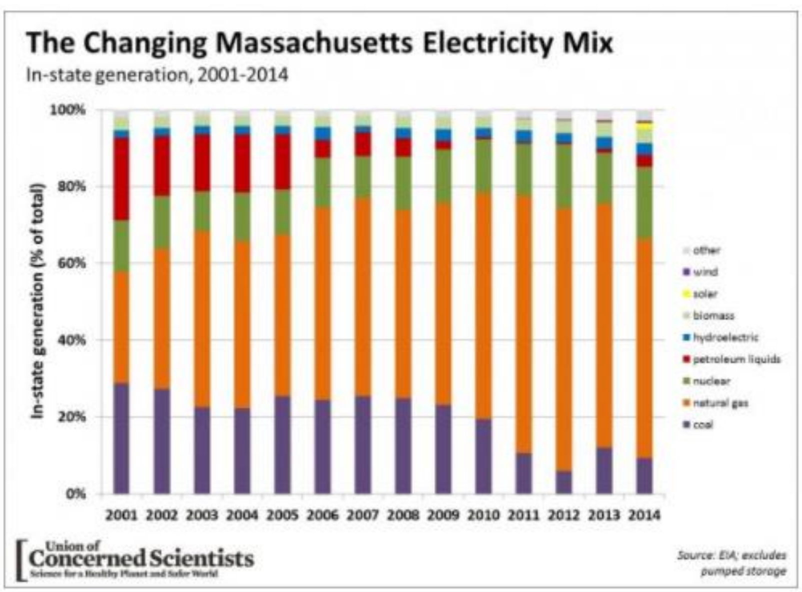
The primary stakeholders in the city are the Boston City Government and the Massachusetts government. The mayor's office has played an important role in incorporating renewable energy resources in the city's operations to develop the Climate Action Plan for the city. The plan mainly focuses on climate change preparedness and mitigating climate change effects by having a greener Boston. Since 2007, the plan has been a guideline for the city's efforts to incorporate clean energy for its use. The mayor's office updates the climate action plan every three years, with the reviews showing the strategies implemented in being a clean city. The review of the Climate Action Plan led to the institution of the 2050 strategy of Boston being a 100% green city (City of Boston, 2020). Therefore, the local government is one of the focal points in gearing the city towards incorporating more renewable energy resources for its operations. There are also lots of companies involved and interested in the development of renewable energy in the city. The people who are hit most by the climatic change from greenhouse gas emissions are the city's citizens and inhabitants. Therefore, citizens are essential stakeholders in integrating renewable energy resources into the current infrastructure of Boston.

Many local industry groups in Boston are actively involved in integrating renewable energy resources into the city's infrastructure. The local groups are primarily from Boston and Massachusetts, with active participation in the city of Boston. The New England Women in Energy and the Environment (NEWIEE) is a group that majorly focuses on promoting the leadership of women whose interests lie in the energy and environment field, especially on promoting green energy (Massachusetts Clean Energy Center, 2020). The Solar Energy Industries Association (SEIA) is a group made up of all organizations supporting solar energy in the city. The group supports solar energy panels' manufacture and installation and advocates for solar power for a greener Boston. Other organizations include the American Council on Renewable Energy (ACORE), a nonprofit organization whose aim is to widen renewable energy use. The group is primarily involved in marketing renewable energy programs and initiatives and supporting renewable energy integration innovations. The group is also actively involved in setting up new policies on incorporating renewable energy into its operation s.

Nonprofit organizations are an essential group of stakeholders as they champion the well-being of the city's residents. Other nonprofit organizations involved in integrating renewable energy resources in the city include the Northeast Energy Efficiency Partnerships (NEEP), which covers the city of Boston, among others in the Northeast and the Mid-Atlantic regions in the United States in encouraging energy efficiency (Massachusetts Clean Energy Center, 2020). The group works towards promoting the efficiency levels of energy consumption in the northeast cities, Boston included. The Northeast Clean Energy Council (NECEC) comprises all groups interested in cleaner energy in the Northeast cities. The group aims to enable companies in the Northeast to start and produce clean power efficiently. As Boston is one of the Northeast cities, the group helps startup energy companies make renewable energy for the residents, allowing the city to meet its 2050 goal of being a 100% clean city. Other groups interested in and taking part in the integration of renewable energy resources in the infrastructure of Boston include the Clean Energy States Alliance (CESA), the Environmental Entrepreneurs (E2), and the Massachusetts Technology Leadership Council (MassTLC) (Massachusetts Clean Energy Center, 2020).

Additionally, energy companies also form a bulk of the stakeholders in renewable energy integration in the infrastructure of the city of Boston. Veolia North America is an energy company that was voted one of the largest clean energy company in the state of Massachusetts (Boston Business Journal, 2019). It deals in green steam in Cambridge, with the Kendall Station Plant providing the steam to be reused instead of it being discarded in river channels. Nexamp is a private company that designs and builds solar panels for commercial purposes. The company's solar panels are simple to operate and accessible to many residents of the city. BlueWave Solar is also another company involved in developing energy consumption solutions by making solar panels for residential and commercial buildings in the city (Boston Business Journal, 2019). EnergySage Inc. helps the city residents compare the quotation prices to install solar panels by different solar power companies through an online platform. The Resolute Marine Energy is also another energy company involved in creating a greener Boston with its development of a technology that converts ocean wave energy into electricity for the distribution in Boston areas that are not primarily developed.

As with the graph below, most of the energy consumed by the residents of Boston, and generally, Massachusetts, is from natural gas. A stated, coal has been a major source of energy for the residents making up more than 20% of the total energy consumption from 2001 to 2010, there being a drop in the consumption of coal from 2011 as depicted in the chart.



Changes afoot in the Massachusetts energy mix: Enter natural gas and renewables, exeunt coal and oil

City's objectives

The plans and strategies of integrating renewable energy in the city were first identified in the Climate Action Plan of Boston in 2007, building on the 2000 address by the then Mayor Menino. The objective was to have the Boston Climate Action Plan revised every three years for better efficiency and sustainability. The plan detailed policies and guidelines to reduce greenhouse gas emission rates, which were to apply to the city's municipal operations and the whole Boston community. The plan's objectives were being built on the strategies laid down in 2000 by Mayor Thomas Menino when addressing greenhouse gases (GHG) on the earth's climate. There were two objectives laid out by the mayor's address in 2000. The leadership of the city, through municipal operations, was to take an active role in increasing energy efficiency as well as decreasing the GHG emission levels. The second objective was for the city's leadership to draw an actionable local plan to reduce greenhouse gases and air-polluting gases. In 2007, the city came up intending to have all new buildings being constructed to be estimating their annual energy use and the emission of greenhouse gases.

Additionally, properties being constructed as municipal operations were also evaluated for their feasibility of installing solar power panels, green roofs, and wind power panels. In 2007, the Climate Action Plan detailed an objective where all the departments under the Boston Municipality would include at least 11% power from renewable energy resources. The city in 2007 also made an objective to annually review and analyze its GHG emission and energy consumption levels. The review was to be carried out by the Boston about Results performance measurement system.

In 2010, the Climate Action Leadership Committee and Community Advisory Committee came up with the goals to integrate more renewable energy resources in the city. The plans included the reduction of GHG by 25% by 2020 and by 80% in 2050. The objective aimed at mitigating the climatic changes brought about by the emission of greenhouse gases. In 2014, Boston aimed at improving the energy efficiency programs put in place by 2014. The city was to have a greater outreach targeting specific audiences and communities on energy efficiency and cleaner energy while at the same time coming up with a new, better working financial mechanism. Boston's district energy and co-generation were to be expanded together with the low carbon energy sources. 2014 also saw the city plan on tracking and updating the previous Climate Action Plans, reviewing the implemented strategies, and the steps taken in meeting the rest of the goals. Two thousand and twenty targets set in 2014 were to have 15% of the total energy consumed in the city come from local co-generation, with 10MW coming from the installed solar power panels across the city. By 2020, the city intended to have completed 72,000 home energy audits, 36,000 upgrades weather and heating systems. The city, in 2017, also came up with a plan of being carbon neutral by 2050. The plan was unveiled in the 100% Renewable Boston Plan in 2017. In 2019, the objectives of integrating renewable energy resources in Boston's infrastructure saw the city focus on making goals on energy supply. The city aims at integrating and improving the community's choice of green energy in its operations. It also plans for the deployment of microgrid systems in all districts in the city. The microgrid systems to be installed are carbon-neutral, integrating renewable energy into the current infrastructure. The city is currently planning on supporting laws, initiatives, and programs to clean energy. It will also support efforts made towards realizing decarbonized energy supply, and most importantly, renewable energy sources.

Implemented strategies

There have been lots of efforts from the city government regarding integrating renewable energy resources in the city dating as far as 2000. The city has played a leading role in implementing policies that encourage energy efficiency and clean energy and policies to reduce greenhouse gas emissions. In 2000, Boston joined the Cities for Climate Protection Campaign of ICLEI-Local Governments for Sustainability. The mayor of Boston in 2005 in the U.S. Conference of Mayors agreed to the adoption of the U.S. Mayors Climate Protection Agreement. This agreement was in support of the objectives set in the Kyoto Protocol. It was a move towards the reduction of GHG emissions by 7% of 1990 emissions by 2012. The plans reviewed in the document were integrative actions in transportation, land use, energy sources, waste management, buildings, and other structures. In 2005, Boston's Energy Management Board completed a study, Integrated Energy Management Plan, analyzed energy use in 36 municipal buildings, and suggested areas where the city could save on energy. It was a move towards greater energy efficiency levels.

Additionally, Boston's energy office completed installing a computerized energy management system (EMS) in all Boston schools. Therefore, the city's school system is monitored by the energy office, which monitors the weather conditions and automatically adjusts air conditions and heating in the classrooms, with devices that consume a lot of energy only being turned on when needed. There was also the installation of green housing and settlements, green roofs, and LED traffic lights. The solar installation of a photovoltaic (PV) system of 2.8 kW in the George Robert White Environmental Conservation Center serves to provide solar energy as a renewable energy resource. In 2006, the city saw 450 diesel vehicles' flagship to use a five percent biodiesel blend (B5). The strategy in the 2007 Climate Action Plan saw all municipal vehicles using B5. In addition to integrating renewable energy in the transport sector, the city made bicycles more convenient, encouraged walking, and initiated Boston Transportation and Air Quality Grants.

Documented in the City of Boston Climate Action Plan Update of 2011, Boston has implemented renewable energy integrative strategies in municipal operations, transport, and buildings. The programs in place include Renew Boston, a utility partnership initiative and a community outreach that serves to bring energy savings to Boston residents. On green energy also, Green jobs Boston connects the residents of Boston to employment opportunities after taking them through green job training. By 2012, more than 15% of the electricity being purchased by the Boston Municipality was coming from renewable energy resources. This was per the objective set in the 2007 Boston Climate Action Plan. As of 2013, the city had made 35,858 energy audits and 18,000 upgrades on weather and heating systems for energy use regulations. Large buildings and institutions had also reduced their energy consumption by 4.1%, with the solar panels installed through the city providing 14.3 MW of solar power.

By 2019, there were 56,714 energy audits, which were all completed through the Mass Save. Inline to have upgrades on the weather and heating systems, there have been 27,631 systemization upgrades. The upgrade projects were all carried out by the Mass Save. In the 2019 update of the Boston Climate Action Plan, the city has implemented a decrease in energy use in all BERDO buildings. There was a 7% reduction from 2013-2017, according to reducing energy use in all BERDO buildings by 7% by 2020. The objective was met earlier than the set date.

Impact of strategies

The Renew Boston and Electric Utility Efficiency Programs have helped Boston residents and businesses have access to energy-efficient resources and electric utility programs. The Renew Boston program also operates the Gas Utility Efficiency programs, enabling the residents to access energy efficiency and utility programs on natural gas. The city has seen a 2% reduction of the GHG emission levels from burning fossil fuels from the Low-Carbon Standard for Heating Fuels program to reduce GHG emission rates by 85% by 2020 (Boston Government, 2014). There was an 18% decrease in the rate of greenhouse gases emission in the neighborhoods from 2005 to 2013. The reduction rate of GHG emitted from large buildings and institutions from 2005 to 2013 was 21.6% (Boston Government, 2014).

Since 2005, the carbon emissions in Boston have been undergoing a gradual decrease due to the implemented strategies to incorporate renewable energy into its infrastructure. There has been a 21% decrease to 6.1 million from 7.0 million metric tons of carbon (City of Boston, 2014). The decline in carbon emissions has occurred when the city has experienced an increase in the number of jobs and the overall population. In 2017, there were nine metric tons of per capita emissions compared to 15 metric tons of per capita emissions in 2005. Despite the ever-growing population, the implemented renewable energy strategies have seen the city inch closer to being a 100% clean city by 2050. There has also been a fall in the emissions per million dollars of Gross City Product (GCP) from 86 metric tons of carbon per million dollars in 2005 to 48 metric tons in 2017 (City of Boston, 2020). A significant impact of integrating renewable energy resources in Boston's infrastructure has been reducing carbon emissions around the city and generally lowering GHG emissions.

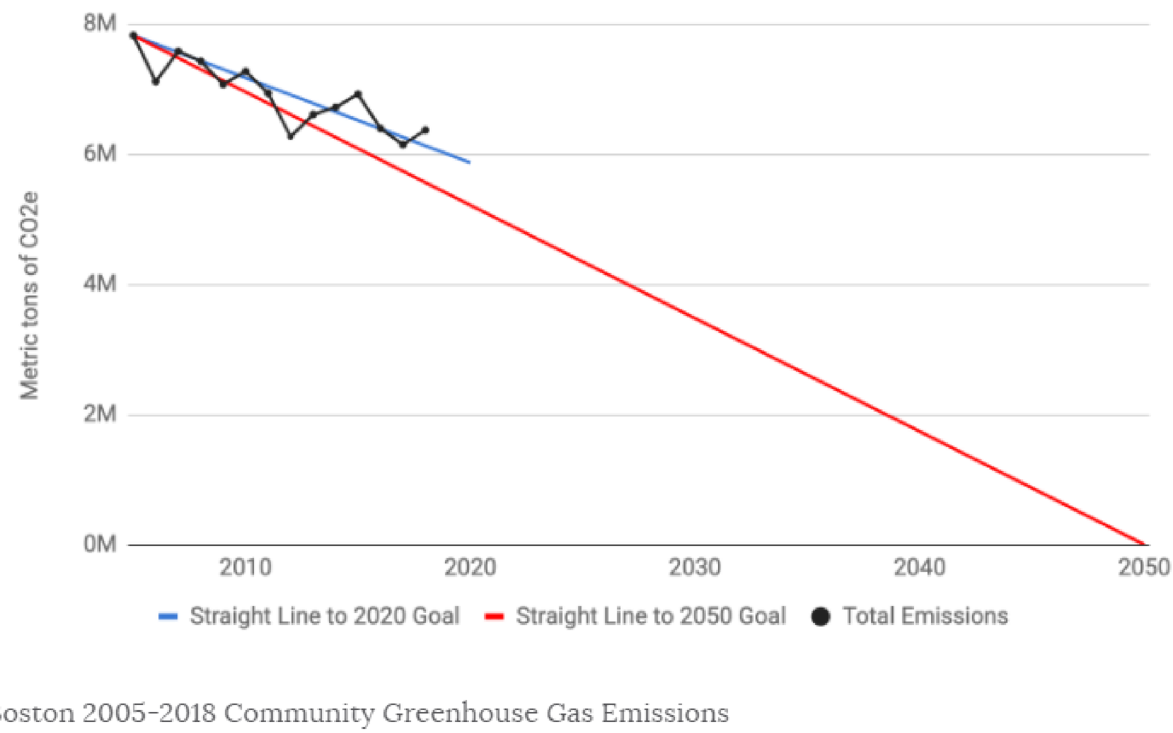
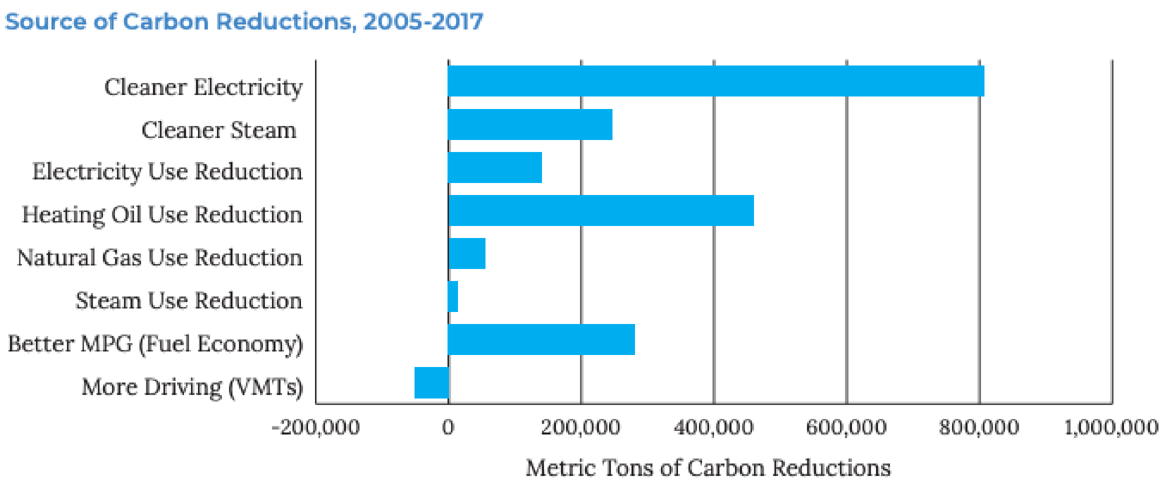


Figure: Emission of GHG in Boston

As of 2019, all the carbon emissions in Boston's city were mainly from large buildings, institutions, and the transport sector. By 2019, the city had almost met its 2020 goals on GHG emissions, with 71% of carbon emissions in the city coming from buildings and transport accounting for 29% of the emissions (Boston government, 2020). By generating cleaner electricity, Boston could reduce carbon emissions, a step towards mitigating climate change effects. Production of cleaner electricity accounts for 45% of the decrease in carbon emissions. Decreasing the natural gas prices was an initiative that encouraged the residents to use clean electricity. The city also joined efforts with the state and regional authorities in cleaning the New England electric grid. This initiative has seen the use of cleaner electricity in the town. The New England electric grid has also benefited from the Regional Greenhouse Gas Initiative (RGGI). The RGGI program, a cap-and-trade program, has collaborated with the state and regional authorities in getting the New England electric grid cleaner (City of Boston, 2020). Boston residents enjoy cleaner electricity from the grid; the more coal and oil are replaced with natural gas and other renewable energy resources. As with the graph below, there has been an increase in cleaner electricity levels in the city with 800 000 metric tons of carbon reduction with the move from coal and oil by power plants.



Over 45 percent of past emissions reductions were due to a cleaner electricity grid, as power plants have switched from coal and oil to gas.

Figure: Source of carbon reduction in Boston

Additionally, there has been a decrease in fuel use by Boston residents from 2005 by half the amount. Natural gas has replaced fuel oil in more than 20,000 households (City of Boston, 2014). Residents embrace natural gas over fuel oil as it is cheaper and has lower carbon emissions. As with the graph below, Boston used 16.8 TWH natural gas compared to the 9.0 TWh of oil in 2015 (Wasser, 2015). The shift to natural gas from oil fuel has also resulted in the Kendall Power Station being cleaner. The power station generates steam and distributes power to most of downtown Boston. Instead of directly discharging hot water into the Charles River, the plant now uses the steam to distribute it as clean energy. The implemented strategies in getting the city cleaner have helped push the city further in attaining a 25% decrease in carbon emissions. The use of solar power has also been on the gradual increase since the first Climate Action Plan with 15 megawatts of commercial solar power in 2019 (Boston government, 2020). Energy used from co-generation has also been on the rise from installing and integrating co-generation energy.

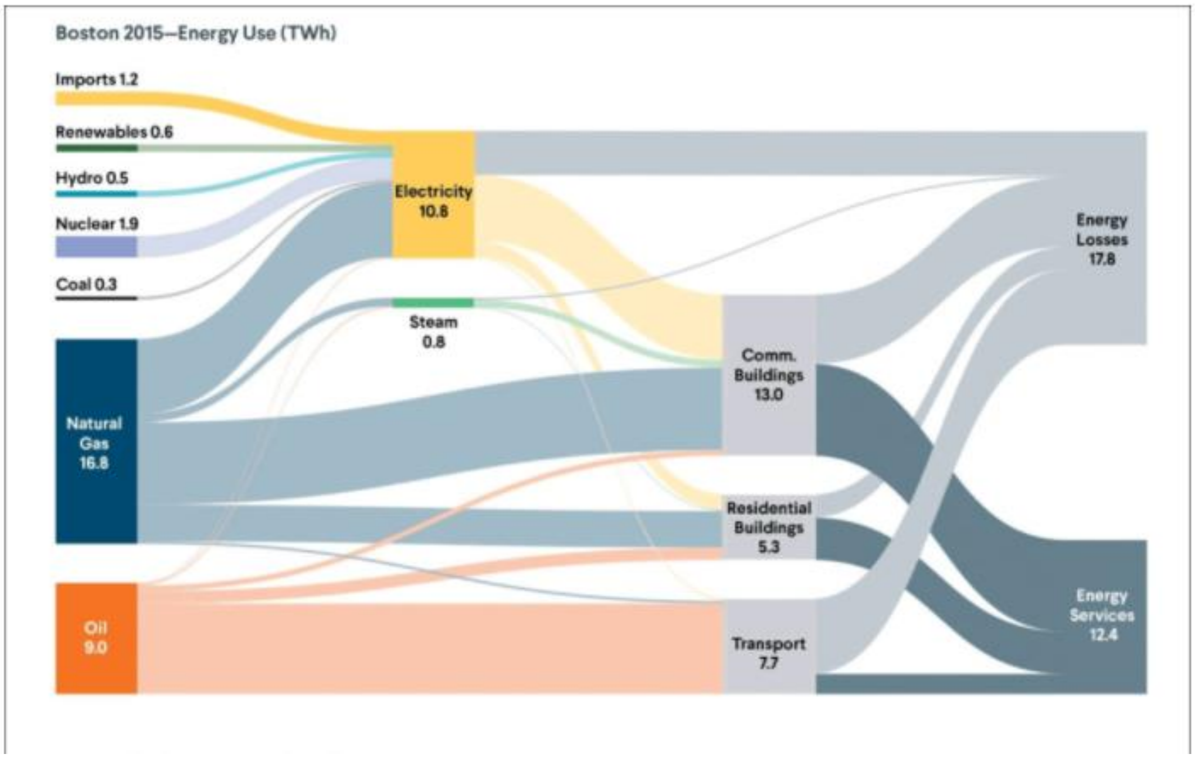
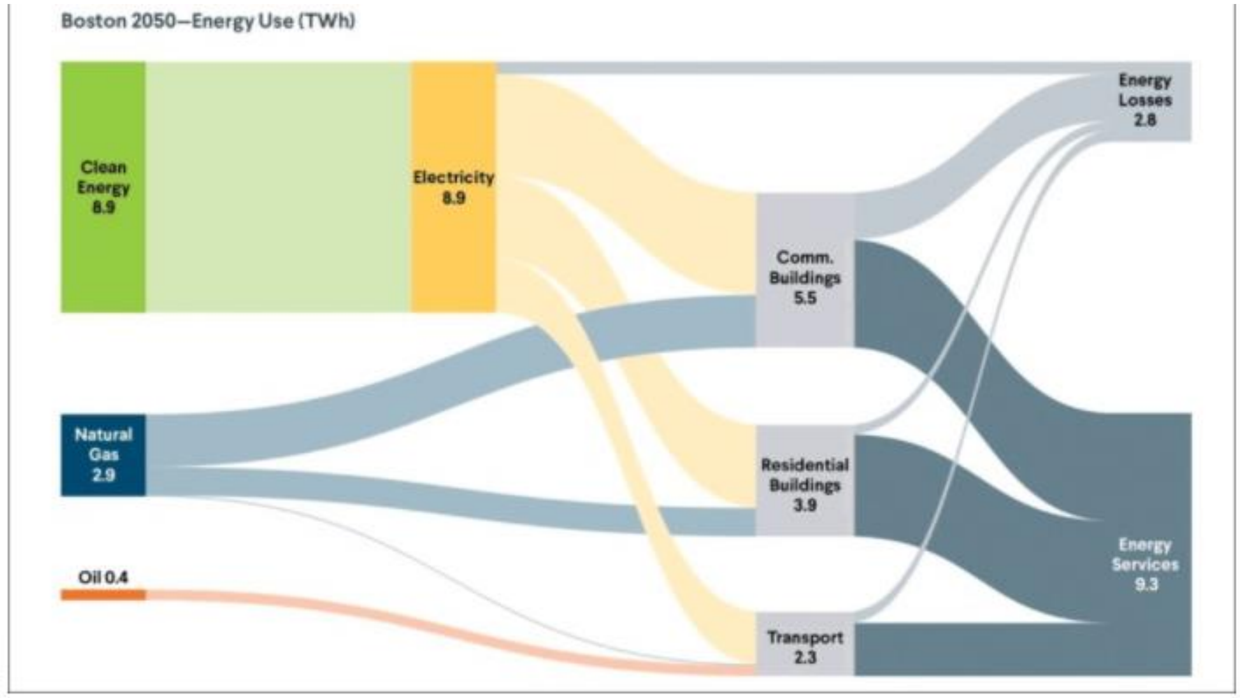


Figure: Use of energy in Boston in 2015



The top shows where Boston got its energy in 2015, and the bottom: where Boston could get its energy in 2050. (Courtesy of the Carbon Free Boston report)

Figure: Use of energy prediction in Boston in 2050

As with the second chart above, Boston city aims at having higher levels of clean energy consumption. By 2050, the city aims to have clean energy in common buildings, residential buildings, and clean energy in transport. In TWh measure, by 2050, oil consumption for energy will be 0.4, with natural gas being 2.9 while clean energy being 8.9.

City 2: Shanghai

Urban and historical context

Shanghai is a city in China and the country's east coast. Shanghai is humid, with a subtropical kind of climate. The summers in Shanghai are humid and warm, with the winters relatively warm. The winters in Shanghai are not characteristically snowy. As of 2019, there were 24 million residing in Shanghai, making it a megacity in China. The large population makes it necessary for the production of massive levels of energy present in the city.

Shanghai has abundant wind energy resources as one of the renewable energy resources. Before the 11th Five Year Plan, Shanghai, commonly used fossil fuels as the primary energy source for the city inhabitants (USC US-China Institute, 2007). As much as Shanghai has ample wind energy resources, there are minimal natural gas energy resources. The location of Shanghai, right

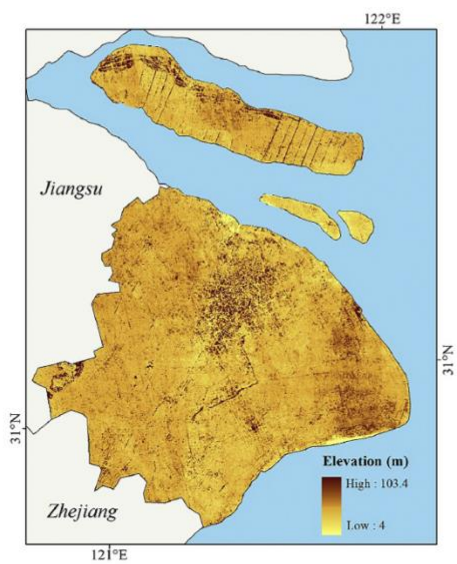


Fig. 1. Location and elevation of Shanghai.

beside the Yangtze River (se figure above), enables Shanghai to have access to abundant water resources. However, the elevation of Shanghai coastal area is not ideal for an efficient hydro power plant. As predicted by National Intelligence Council, "the demand for water and energy will grow by approximately40% and 50%" in 2030. So the inadequacy in renewable energy made using fossil fuels for the production of power an easy way out in the long-term development.

Also, Shanghai relies on energy imported from other provinces (see figure below). Only a small portion of the energy consumed in actually produced in Shanghai.

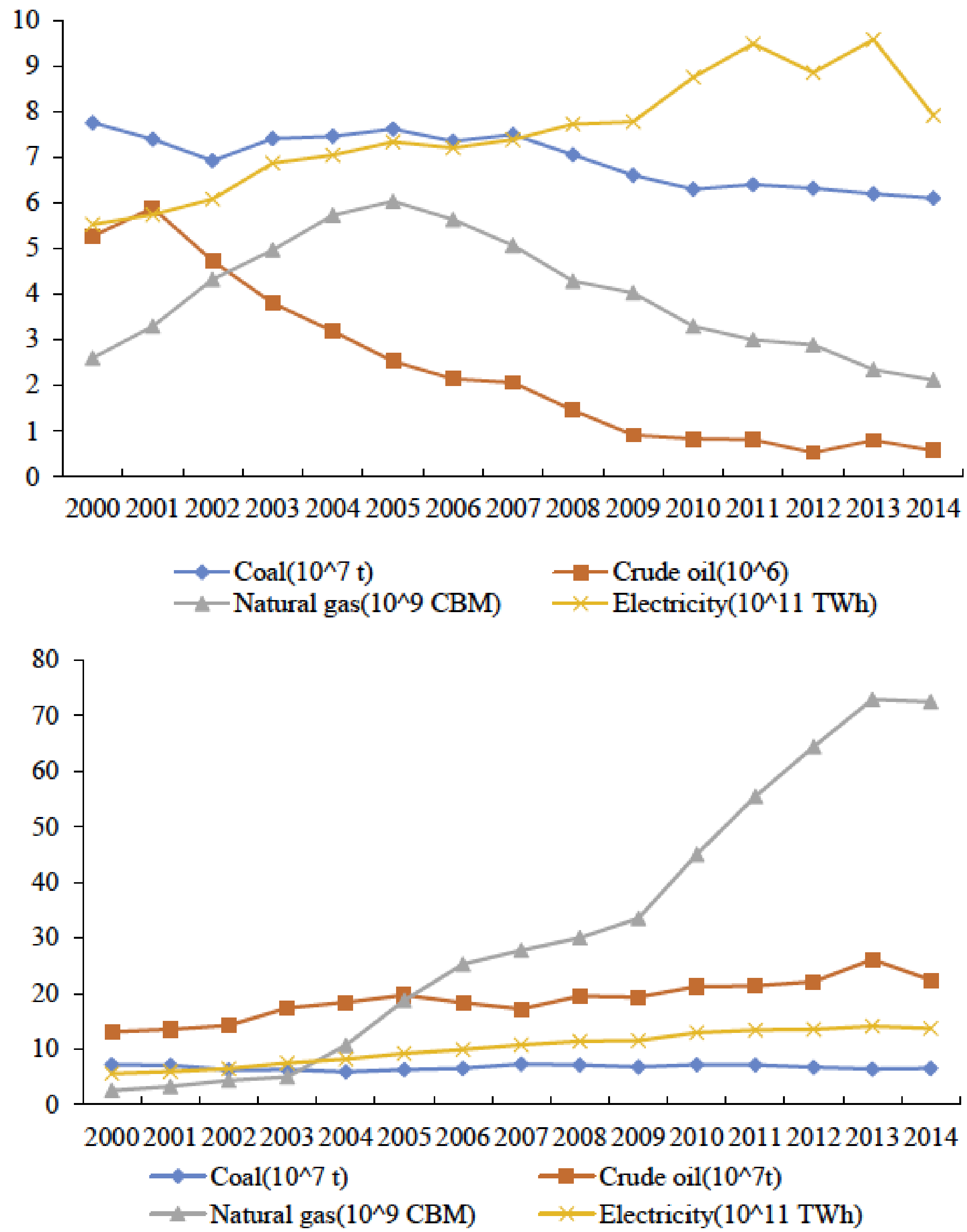


Fig. 3. Energy consumption in Shanghai, China.

Shanghai receives a total of 4658 MJ/ (M^2*a) radiation, with the total sunshine per year being received for 1997.5 hours (Xie et al., 2018). In summer, there are higher levels of global radiation in the city than in the winter. The highest global radiation levels reached in the city are approximately 800W per square meters in a year. Shanghai also has invested in-ground geothermal energy, with the city being divisible into rank suitable areas according to the bedrock. The shallow geothermal energy in the city is widely abundant with many reserves, as in the charts below. The city's geological conditions also make it easier to exploit shallow geothermal energy in the city with technology such as the GHSP system. The second chart shows the surface water energy in the city with the main sources of water in Shanghai being local water resources and transit water resources and the Yangtze River (Xie et al., 2018). The Yangtze River is a huge water source making filling up the deficit from local water sources. As abundant as water sources are, they are not mainly tapped for renewable energy production as the groundwater source heat pump is affected by river water or seawater compared with the popular ground heat solar heat pump (Xie et al., 2018).

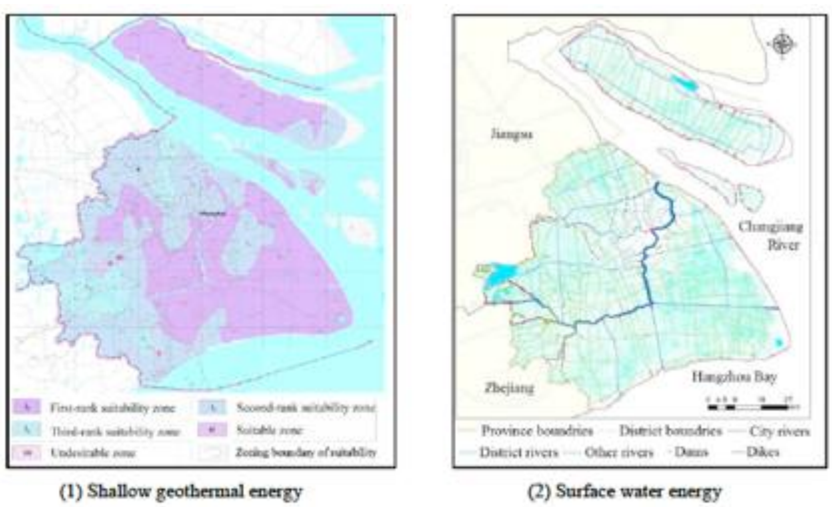


Figure: Shanghai geothermal and surface water energy distribution

The 10th Five Year Plan saw Shanghai devise a system that saw a renewable energy system. The city also used the FYP to finalize the technical innovations in the sector of clean energy. Moving on to the 11th Five Year Plan, Shanghai majored in developing a stable renewable energy system. The created system was one that was clean, safe, and cost-effective in its implementation. At the end of the 12th FYP, Shanghai had made strides in implementing clean energy policies, with the wind resources producing three times the energy produces at the close of the 11th Five Year Plan (Asia Pacific Energy, 2012).

Additionally, with the city's implementation of laws on renewable energy resources, the photovoltaic system had a supply capacity that was way over ten times at the close of the 12th FYP than the supply marked at the end of the 11th FYP. The Five-Year Plan's latest issue has been dealing with the increased need for innovation in renewable energy management. The FYP also details plans for implementing a more effective system for wind and solar power production.

Contrary to its current state as one of China's cities, which leads to integrating renewable energy resources in its infrastructure, Shanghai has not always been aiming to be a greener city consuming cleaner energy. With one of the country's largest populations, the city has always been faced with energy consumption constraints (Asia Pacific Energy, 2012). For years, energy produces from coal has been a simple and affordable energy choice for the residents. From the chart below, coal was a major energy source from 1994 to 2006. In 2012, a large percentage of China's electricity still came from coal (see figure on the next page), with Shanghai mainly contributing to the figures. Being a large consumer of coal, the city also contributes to its high carbon dioxide emissions levels. China is ranked with the highest carbon dioxide emissions from

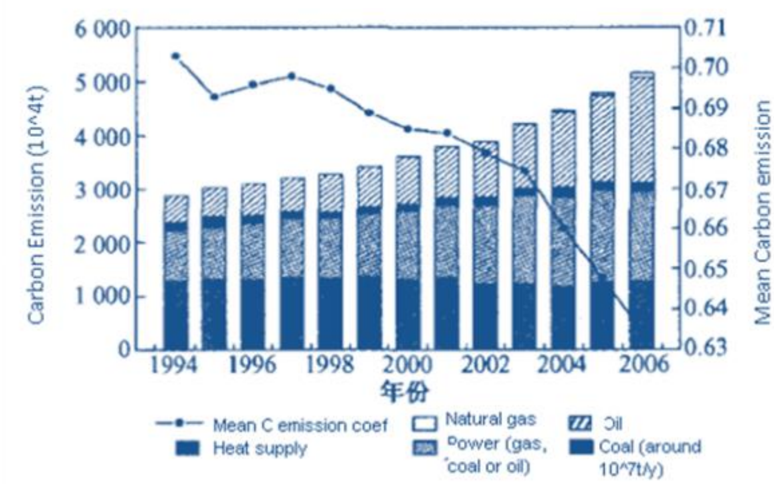
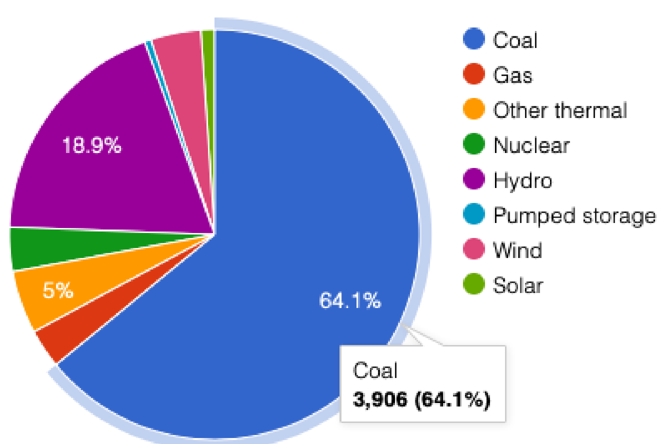


Figure 30 Carbon emission structure of different types of energy consumption in Shanghai, and mean carbon emission coefficient (ZHAO Min & al, August 2009)

2007 (Asia Pacific Energy, 2016). From the pollution that coal metes out to the environment and the resulting climate change, Shanghai's local government has been instituting changes to reverse the city's large coal energy consumption.

Figure 2: China's electricity mix in 2016 in TWh



Over the past few years, the country's government authorities have been implementing policies favoring renewable energy over fossil fuels' burning, as documented in the FYP.

Implementing the plans therein has brought remarkable changes to the state of the environment and contributed to the city's efforts in inching the country closer to its goals of using cleaner energy. Shanghai has recently immensely contributed to the country's production of technology on the integration of renewable energy. China has, in the past few years, been the leader in producing renewable energy. Shanghai is also one of the largest in the country in consumer technology to integrating renewable energy. Shanghai has also been increasing its investments in technology that incorporates renewable energy in its operations. The city is hugely involved in renewable energy consumption due to implementing the strategies in the FYP, which has contributed to China accounting for close to 40% renewable energy consumption growth in the world (The Shanghai Hub, 2020). The city implements wind power sectors, biomass energy, wind power, clean coal energy, and solar power energy.

Government and stakeholders

The central government authorities in Shanghai are the Chinese government and the Shanghai City Municipality Government. As one of the city's most significant stakeholders, the government structure is similar to Beijing. The companies dealing with energy and electricity in the city are also other stakeholders. Citizens in Shanghai make up the largest percentage of stakeholders concerning clean and renewable energy. As Shanghai produces electricity outsourced to other provinces in China, those provinces are also part of the shareholders. Every district government and Municipality in the city is also part of the stakeholders as they implement the plans on each district's grassroots levels. The stakeholders are the project developers who work on projects for low carbon emission and energy efficiency. Development banks in the city aid in funding renewable energy projects, with the Shanghai Pudong Development Bank funding such causes. The Bank of Shanghai is a stakeholder by all its buildings, green energy buildings with low carbon emissions, fitted with renewable energy sources.

The 10th meeting of the Fourth NPCSC was the insurance organ of the eleventh Five Year Plan for National Economic and social development (Government of Shanghai, 2006). The Five-Year Plan was to run from 2006 to 2010 with the insurance organ to oversee the policy's strategies. The insurance organ's policy was on national economic and social development in which renewable energy incorporation was also included. The body has been a stakeholder of renewable energy integration since 2006 with the start of the 2006-2010 Five Year Plan.

The State Council is also another stakeholder in the city's efforts to use cleaner energy. The organization is planning for the city's energy consumption as of 2006 to incorporate cleaner energy resources. The State Council enacted the policy on The Plan for Energy Consumption per Unit of GDP Targets among the Regions. The Council has repeatedly passed the procedure during every Five Year Plan with reviews and improvements to the system that accounts for the increase in the city's energy efficiency levels. The State Council is also concerned with the implementation of decisions on further strengthening the Energy Conservation Work. As a body that sees the implementation of renewable energy plans, it also makes decisions to save on energy with Shanghai's high energy consumption levels. Moreover, the Council is involved in implementing the Notice of the Implementation Plan for Energy Conservation and Emission Reduction policy. The council majors on policies covering energy conservation, promoting energy efficiency among the residents, and commercial activities.

Shanghai Municipality is the city's principal government authority and is therefore very much involved in instituting renewable energy in Shanghai. Significant policies that are implemented are always suggested and planned by the Shanghai government. The Shanghai city government has implemented policies on the Shanghai Energy Conservation Regulations and is involved in the amendment of the policy name. Furthermore, it actively participates in the system on the Shanghai Building Energy Management Approach. Most importantly, it is the governing body of implementing renewable energy policies in the Five-Year Plans. It strategizes on energy following the plans laid out in the FYP. The Shanghai Government implements the FYP plans concerning renewable energy conservation in the city, energy development on emission reduction, conservation regulations, energy management, energy efficiency, and energy-efficient building design standards.

Private companies in Shanghai make part of the stakeholders include the Shanghai Topsolar Green Energy Company Limited, which is mostly concerned with the production of batteries used together with solar power panels (Bloomberg, 2020). The company manufactures photovoltaic cells and solar power production systems for commercial purposes for the city's residents. The Shanghai Laogang Renewable Energy Company Limited is involved in landfill gas power (Bloomberg, 2020). By producing renewable energy, green energy companies pivot the city to meeting its clean energy objectives.

Electricity distributors are also important stake holders of the implementation of renewable energy. In China, there are two main companies that are involved: The State Gird Electric Power Company, a State-owned Enterprise; and the China Southern Power Grid, a Central Government-owned Enterprises. In Shanghai, the State Grid Shanghai Municipal Electric Power Company is responsible for all the electricity distribution, with its sub-district companies control different district in Shanghai.

City's objectives

Shanghai's objectives concerning integrating renewable energy resources in its current infrastructure are in the Five-Year Plans' policies. The paper will review past FYPs, from the 11^{th} to the 13^{th} Five Year Plan. Documentation of Shanghai's objectives in integrating renewable resources in its infrastructure has been in the Five-Year Plans of the 11^{th} FYP to the 13^{th} FYP. The city planned to reduce the carbon emission intensity by 19%, together with a drop of 18% on energy intensity by 2015. The city also had a goal, according to the 12^{th} FYP, on energy conservation and climate change to reduce the annual energy consumption to 950,000 tons by 2015 (Asia Pacific Energy, 2016). The 12^{th} FYP also outlined the goal of 'Accelerating the implementation of the construction of an energy consumption monitoring system for a public building.' From this policy, Shanghai aimed at improving its energy-saving systems on buildings across the city. There was the establishment of 17 Energy Monitoring District Sub-Platforms and a Municipal Office Building Energy Consumption Sub-Platform. The building on energy consumption sub-platform would house the energy consumption rates analysis and monitor the city's energy consumption in public and municipal buildings. The 17 sub-platforms would accommodate statistics on energy consumption.

As in figure 4, by 2030, the city had an aim to have decreased the consumption of oil and coal as sources of energy while having upped the consumption of natural gas. The Municipality of Shanghai projected that Shanghai, in terms of Energy Consumption per petajoule, would have surpassed the 3000 marks of natural gas energy consumption. By 2030, coal consumption would have reduced to below 1000 petajoules with even a lower carbon imprint from coal consumption. Oil consumption was projected to reduce through the decade from 2020 to 2030 to below 2500 petajoules. The city also aimed to have a lower carbon imprint from the consumption of oil as a source of energy to a level of below 200 carbon emissions by 2030.

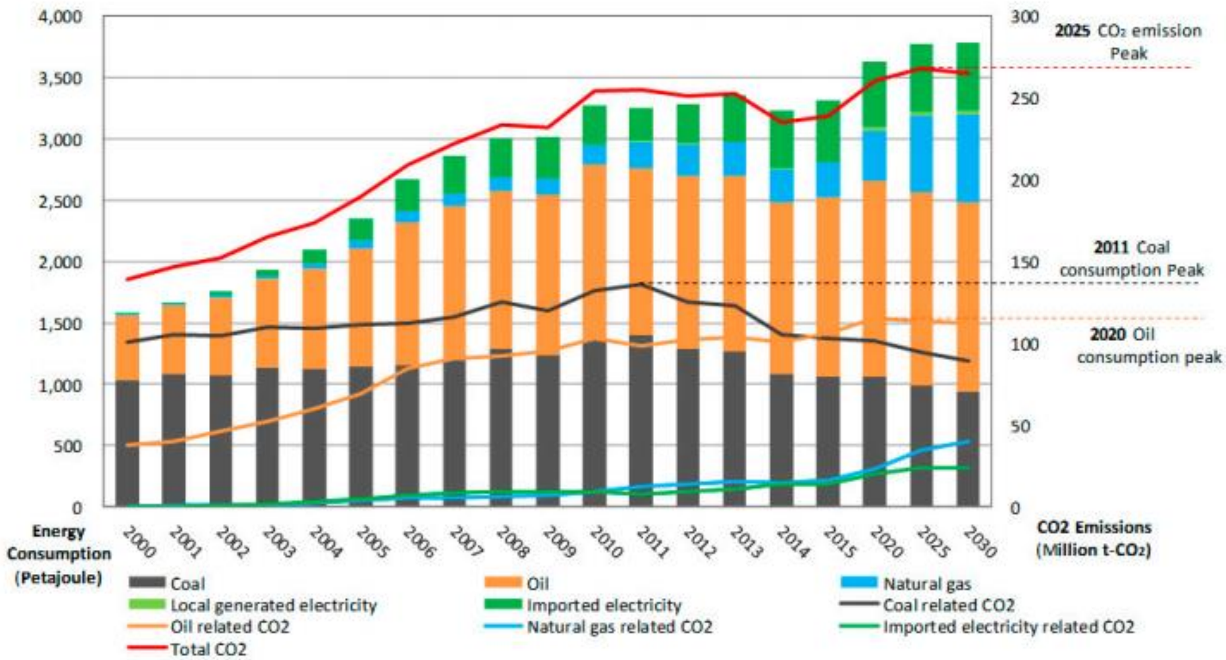


Figure: Trends and Predictions of Shanghai's energy consumption and energy related carbon emissions from 2000 to 2030

With the implementation of the 12th FYP, Shanghai aimed to have a substantial decline in the consumption of coal, with reduced carbon emissions, with a peak by 2025. The city aims to have an increase in the imported clean electricity together with an increase in the consumption rates of natural gas. Coal related carbon emissions are predicted to decline with the decline in coal consumption around the city. From the 12th FYP, the city government of Shanghai planned to reduce Shanghai's energy intensity by 3% in 2014, majorly contributed by the shift from coal to natural gas as sources of energy. In 2014, it aimed to reduce the growth of carbon dioxide emissions to 8.5 million tons (Reuters, 2014). This would be implemented to achieve the plan to cap the total energy consumption by 34.64 million tons by 2015. The 12th FYP period would also see the city increase its electricity imports and the consumption of natural gas and motivate the residents on the use of distributed gas and renewable energy resources such as wind, solar, and biomass. From 2011-2015, the city would also implement policies against the inception of new manufacturing sites for iron and steel and all non-ferrous materials. From the 2010 energy intensity levels, Shanghai planned to have an 18 percent reduction.

Moreover, Shanghai planned to focus on the Changning District on 'Low Carbon Development Special Funds Management Measures.' The policy issued in January 2013 was to be useful for three years under which project developers of Changning District would receive subsidies (World Bank, 2019). Support would be given to the renovation of old buildings to match the energy-saving standards, construction of new buildings fitted with energy-efficient systems, and projects on low carbon-emitting transport systems. The Shanghai government in 2016 issued a policy on 'Special Support Measures for Building Energy Saving and Green Building Demonstration Projects,' which focused on setting up special funds for measures on energy conservation and lowering carbon emission levels. The funds would be directed to constructing green buildings for residential and commercial purposes, especially facilities with projects to install solar energy panels and integrate geothermal energy in their operations.

The '13th Five Year Plan for Energy Conservation and Climate Change' issued by the Shanghai Municipality in March 2017 planned on awarding buildings with ratings to ensure that they followed the set standards in energy conservation (The Shanghai Hub, 2020). Existing buildings in the city would be fitted with technology for low carbon emissions. The Shanghai government set to accomplish a carbon intensity reduction by 20.5% and a 17% drop in energy intensity by 2020 compared to 2015 levels.

With a focus on Changning District, Shanghai's municipal government issued a policy in May 2018 on 'Low Carbon Development Special Funds Management Measures' with the measures helping to fund projects contributing to low carbon emissions in the city (World Bank, 2020). The funds would be directed to buildings being renovated and seek to meet the energy-saving standards. Subsidies would also be given to structures that would adopt new management systems to manage energy consumption in a building better. The funds would also support projects on low carbon emission incorporation with the Shanghai Green Renewal Project, with the title's winners receiving ¥250 000 (World Bank, 2020). Also, the Shanghai municipal government, in 2018, per the 13th FYP, issued the 'Public Buildings and Large Buildings Energy Monitoring System Management Measures' policy. The policy concerns setting up an energy monitoring system for large buildings, institutions, and establishments from 2018 up to 2023. The monitoring system's establishment would be in every district in e city, with collaborative efforts between the district government, Ministry of Housing, and urban-Rural Development in Shanghai and the Development and Reform Commission. From this policy, all the residential buildings in the city are required to meet the GBEL ratings.

There would be energy efficiency management measures after the review of the previous measures implemented in 2013 (World Bank, 2020). The district would set up a center for piloting projects on low carbon emissions in the area. The center would monitor large buildings with an area of 20 000m squared or more on their energy consumption and carried out energy-efficient projects in the area, focusing on low carbon emissions. The timeline for implementing this project would be op to 2020 from 2018 (World Bank, 2020).

Shanghai Changning Economic and Technological Development Zone

Figure: The green economic and technological development zone in Changning district. Photo from the Urban Regeneration and Low Carbon Project Management Center, Changning District in Shanghai.

Implemented strategies

In 1986, the Ministry of Housing and Urban-Rural Development (MOHRUD) initiated the Domestic Building Energy Conservation Standard in China. The ministry also released the National Standard Evaluation Standard (GB/T503782006) in 2006, a three-started system for rating the performance of sustainable buildings (Mohruds, 2016). It has then since been involved in the formulation of building codes to ensure that there is efficiency in building energy and performance in constructing sustainable buildings. The charts below show energy performance measurement and evaluation as with the standard of the green building.

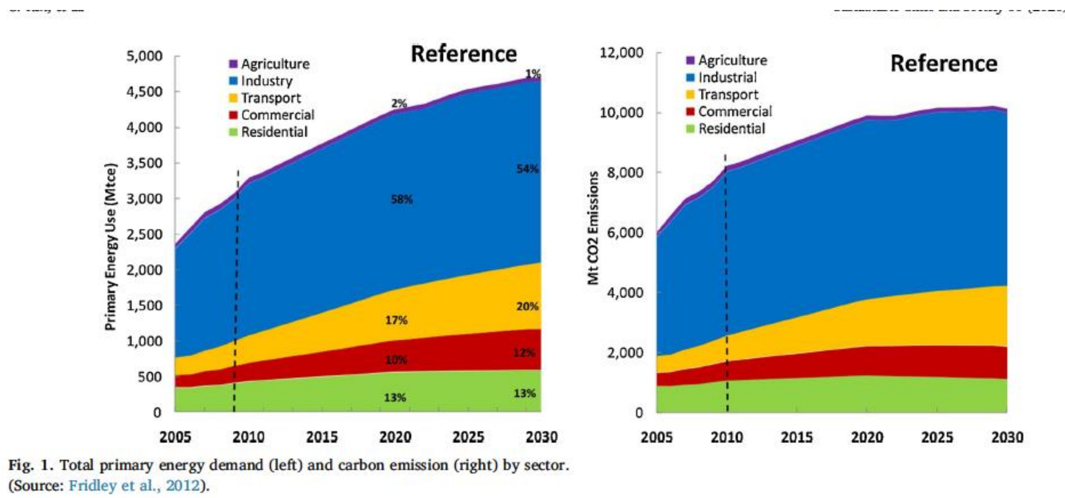


Figure: Total primary energy demand (left) and carbon emission (right) by sector in Shanghai from 2005 to 2030

From the 11th FYP to the 13th FYP, new innovative policies were developed on constructing green energy buildings. The policies were on how renewable energy would be integrated into new buildings and fitted in old buildings undergoing renovation. The NZE Hongqiao Guest House was part of a project where old buildings were being retrofitted with energy-efficient systems in 2017 (World Bank, 2019). At least one project was completed under the Five-Year Plans' strategies to construct a building with almost zero carbon-emitting rates. The development of a funding system was directed towards building energy-efficient buildings and fitting old buildings with energy-efficient systems. The period also saw the establishment of at least one center on distributed generation. The completion of a study in 2015: Public building energy baseline, which initiated conversations on the integration of renewable energy in the city between the Shanghai Municipal Government and the city's constituent districts. By 2013, the city's districts had created a development fund to invest in low carbon projects.

The city also achieved other studies that gave recommendations on implementing strategies concerning technology supporting renewable energy in the town, on the policies on low carbon emission, and mechanisms on integrating energy-efficient systems in old and new buildings throughout the city. The studies were completed from 2007 to 2018 during the 11th FYP and 13th FYP (World Bank, 2019). The town achieved building design on the distribution of clean energy throughout the city to establish greener communities, where all the districts would have access to renewable energy.

The city increased its support of low carbon-emitting buildings by providing project management to the construction of green buildings, construction of buildings installed with renewable energy sources, and low carbon energy distribution throughout the city. In this regard, the city has implemented its policy on commencing the establishment of low carbon-emitting communities. There were studies carried out on green buildings' policy, there being recommendations on the steps to take in fitting renewable energy in public buildings in the city. There was also establishing an energy consumption platform that has continued improving through the years, with the software able to monitor residential and commercial buildings in all the city districts. There was also the development of a funding system for green energy buildings, whether in the private or public sector. Finally, there was a survey mechanism by which evaluations on the green building would be carried out concerning energy efficiency in green energy buildings.

Solar panels on the roofs of the Shanghai Mart. Photo credit: Urban Regeneration and Low-Carbon Project Management Center, Changning District, Shanghai

Figure: Solar panels on Shanghai Mart

On creating low carbon-emitting communities, there was the establishment of an electricity scheme that uses renewable energy. The project was completed as a pilot project on low carbon emissions. The renewable energy project for Wuyi Road commenced creating more green communities (World Bank, 2019). The city also achieved project management aid by training the project developers and the city's involved banks. The city is one of the seven regions in China chosen by the national government in spearheading the implementation of policies on carbon trading. Even though the levels of carbon emissions and consecutively pollution are not as high as in Beijing's capital, Shanghai is one of the largest cities in the country with high carbon emission rates. Therefore, Shanghai was a piloting region in a bid to cap the carbon emissions as part of the national government's trading scheme (Reuters, 2014). Its piloted carbon trading from 2013 in almost 200 power generation and manufacturing sites. The trading scheme on reducing CO2 emissions in the city was also carried out in facilities dealing in petrochemicals, aviation, and ports.

In line with the 13th FYP, Shanghai has been promoting the enacting of GSHP technology to integrate renewable energy resources and, precisely, geothermal energy. Additionally, to promote the integration of renewable energy resources, the city has also been using the solar hot water system (SHW) and the solar photovoltaic system (PV). The GSHP technology is a system on ground source heat pumps that uses underground pipes in extracting heat from the ground. The SHW system is a solar hot water low energy-intensive system that uses solar energy for heating water. On the other hand, the solar photovoltaic system is a power system for the supply of solar power through photovoltaics. The city has seen the flagship of more than 500 engineering projects with the application of GSHP (Xie et al., 2018). The projects are on both residential and public buildings. GSHP technology has mainly been used in public, office, and hotel buildings. They make up more than 47% of the total projects under this initiative. Through the GSHP system, the city is economically integrating renewable energy as the investment recovery period with the heat pump units having a life of up to 20 years. As to measured and calculated data, GSHP offers stable energy saving with values averaging 15% (Xie at al. 2018). As with the application of GSHP technology, Shanghai has also been incorporating the SHW system, which is also economical with its life span of approximately 15 years. The PV system has mostly been incorporated in residential and cultural buildings yielding the highest energy saving date in the two buildings. It has also been incorporated in sports facilities and education centers.

Moreover, the city achieved an increase in the investments injected towards building integrated with renewable energy. Mostly, the investments were directed to new buildings coming up in the Changning district. From the investments, there was a reduction in the rates of carbon emission in the district. There was also an increase in investments geared towards fitting old buildings with renewable energy. There was also an increase in the investments directed towards promoting energy efficiency in old buildings to fit energy management mechanisms. New buildings being constructed also saw additional investment for the installation of energy-efficient systems. Apart from supporting the construction of green buildings, the city also supported other renewable energy initiatives to get the city to consume higher levels of renewable energy.

The chart below shows all the powerplants based in Shanghai. While the natural gas and

Thermal power stations [edit]

Coal-based

Station	Name in Chinese	Coordinates	Capacity (MW)	Operational Units	Under Construction Units
Waigaoqiao Power Station	外高桥电厂	31°21′21″N 121°35′50″E	5,000[1]	4*300MW, 2*900MW, 2*1000MW	
Shidongkou Power Station	石洞口电厂	31°27′49″N 121°24′15″E	3,600	4*300MW, 4*600MW	
Caojing Power Station	漕泾电厂	30°45′36″N 121°23′59″E	2,700	2*1000MW, 2*350(IGCC)	
Wujing Power Station	吴泾电厂[2]	31°03′31″N 121°27′56″E	2,400	4*300MW, 2*600MW	2*300MW
Baosteel Power Station	宝山钢铁自备电厂	31°26′41″N 121°26′10″E	1,200	1*150MW, 3*350MW	
Shanghai Petrochemical Power Station	上海石化自备电厂	30°41′55″N 121°16′40″E	375		

Natural Gas Based

Station	Name in Chinese	Coordinates	Capacity (MW)	Operational Units	Under Construction Units
Lingang LNG Power Station	临港燃气电厂	30°51′03″N 121°47′16″E	1,400	4*350MW	
Minghang LNG Power Station	闵行燃机示范工程		1,213		1x468MW, 1x745MW
Shidongkou Power Station	石洞口电厂	31°27′49″N 121°24′15″E	1,197	3*399MW	
Chongming LNG Power Station	崇明燃气电厂	31°35′18″N 121°28′28″E	848	2*424MW	
Fengxian LNG Power Station	奉贤燃机电厂	30°58′33″N 121°29′46″E	720	4*180MW	
Shanghai Chemical Industry Thermal Power Station	上海化工区热电联供	30°47′33″N 121°27′00″E	656	2*328MW	

Wind power [edit]

Station	Name in Chinese	Coordinates	Operational Capacity (MW)	Operational Units	Under Construction Units	Planned Units
Donghai Bridge Wind Power Farm*	东海大桥海上风电场	30°45′43″N 122°0′15″E	102[3]	34*3MW		
Nanhui Wind Power Farm	南汇风电场	30°57′31″N 121°55′13″E	16.5	11*1.5MW		
Chongming Dongtan Wind Power Farm	崇明东滩风电场	31°31′14″N 121°55′57″E	4.5	3*1.5MW	10*1.5MW	
Chongming Beiyan Wind Power Farm	崇明北沿风电场	31°35′41″N 121°50′30″E				24*2MW
Fengxian Bay Wind Power Farm	奉贤海湾风电场	30°48′53″N 121°30′36″E	3.4	4*0.85MW	4*2MW	

- Donghai Bridge Wind Power Farm is the first marine wind power farm in China.

Solar power [edit]

Station	Name in Chinese	Coordinates	Operational Capacity (kW)	Under Construction Capacity (kW)	Planned Units(kW)
Hongqiao Transportation Hub Solar Power Station	虹桥车站太阳能电站	31°11′45″N 121°18′58″E	6,688[4]		
Chongming Solar Photovoltaic Power Station	崇明太阳能光伏电站	31°43′18″N 121°30′38″E	1,046[5]		
Shanghai Lingang Solar Photovoltaic Power Station	上海临港太阳能光伏电站	30°53′08″N 121°49′28″E	1,080[6]		

coal-based powerplants that produce thermal power account for majority of them, there are several small-scaled wind power plants and solar power plants in Shanghai. Although not installed in Shanghai, China's first 8MW Offshore wind turbine is installed by Shanghai Electric in Fujian Province in 2020, which will also be used in providing energy to the city. This is a milestone indicating the start of the mass-produced-commercial-used Chinese 8MW Offshore Wind Turbine. It is also worthy to notice that the China Energy Conservation and Environmental Protection Group Headquarters is proposed to be completed in Shanghai in 2020 but was delayed due to the COVID-19 pandemic.

Impact of strategies

The earlier years shows a rapid increase in GHG emissions in Shanghai from 1995 to 2007. However, there's a steady decrease in the GHG intensity which indicates there's less

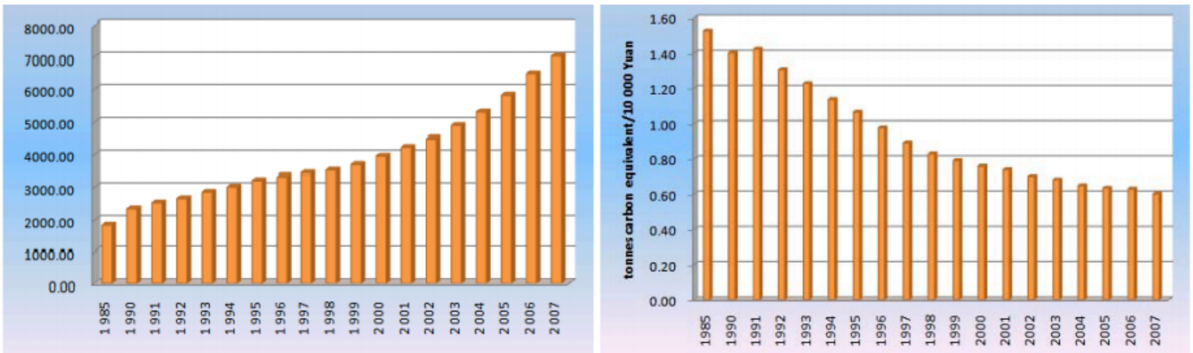
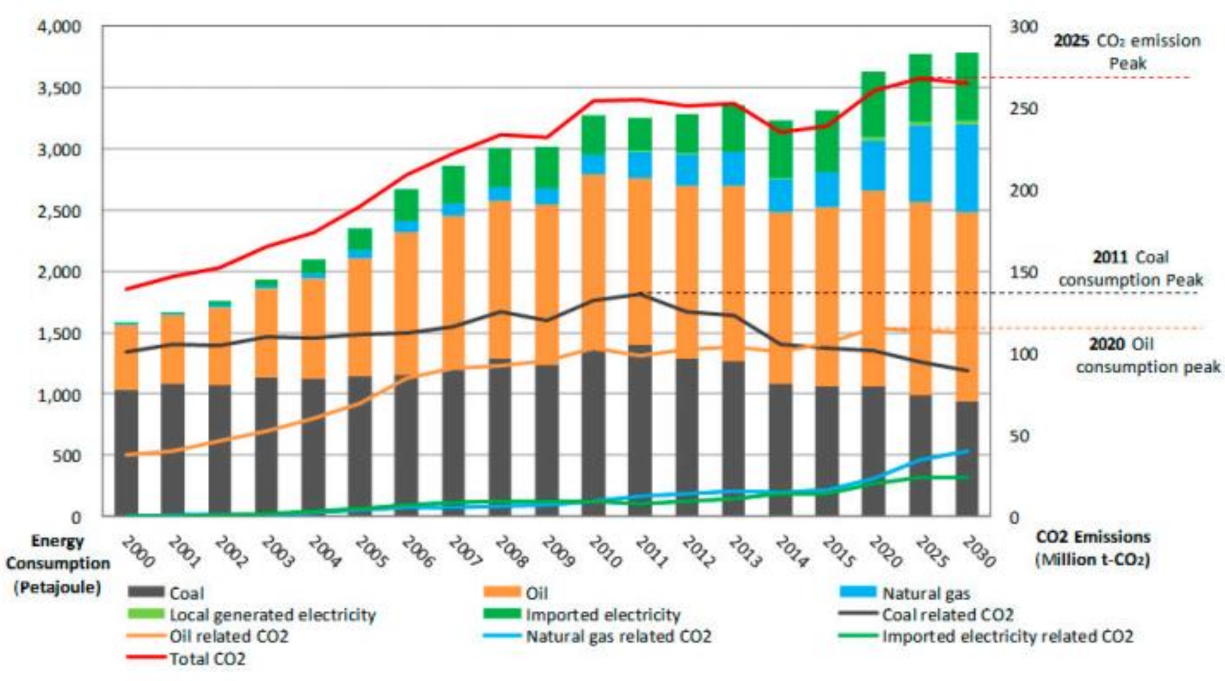


Figure 29 Figure: Left: Total GHG emissions in Shanghai (tons of Carbon equivalent); Right: GHG intensity of Shanghai economy (tCeq/10000RMB) (Niu & Al, CO2 Emission Reduction in Shanghai:Responding to Climate Change Mitigation, 2009)

GHG emitted to produce the same amount of gross domestic product. The graph below shows the overall trend of the city's energy consumption and the CO2 emission from 200 to 2030. The total energy consumption remains a rising trend, with relatively decreased rate of increase in CO2



emission since 2010. There's a continuous decrease in the consumption of coal since 2011 while during the previous years, coal consumption was still at a significant level. There's a lightly increase in the local generated electricity since 2010, but still rely on more imported electricity.

Shanghai has been increasing its capacity to produce hydropower with its contribution to the country, producing 1150 terawatt-hours in 2016 (The Shanghai Hub, 2020). The production of electricity from hydropower has been on the rise, with the highest mark reached in 2016, accounting for approximately 18% of the electricity sources (Shanghai Hub, 2020). Residents of Shanghai have taken up the consumption of electricity from hydropower to move towards cleaner energy. From the increased hydropower proportion relative to the national total generating capacity increased from 16.0% to 19.7%, Shanghai has set higher goals of more massive electricity consumption from hydropower by 2050 (Zhang et al., 2017). Shanghai aims to contribute to the country's hydropower capacity of 150GW by 2050. It has resulted from the successful implementation of the hydropower production goals in the FYP.

Secondly, there has been a notable increase in the city's wind power production with the 8MW-167 offshore turbine from the implemented strategies, as documented in the FYP from the 11^{th} to the 13^{th} FYP. Shanghai Electric has been involved in installing an 8MW offshore turbine set to increase the production of wind power to 26GW by 2025 and has also been involved in delivering wind power energy solutions to the city (Onag, 2020). In Shanghai, wind power production is growing at an extremely fast rate compared to other renewable energy sources. The policies instituted by the Shanghai city government in promoting wind power production include tax and financial incentives. The guidelines encourage Shanghai residents to take up more projects on wind power energy production. Additionally, the local government's fiscal incentives encourage the residents to substitute the burning of fossil and fuel oils for energy with wind power energy (World Bank, 2019). The output of energy from wind power plants in Shanghai is expected to grow, and further implementation of plans will see the installed wind power capacity in the city rise. The city is taking steps towards increasing renewable energy resources from increasing wind power energy consumption rates.

Furthermore, the computation of the carbon intensity per unit of GDP in the city's districts has reduced the carbon emissions from the increased investments geared towards constructing energy-efficient buildings. Initiatives on integrating renewable energy in the city have been receiving attention from local and international leaders who can then initiate such projects in other areas. The green energy projects in Shanghai are, therefore, having an impact in other areas when replicated. The retrofit of the Hongqiao State Guest Hotel Building To an almost zero carbon-emitting establishment has resulted in the replication of the project on another building on Neijang Road, Yangpu District (World Bank, 2020).

The city has an easy time assessing public buildings' energy consumption in the city from establishing the online energy evaluation platform. The Shanghai Municipality can also manage and verify the energy consumption and efficiency in the buildings. Establishing a funding mechanism for constructing green buildings has led to a remarkable increase in the investments injected into integrating renewable energy in Shanghai's infrastructure (World Bank, 2019).

Table 1. The static recovery periods of SHW.

Collector types	Flat plate collector	Vacuum tube collector	Glass U-tube collector
Initial increase in investment(¥/m^2)	900-950	680-800	2800-2900
Annual cost savings(¥/m^2•a)	360	360	360
Static investment recovery period (a)	2.50-2.64	1.89-2.22	7.78-8.06

As with the table above, Shanghai has found it economical to use the SHW system, having a static investment recovery period of 2.50-2.64 of the first plate collector. The vacuum tube collector in the system and the glass U0tube collector both have an investment recovery period of 1.89-2.22 and 7.78-8.06. All the collectors have an annual cost savings of 360 ¥ per square meter. As in the chart below, the GSHP system has an energy-saving rate of above 10% in all projects embarked by the city with an average energy saving rate of above 15% in all projects.

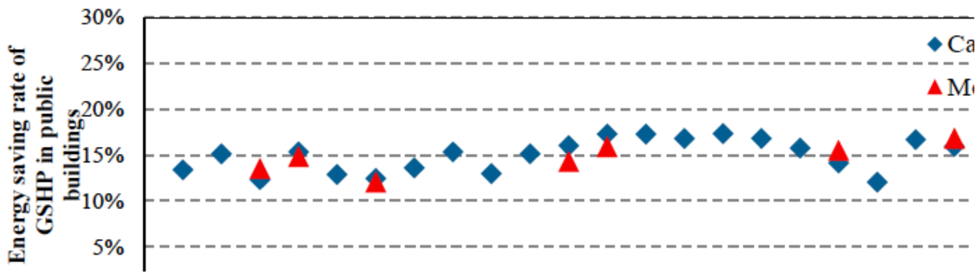


Fig 5. Energy saving rates of GSHP system in different projects.

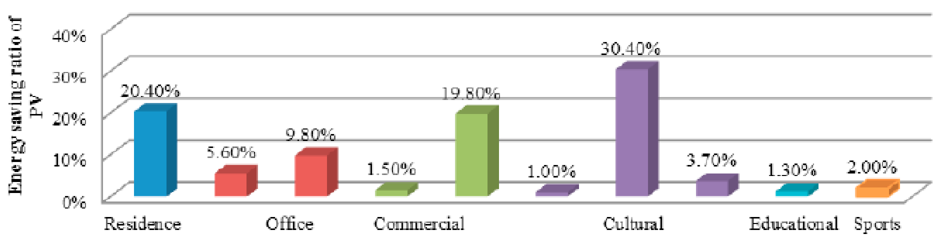


Fig. 4. Energy saving rates of PV system in different building types.

The city's solar photovoltaic system projects have an energy-saving rate of 20.4% in residential buildings, with the highest rate being 30.4% on cultural buildings. As in the graph above, the PV system has an energy-saving rate of 1.5% on commercial buildings, 2% and 1.3% on sports facilities and educational institutions.

City 3: Beijing

Urban and historical context

Beijing is the capital city of China, which is to the northeast of the country. Climatically, the city is mostly influenced by monsoons, with the summers being very hot and humid, with the winters being conversely cold and dry. Urbanization in Beijing has been on the rise for the last two decades, with a tremendous increase between 2000 and 2009. During that period, the urban extent in the city more than quadrupled. With urbanization came greater industrialization with excess amounts of fossil fuels being burnt. The burning of fossil fuels in the many manufacturing sites that had sprung up saw an increase in environmental concerns. Environmental issues such as smog came up due to the emission of burnt fossil fuels. With the wave of urbanization also came an uptake of energy in the city. The consumption of energy rose between 1997 and 2007, from 37.2 million tons of standard coal to 62.9 million tons (Asia Pacific Energy, 2012). The rise was an annual increase in the energy consumed. However, even with the rise in energy consumption, the city accounted for only 6% of the total energy consumed in 2007. Beijing was drinking a lot of energy drawn from other provinces in the country.

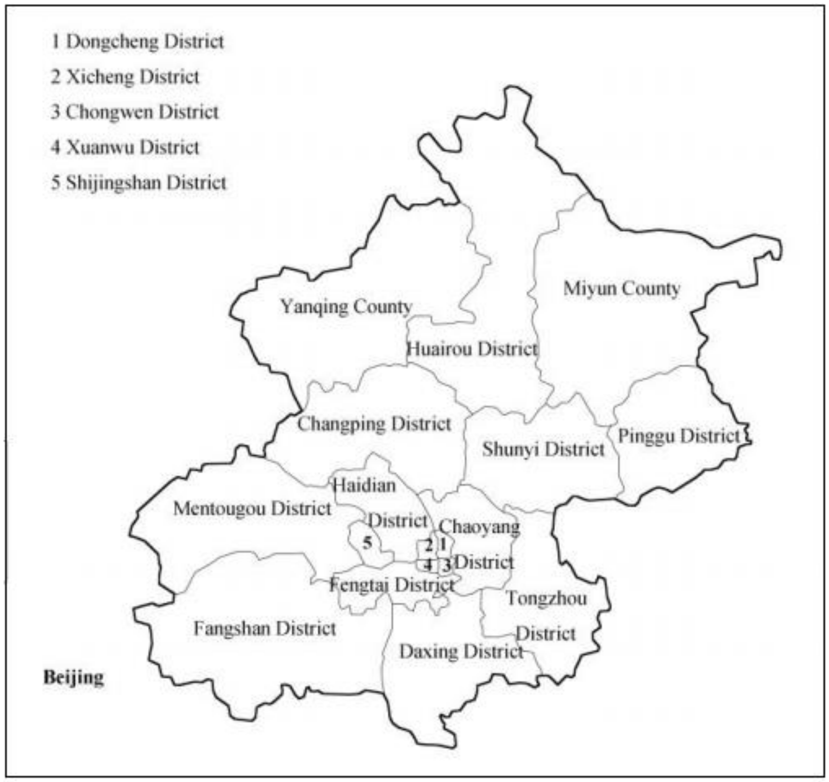


Figure 7: Districts in Beijing, China

There is an abundance of solar, geothermal, and biomass energy in Beijing, while there are fewer resources to tap wind energy from and fewer yet water energy resources. For a long time, the city largely depended on fossil fuels for its energy production until 2006. As in the graph below, the solar energy availability in the city is 31.9% in proportion, with the proportion of geothermal energy being 27%. On the other hand, wind energy is 1.2%, with small hydropower and biomass energy being at 04% and 39.5%, respectively.

Table 1
The amount and availability of Beijing's renewable energy resources [11,12].

	Amounts (10^4 tce)	Proportion (%)
Renewable energy resources	3860	
Availability	720	100
Biomass energy	284.4	39.5
Solar energy	229.68	31.9
Geothermal energy	194.4	27
Wind energy	8.64	1.2
Small hydropower	2.88	0.4

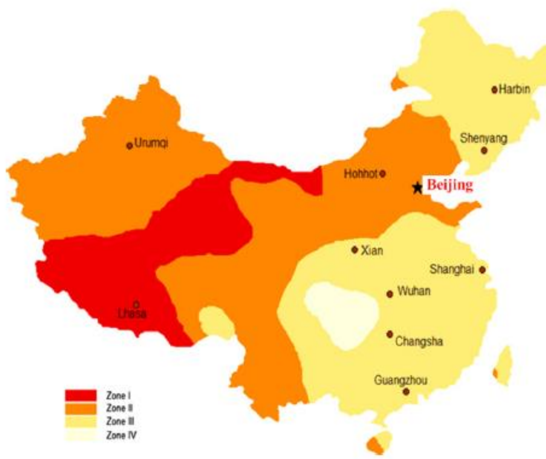


Fig. 1. Solar energy resource distribution in China [17].

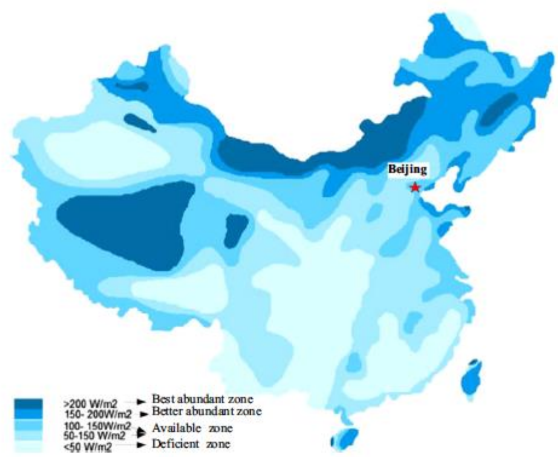


Fig. 2. Distribution of China's wind energy resource [15].

Figure: Distribution of China's solar energy and wind energy

As with the charts above, Beijing city is one of the areas with high levels of solar energy resources in China. The distribution of solar energy resources is high in Beijing compared with other regions such as Wuhan and Xian. It is in the second region of the most abundant solar energy resources. The city is also located in a well distributed region with wind energy resources, as in the second chart. The city is in a better abundant zone of wind power energy resources.

There was the implementation of locally integrating renewable energy resources in the 11th Five Year Plan (FYP). It was a strategy favoring renewable energy resources over fossil fuels that led to catastrophic environmental occurrences. The plan was focused on protecting the environment and promoting sustainability in the first stages of implementation. The plan enabled the use of renewable energy resources that would, in turn, serve to protect the environment from the danger being posed by the use and burning of fossil fuels. The 11th Five Year Plan in 2006 that incorporated the implementation of renewable energies has been one of the greatest strategies in promoting the use of renewable energy resources. Through the Five Year Plans, a system sees the incorporation of renewable energies in the strategies. Building a stable system of integrating renewable energies in the Five Year Plan has improved city development using renewable energy resources.

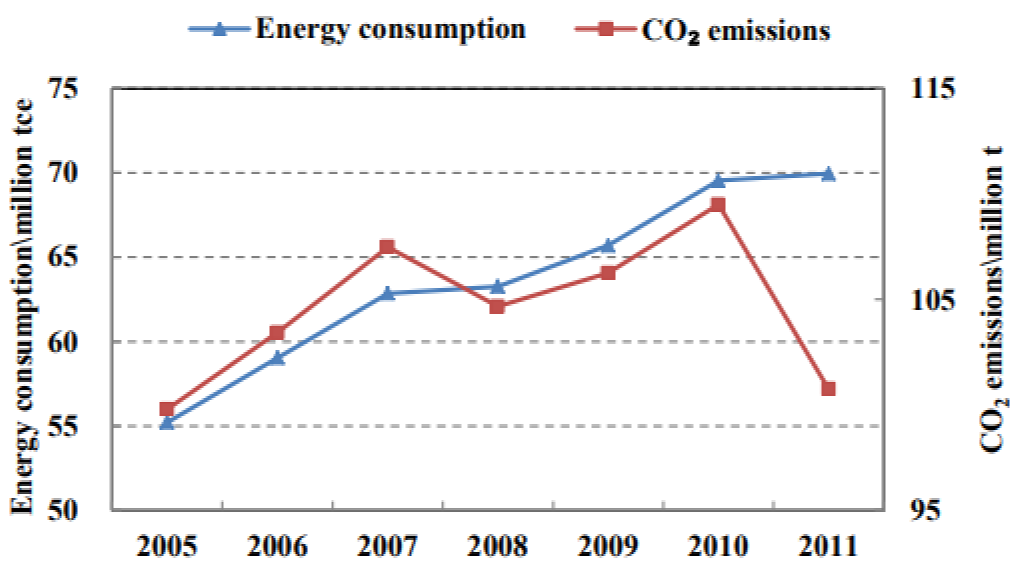


Figure: Beijing's total energy consumption and carbon emissions from 2005-2011

As in figure 8, Beijing has seen a reduction in carbon emission levels from 2005 to 2011, with the steepest drop in 2011there was approximately 100 million tons of carbon emissions produced. This was a far cry from the previous year, where there 110 million tons of carbon emissions. Figure 8 also depicts the gradual increase in energy consumption in a million per tons from 2005 to 2011.

Through the years of implementing strategies in the past Five Year Plans, Beijing has seen notable changes in the city's number of renewable energy resource projects. From the 11th to the 13th Five Year Plans, there has been a steady growth in renewable energy usage and a drop in the city's polluting factors (Asia Pacific Energy, 2016). The Beijing Municipal Commission of Development and Reform is one of the city's bodies concerned with implementing strategies in the FYP. As of 2019, the commission reported that the city's use of renewable energy equaled 7.6% of the total energy consumption. Compared to previous years, it increased renewable energy use, where the numbers have been too low. In 2010, the usage was only 3.3% of the total energy consumption. The increase of renewable energy consumption is also par with the city's attaining 8% renewable energy usage by 2020 (Xinhuanet, 2018). Therefore, the city is on the right racks according to its goals to be a greener city using clean energy to reduce polluting factors into the environment. Renewable sources such as solar power and biomass are mostly used in the city as energy sources. Solar power accounts for the largest amount for the largest percentage of renewable energy usage as of last year. 31% of renewable energy in the city came from solar power panels installed all over the city. With continued efforts on the part of the stakeholders in integrating renewable energy in Beijing's infrastructure, the city can achieve the goals set out in the Five Year Plans to be a greener city, thus contributing to control climate change worldwide.

Government and stakeholders

The main government authorities in Beijing are the Chinese government and Beijing's City Government. There are also the city's local decision-makers in Beijing as part of the government. Other stakeholders, other than the government bodies, include the energy and electricity companies in the city. The companies contribute to integrating and implementing renewable energies by adhering to the government bodies' laws on renewable energy. Of great importance in Beijing are the citizens and locals of the city as stakeholders, for they are the direct recipients of the effects of pollution from burning fossil fuels. The citizens are the ones affected by air pollution by smog and health difficulties from poor air quality.

The local government of the city has been at the forefront in promoting low-carbon development. The local government authorities are the main actors in pushing for integrating renewable energy resources in Beijing's infrastructure to mitigate severe climatic conditions. From the 11th FYP, there were efforts from the Beijing government in setting up programs encouraging the use of energy with low carbon emissions. Some promotions served to create awareness for Beijing residents and sensitize them on objectives on energy saving. The authorities reached out to the people identifying the goals set concerning energy consumption and saving on energy. The local government also endeavored to establish agencies that dealt with energy-saving initiatives in the city. The established agencies dealt with accountability on meeting the set objectives in reducing the rates of energy consumption. The local government was also in charge of coming up with relevant, actionable steps to meet the Chinese government's goals.

Apart from the local governments, the industries, manufacturers, and generally, the city's enterprises are vital stakeholders in integrating renewable resources in Beijing. Private companies in Beijing concerned with the production of green energy include Beijing Enterprises Clean Energy Group Ltd. It mainly generates photovoltaic and wind energy and involves the micro-grid network and geothermal power generation (Bloomberg, 2020). Beijing Energy International Holding Co Ltd is another green energy company in Beijing that mainly deals in constructing solar power plants. It offers solar energy projects development and investments and management. (Bloomberg, 2020). Additionally, it deals with wind and hydroelectric power generation and development projects. Additionally, it also pushes for developing renewable energy technology in the city with product testing and certification.

The public sector is of great importance when integrating renewable energy resources into the city. The China National Renewable Energy Center (CNREC) is one of the public agencies whose efforts in integrating renewable energy are felt in Beijing (CNREC, 2020). The center helps the city government carry out policy research on renewable energy and the management and coordination of renewable energy development projects. Additionally, it also pushes for developing renewable energy technology in the city with product testing and certification.

The city aimed at replacing fuels with carbon emissions with cleaner energy resources in commercial and residential buildings. Apart from enterprises with the production of goods and services, other city activities also contribute to GHG emissions. With the growth in infrastructure in Beijing, constructions are part of the day to day activities. Together with transport activities, the operations account for the direct and indirect carbon emissions in the city. From 2005 to 2010, there was an increase in the carbon emission levels by 41%. Therefore, the public sector is a critical factor in setting goals for lower carbon development in the city. With the pressure on the city and the whole country, in general, to reduce carbon emissions and reduce energy consumption levels, the public's energy consumption levels matter a great deal. The local government in Beijing targets the residents' consumption levels to transform to lower rates in energy consumption in either residential or commercial establishments. Beijing residents are also important stakeholders to enact policies together with the government on low carbon emission levels. Beijing has collaborative efforts with the residents to reach low carbon levels, guiding the residents' behavior on clean energy consumption and energy efficiency.

Just as Shanghai, electricity distributors are also important stake holders of the implementation of renewable energy. In China, there are two main companies that are involved: The State Gird Electric Power Company, a State-owned Enterprise; and the China Southern Power Grid, a Central Government-owned Enterprises. In Beijing, the State Grid Beijing Electric Power Company is responsible for all the electricity distribution.

City's objectives

The main strategies in incorporating renewable energy resources in Beijing in the current infrastructure has been in the Five-Year Plans for the city, dating from the 11th Five Year Plan in 2006 to the 13th Five Year Plan. Beijing's City Plans are the blueprint of the policies that the Chinese government aims at integrating locally, with the development and incorporation of renewable energy resources being one of them. In the 11th Year Plan on energy efficiency, a plan was set to reduce the energy consumption rate per unit of GDP by 20% (Asia Pacific Energy, 2007). The reduction rates were to cut across all the economic sectors of the country. As China's capital, the strategy was also to apply to Beijing as a city with one of the population's highest numbers. From the FYPs, the city was to cut the greenhouse gas emissions in line with the country's plan of reducing GHG emissions by 40%-45% per unit of GDP by 2020 (Asia Pacific Energy, 2016). The strategy was to take effect from 2005, with its implementation to lower greenhouse gas emissions. There was also to be an increase in the usage of non-fossil fuels for energy by 15%.

The 11th FYP majored in setting strategies for low-carbon performance throughout the country, including Beijing city or integrating renewable energy resources. The city planned to put policies promoting clean energy production and shifting the focus away from fossil fuels being the primary source of energy. The city also planned to implement the policy on National Energy Development and Energy Savings. The energy-saving projects would be imitated in the city's buildings to promote energy security. From the 2006-2010 Five Year Plan, the city planned to reduce the energy intensity levels by 20% by 2010 compared to the 2005 levels. On this, the city would first investigate the methods for reducing the alarming rates of energy intensity. From gathering the city's residents' opinions, the Beijing Municipality would then go-ahead to implement plans on energy efficiency fortified with the residents' suggestions. The 12th FYP built on the previous plans on increasing the number of renewable energy projects in the city. The update had a review of the city's-initiated projects and added on the plans to integrate more renewable energy projects across the districts in the city.

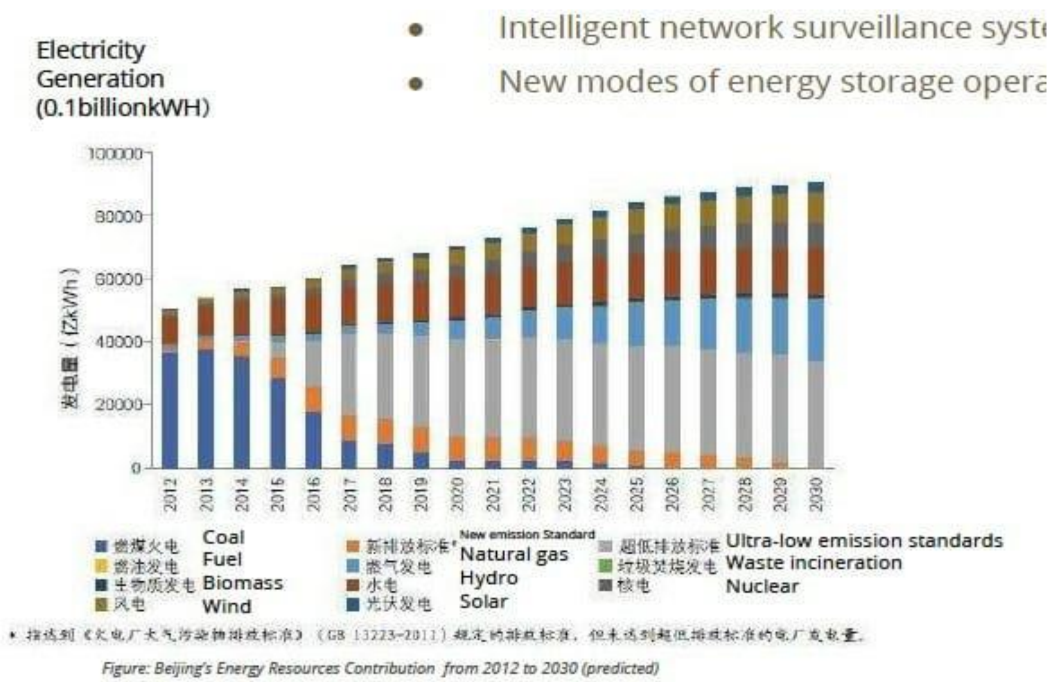


Figure: Beijing's predicted Energy Consumption Contribution from 2012-2030

From the figure above, the city aimed at achieving 100% ultra-low emission rates by 2030, with zero emissions from burning coal by 2026. The fuel consumption rates decreased gradually from 2015- 2030, whereby 2030, there would be zero carbon emissions from fuel. On the other hand, by 2030, the natural gas generation was to be over 40,000 billion kWh, with solar energy generation also surpassing 40,000 billion kWh by 2030. Hydropower energy generation was to be over 60,000 billion kWh by 2030.

The city was to initiate the expansion of the integration of solar energy in all the districts in the city and put in place measures supporting the development of solar panel installation. The Municipality was also to continue installing solar panels in upcoming buildings to harness solar energy. There were also collaborative efforts between the Beijing government authorities and other municipalities in the Beijing-Tianjin-Hebei-Shandong region in implementing residential and industrial heating. Heating would come from renewable energy resources such as solar and geothermal sources. For solar energy, the projects would be supported by the installation of photovoltaic cells on buildings. In remote areas of the city, photovoltaic power plants would be established to harness solar power and distribute it to households, residential and commercial buildings alike.

The city would also increase its efforts in increasing the capacity for harnessing biomass and geothermal energy. The existing power plants would be expanded, as in the case of solar power expansion. The city would also invest in injecting more funds into expanding the city's capacity to produce more renewable energy. A funding mechanism would be established to complete and expand the biomass and geothermal projects throughout the city. There would be an increase in the funds allocated for the projects through a proper channel of accumulating funds for renewable energy projects. There would also be the successful completion of the initiatives, which would go a long way in ultimately lowering carbon emissions in the city. Successful completion of the projects would also enhance energy security by incorporating renewable energy into the infrastructure of Beijing.

The City, under the 13th FYP, would develop an index management mechanism on the total renewable energy consumption. The management mechanism would be a renewable energy index assessment constraint mechanism index that would pit the total consumption of renewable energy against the total energy consumption. The development of this mechanism would analyze how the city is leveling up on renewable energy resources integrated. The Beijing Municipality would be the governing body in charge of establishing the renewable energy index assessment constraint mechanism index. It would also establish a transparent mechanism of analyzing and managing operations in renewable energy plants. Creating a transparent management mechanism would be essential in monitoring renewable energy projects' goings with the correct data acquisition. The Municipality would also see the establishment of a system that could improve project developers' supervision by the Municipality. The city plans to gather accurate and reliable information on the projects' progress for a transparent process of establishing viable policies.

Throughout the city's public buildings, the Municipality would put in energy management measures to incorporate renewable energy in the establishments. The programs would involve the Municipal coming up with systems to reinforce energy conservation for energy security and supervise the project developers when installing renewable energy in construction. The energy management measures would be an indicator to the Municipality on the residents' energy consumption rates, enabling the Council to come up with policies on energy efficiency. The city also planned on creating a public platform where the residents would be informed on renewable energy projects, majorly project developers. A review of the plans and their implementation across the city would also be publicly posted on the platform.

Implemented strategies

From 2006 to 2010, the period through the 11th Five Year Plan, there was a switch in growing energy intensity. Energy intensity in Beijing and generally in China refers to the energy usage per unit of GDP (Zhao, 2011). The energy intensity in the years through the 11th FYP dropped from the previous levels as several strategies were implemented. The strategy implemented was policies promoting energy efficiency and renewable energy to adapt to climate change. The policies involved large scale and long-term investment by the government in renewable energy projects

Additionally, Beijing also focused on developing the technology enabling low carbon emission around the city. The technology improved the efficiency of wind and solar energy production plants and panels. Technology development was also geared towards carbon capture in the city. Generally, the city implemented advanced technology in encouraging renewable energy use rates. Beijing also implemented incentives and support for the enacting of technology, promoting low carbon emissions. Offering financial support to commercial and city residents brought tremendous energy efficiency improvements, especially in the transport and construction industries.

Implementing strategies to lower the city's energy intensity has been primarily carried out by the Beijing Municipal Development and Reform Commission under the Beijing Municipality. The Municipal Council has followed up on the 12^{th} and 13^{th} FYP, causing a shift to cleaner energy in natural gas, wind power, geothermal energy, and other renewable energy sources.

Beijing has been importing natural gas from other provinces to incorporate renewable energy into the city's infrastructure. The total consumption of natural gas in the city has been rising, contributing to the increase in renewable energy consumption. With the importation of natural gas into the city, Beijing has also reduced the carbon emission rates. Higher consumption of natural gas means carbon-emitting energy sources are slowly being substituted. Renewable energy sources are great alternatives for fossil fuel without negative impacts on the environment and, ultimately, the climate. The city has increased its distribution of natural gas to both residential and commercial buildings for heating purposes. The Beijing Municipality has also been converting natural gas to electricity as a source of energy.

The Beijing Environmental Protection Bureau has also collaborated with the Municipality in doing away with equipment for burning fossil fuels. The bureau is famous for doing away with coal using boilers and replacing them with renewable energy ones (Asia Pacific Energy, 2016). It integrated solar and geothermal energy to be used in the boilers for heating purposes. Some boilers were also converted to be compatible with liquefied petroleum gas. Beijing City Municipality increased the number of plants for geothermal energy conversion to produce electricity, as detailed in the FYP. Geothermal energy has worked as an excellent substitute for fossil fuels, with the city implementing its goals on reducing carbon emissions from fuel oils.

Wind power generation was increased with the construction of the Guanting Wind Farm. The wind farm has a great capacity to harness and generating energy from wind power. With its completion in 2008, the wind farm has met more than 100,000 households' electricity demand (Zhao, 2011). The city also expanded the farm to a capacity of 100 MW. Beijing has also constructed another low capacity wind farm with ten turbines, increasing the city's total capacity for converting wind power into energy for electricity. The Deqingyuan Egg Farm was also a renewable energy project completed by the city to convert methane gas into electricity. The Egg Farm, which uses chicken manure, generates over 140 MWh of electricity per year (Zhao, 2011). Apart from the construction of wind farms, the city has also concentrated its efforts on establishing biomass generation facilities. The establishments have a high capacity for generating electricity, adding to the energy mix of renewable energy resources in the city.

Impact of strategies

Beijing renewable energy projects during the *11th five-year plan period* [24].

Projects	Scale	Power generation (10^4 kW h)	Standard coal equivalent (10^4 t)
1 Power generation	(10^4 kW)		
(1) Wind farm	10	20000	6.5
(2) PV power plant	0.3	450	0.2
(3) Livestock and poultry farm biogas power plant	3	16500	5.4
(4) Landfill gas recovery power plant	1	7200	2.3
(5) Trash-fired power plant	10	72000	23.4
(6) Solid biomass power plant	12	72000	23.4
(7) Small hydropower transformation	5	8675	2.8
Sum		**196825**	**64**
2 Heating			
(1) Geothermal heating	5 million m^2		10
(2) Heat pump	30 million m^2		56
(3) Solar water heaters	5.4 million m^2		64.8
(4) Biomass pellet fuel	0.1 billion t		4.6
Sum			**135.4**
3 Biological liquid fuel			
(1) Biodiesel derived by gutter oil	5000 t		0.7
Sum			**200.1**

From the 11th FYP, Beijing implemented renewable energy projects in power generation, heating, and biological liquid fuel. Power generation projects with the highest power generation levels were wind farms, solid biomass power plants, and trash-filled power plants, both of which generated 72000 kWh. The wind farm generated 20000kWh. Heating renewable energy projects included geothermal heating, heat pumps, and solar water heaters on a scale of 5, 30, and 5.4 million square meters, respectively. The city also invested in biodiesel derived from gutter oil on a scale of 5000t.

There has been a remarkable growth in the usage of renewable energy by the city residents as more efforts are directed towards getting the city greener. The installation of solar power panels across the city has seen a tremendous increase in residents consuming solar power. There is an increase to 7.6% renewable energy consumption out of the total energy consumed in 2019. The increase is from a meager 3.3% in 2010 and 6.6% in 2015. There is, therefore, a notable impact from the residents consuming more renewable energy in the past four years. The city is also well on achieving an 8% renewable energy usage of the total energy consumed by 2020. The implemented strategies serve to steer the city to cleaner forms of energy.

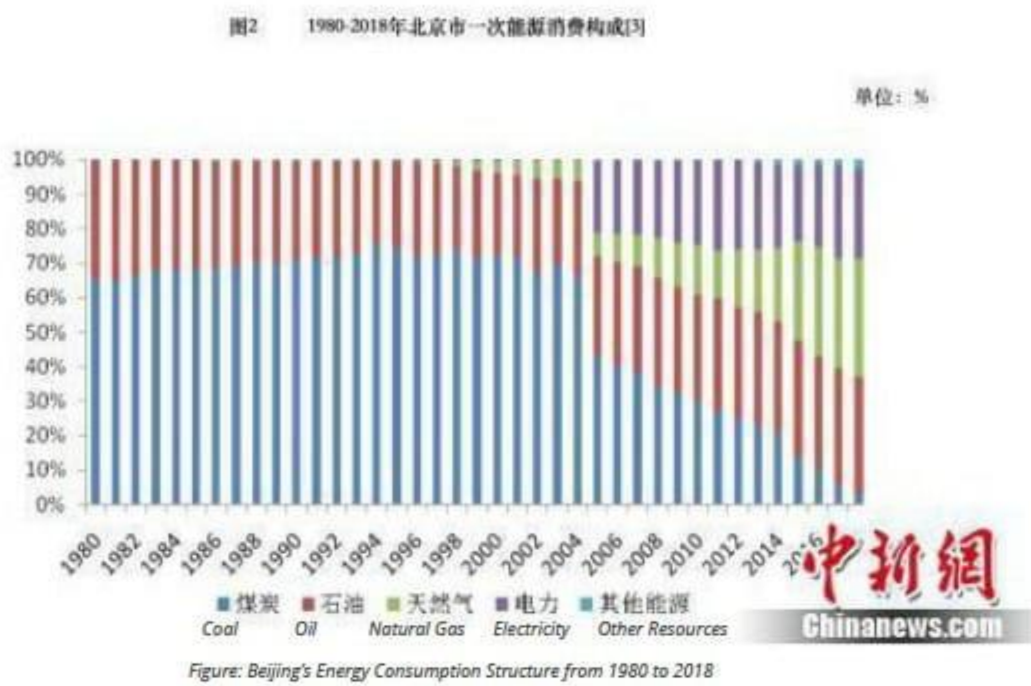


Figure: Beijing's Energy Consumption Structure from 1980-2018

With the inception of renewable energy strategies from the 11th FYP, there has been a notable decrease in coal usage from 2006 to 2018, with a corresponding notable increase in the usage of natural gas. Consumption of coal before 2005 was well over 60% of the total energy consumption rates. The rates have been falling, with a decrease to below 10% in the total energy consumption rates. Conversely, natural gas consumption has been on the rise from 2005 according to China news on Beijing's energy consumption structure from 1980-2018. The city's switch to cleaner forms of energy has seen the residents consume energy from renewable sources such as the wind, sun, and terrestrial heat. The sun is the most significant renewable energy source, contributing to approximately 31% of the total renewable energy consumption. Natural gas as an alternative energy form from conventional sources such as fossil fuels has also increased. Over the recent past years, Beijing's air quality has been notably better from the city's efforts to cut on coal consumption. Beijing emphasizes the consumption of natural gas over coal consumption, thus the improved air quality.

From the importation of natural gas into the city from other provinces such as Shanxi, more residential and commercial buildings use natural gas for heating instead of burning fuel oil. This has, in turn, been reducing the carbon mission rates in the city. The city has also increased its uptake of electricity from natural gas energy. By 2008, natural gas consumption was well over 5 billion cubic meters. The closure or conversion of coal burning boilers into ones that can use renewable energy has reduced carbon emission rates from factories with boilers. Initially, boilers that used burned coal contributed in no small amount to the city's carbon emissions. With the conversion of many of these boilers and the closure of some, there has been a remarkable decrease in carbon emission rates. The construction of wind farms in the city has resulted in a reduction of carbon dioxide emission levels. The wind farms play a part in the reduction of over 100,000 tons of carbon emissions each year. The Guanting Wind Farm expansion saw a further decrease in the city's carbon dioxide levels by over an additional 100,000 tons.

Pollution in the city has also been gradually decreasing, with remarkable results been obtained in 2019. Greatest results have been achieved in reducing air pollution, with the State Council reporting that there was a 20.5% drop in the density of PM2.5 in 2019 from the figures reported in 2016. The State Council reported on PM2.5 since it is the most significant indicator of air pollution. The reduction in air pollution is a testament to the positive impact of integrating and using renewable energy in the city. The PM2.5 had an average density of 58 micrograms per cubic meter in 2019, which surpassed the city's set target.

With the gradual development of renewable energy technology and increased consumption of renewable energy in the city, further integration may come as a result of demand from the city residents. For a long, the integration of renewable energy in the city's infrastructure has been highly influenced by supply. The development of technology aiding in the incorporation of renewable energy has been mostly driven by the city government seeking to create a greener city. Further integration of renewable energy in the city's operations may stem from the residents' demand and not necessarily the government's incentives.

<u>Comparison between objectives and implementation of strategies in Beijing and Shanghai</u>

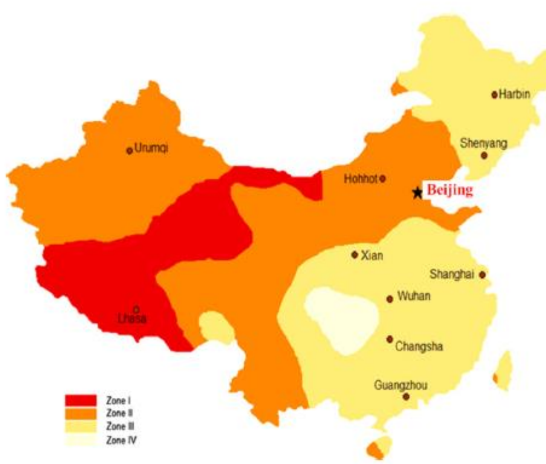


Fig. 1. Solar energy resource distribution in China [17].

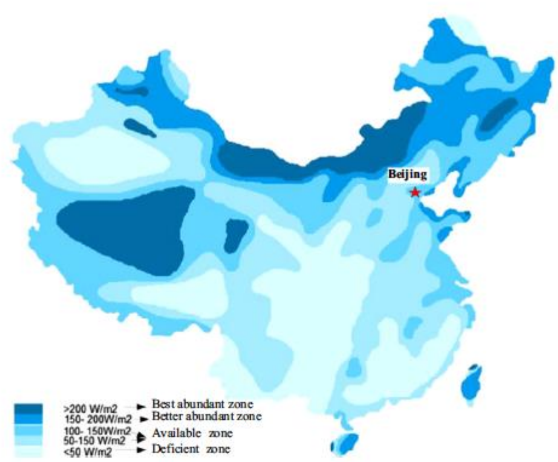


Fig. 2. Distribution of China's wind energy resource [15].

Figure: China's solar and wind energy distribution map

The city of Beijing is located in a region with abundant solar energy resources in the country than Shanghai. This implies that the solar energy projects implemented in Beijing are more than the ones in Shanghai. From the charts above, Shanghai is in the third zone compared to Beijing in the second zone concerning the distribution of solar energy resources in China. Comparatively, as in the charts above, both cities are located in available to better abundant zones regarding the distribution of wind power energy resources.

Beijing and Shanghai are both cities in China whose objectives are to integrate renewable energy drawn mainly from China's Five-Year Plans. Both cities have incorporated strategies highly borrowing from the country's blueprint of initiating green projects to lower the carbon emissions and incorporate ocean energy into its operations. The two cities' culture is almost similar as they are in the same city, making them have the same manner of initiating and implementing strategies.

Beijing has completed projects installing solar panels and Shanghai, from the 11^{th} to the 13^{th} FYP. Both cities have policies in place where upcoming buildings are being fitted with energy-efficient mechanisms. Both cities have also enacted policies on residential and commercial buildings to monitor their energy consumption levels. The reviews' statistics enable the cities to manage energy consumption better using green energy in the buildings. Both cities have also set up organizations that deal with the management of energy consumption levels, thus improving the cities' energy efficiency levels. There are funding mechanisms that have been set up in both cities for the injection of funds into establishing green projects. Both cities are similar in the way they implement the strategies with them enjoying similar cultures. They, therefore, do not differ along many lines.

Introduction

For the past centuries, countries have heavily relied on coal, oil, and other fossil fuels to produce energy since the industrial revolution. This has a major impact on climate change as well as human health that creates a huge challenge for cities' development. Rising sea levels, extreme weather events, land degradation and air/water pollution are all downsides of using fossil fuels. Burning fossil fuels, particularly for the power generation and transportation sectors, are responsible for the largest amount of greenhouse gas emissions and the main contributor to the local air pollution. Therefore, to reduce carbon dioxide and other greenhouse gases, the world has started to look at renewable energy, which is a clean and carbon-free technology that helps cities reduce the carbon footprint and increase energy resilience to climate change.

Renewable energy is the energy collected from renewable resources that can be naturally replenished by themselves. Major renewable energies are solar, wind, hydroelectric, geothermal, and tidal energy. It is the fastest-growing energy infrastructure in the world that is currently incorporated in electricity generation, air/water cooling and heating, transportation, and rural energy services. According to the International Energy Agency, 13.5% of world total energy supply and 25.2% of global electricity production comes from renewables and in 2018, and investment in renewable energy capacity has reached $300-$400 billion per year. On a global level, the majority of renewable energy consumptions are in transformation sectors (electricity and heat), followed by residential, commercial, and public sectors. Figure 1 shows that since 1990, renewable energy sources have grown at average annual rate of 2.0%, with especially high for solar PV and wind power which are 36.5% and 23.0% respectively.

Nowadays, a wide range of cities is promoting renewable energy integration in infrastructures. The cities I chose for the case studies are Copenhagen in Denmark, San Francisco in United States and Munich in Germany. The reason of choosing these three cities to analyze is that they are all the role models in integration of renewable energy in urban infrastructures in their countries as well as in the whole world. Copenhagen and Munich are achieving the 100% renewable energy by 2025 with the goal of being carbon neutral within next twenty years, and San Francisco set its goal of reaching 100% renewable energy by 2050. Various approaches are used to incorporate renewable energy, distributed generation, and energy storage into the electricity distribution and transmission system including wind energy, large hydro, solar, biomass, geothermal and so on. These cities have the ability to address the technical, economic, regulatory, and institutional challenges of the integration, and develop suitable business models for supporting greater energy capacity and more stable operations. As three cities have different governance backgrounds, it is interesting to compare between the governance structure and the strategic plans regarding the renewable energy to see the difference and similarities that lead all three of them being successful on the path of 100% renewable. The paper will give case performances on all three cities and conclude on the key strategies taken by the cities that can be referenced in the future for other cities to pursue the renewable energy integration. Overall, the goal of renewable energy integration is to improve the energy system designed in major infrastructures to reduce carbon emissions and air pollutants, mitigate the climate change, reduce the costs of electricity, and enhance the reliability, security, and resiliency of the energy production.

Case Study – Copenhagen

Problem Domain Definition in the Urban Context

Copenhagen is the capital and the most populous city of Denmark with a population of 559,440 or one tenth of the total Danish population. The city is recognized as one of the most environmentally friendly cities in the world because of its commitment to high environmental standards. Ranked as the top green city for the second time in the 2014 Global Green Economy Index, Copenhagen has highly focused on the green economy since the turn of the 21st century. Strong urban and cultural developments were facilitated by investments in infrastructures and public sectors, and its economy has seen increasing progress in service sector, especially through initiatives in information technology, clean technology and medicine.

Today, Copenhagen has long put sustainability at top of its agenda with major initiatives on the strategies combating the climate change, creating smart urban developments and having more sustainable transportation. Copenhagen's economy, measuring in Gross Value Added (GVA) per Capita, grew by nearly 25% from 1993 to 2010. In the meantime, greenhouse gas (GHG) emissions per capita in the city decreased by 40% from 7.31 tCO_2e to 4.38 tCO_2e in the major sectors of transport, heat, and electricity, and the annual CO2 emissions were reduced to approximately 2.12 million tons. Electricity accounts for the 51% as the major source of CO2 emissions, followed by heating (25%) and traffic (22%).

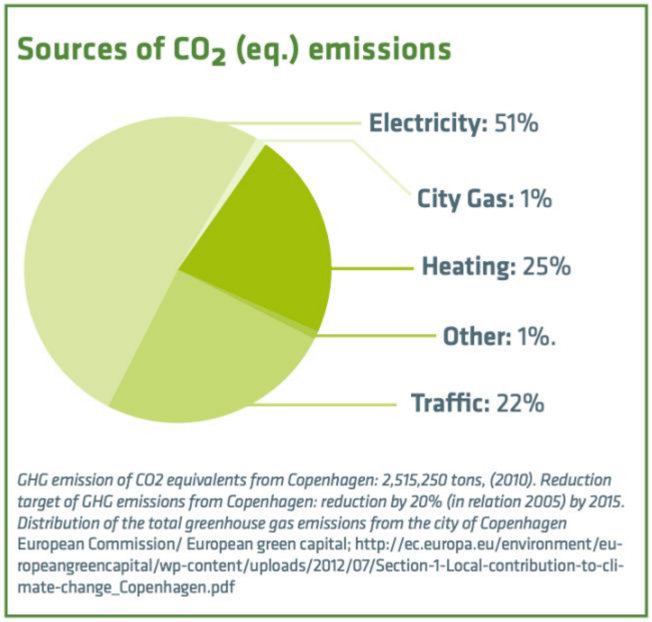


Figure 2: Sources of CO2 emissions

As one of the most sustainable and energy efficient cities in the world, Copenhagen has the ambition of becoming the first carbon neutral capitals by 2025. To achieve that, the city adopted the master plan CPH 2025 Climate Plan which incorporates various specific initiatives and goals with four major pillars: Energy Consumption, Energy Production, Green Mobility, and City Administration Initiatives. Among them, energy consumption (7%) and production (74%) initiatives account for total of 81% of the total emission reductions in Copenhagen. With the plan's strong emphasizes on the energy sector to reduce the carbon emissions, this particular analysis will focus on how Copenhagen integrate the renewable energy in the infrastructure to reach the goal of carbon neutral and handle the global challenge of climate change efficiently.

For a number of years, Copenhagen has worked on reducing greenhouse gas emission and increasing the integration of renewable energy. Climate change is a real challenge, and Copenhagen is a unique city that is large enough for having climate solutions in a global context but also small enough to manage and test the new solutions. It is estimated that world-wide demand for energy will increase by 30% toward 2025 with growing consumers. The demand for energy sources and raw materials relates to the inevitable need of increasing supply. Renewable energy resources will be the exact sector to tackled with.

With the goal of reaching carbon neutral by turning to 100% renewable energy, Copenhagen has focused on building a new integrated energy system by adding diversified selection of renewable energy resources to current power infrastructure. These include implementation of renewable energy technology for heating and electricity supplies, integration of energy sector, and transport in a renewable energy context. A broad range of initiatives are responsible for the renewable energy integration as Copenhagen is currently working on installing land and offshore wind turbines, exploring new biomass-fired combined heat and power, establishing geothermal plant, and gradually phasing out the use of fossil fuels. In addition, CO2 can be reduced from district heating production by utilizing solid waste from separating and reusing plastics. The city is continually brining new solutions, strategies and plans to enhance the renewable energy sector through interdisciplinary approach with local government, public authorities, business, knowledgeable institutions, and citizens' interests.

Historical Context and City Policy/Strategies Implemented

As the capital of Denmark and the second largest city in Scandinavia, Copenhagen is located at the east coast of Zealand island alongside the Sound (Øresund) and another portion of the city is placed on Amager. It is the urban core of the Greater Copenhagen area that has population of 1,330,993. A bridge and tunnel called Øresund bridge that was built in 2000 connects Copenhagen and Malmö, Sweden for both rail and road traffic, in which Copenhagen has become a major metropolitan area that spans both nations. Considering that central areas of the city were relative low-lying flat grounds, and that the city is in the oceanic climate zone with the weather subject to the low-pressure system, Copenhagen is girding itself for the impacts of climate change with more intense raining and rising sea level. In 2009, the city hosted the worldwide United Nations Climate Change Conference and has seen tremendous efforts on combating the problem.

Originally as a fishing village, Copenhagen became the capital of Denmark in the early 15th century and gradually consolidated its function as a regional center of power with institutions as well as a cultural and economic center of Scandinavia. Into the 21st century, Copenhagen has experienced constant and stable economy growth and now is one of the most dynamic cities in Europe with the cityscape characterized by parks, open spaces, and waterfronts. The economy of Copenhagen is primarily based on service industries, trade and industries. Located near North Sea, Copenhagen/Denmark has considerable sources of oils and natural gas. With high living quality and low carbon footprint, sustainability always plays a major role in the development of the city. The result can be seen from the declining energy consumption and greenhouse gas emissions over time from 1990 to 2015. However, it was not quite smooth going from the initial energy economy in Copenhagen.

The history of renewable energy in Copenhagen goes back many years ago when Denmark experienced an extremely high dependency on oil in the 1970s. During the early 1970s, more than 90% of energy consumption was based on imported oil, and this led to large economic difficulties in 1973 and 1979 where prices quadrupled in a few days. The 1973 and 1979 oil crisis forced Denmark to rethink about the energy use and related policies. In response to it, a diversification process was involved by first replacing oil with coal and natural gas. Later on, Denmark was triggered to shift from coal to nuclear energy. As nuclear power was excluded by Danish parliament in 1985 due to oppositions regarding the cost and safety, the country has started to formally look at the alternative plan - renewable energy, mainly wind energy and bioenergy. The oil crisis produced a strong social mandate for change and created an opportunity for political national energy agreement, which liberates the policy makers to look at the energy economy in a long-term. Four decades of progress that carried out by the collaboration between cross-parliaments can be seen from the figure 3. It is a remarkable achievement from the first energy plan with CO2 reduction target in 1990 to current large investments in renewable energy and energy efficiency, which has become a model of transforming to a low-carbon economy by combining market-based and regulatory approaches.

1973–1990 **Security of supply**	**1990–2001** **Decarbonization**	**2001–2011** **Market liberalization**	**2011–Current** **Renewed decarbonization focus**
• Extraction of oil and gas from the North Sea • Establishment of nationwide natural gas transmission and distribution system • Energy efficiency measures introduced • Further development of district heating system • First energy plan compiled (1976)	• First energy plan with CO_2-reduction targets • Moratorium on new coal-fired plants • Decarbonization through combined heat and power and renewable energy • Various taxes and support schemes to support transformation • Energy efficient building standards	• Liberalization of gas and electricity markets • No particular focus on decarbonization • Establishment of the European Emissions Trading System • Market-based incentives for offshore wind turbines	• Current 2012–2020 energy agreement is ambitious, includes large investments in renewable energy and re-focus on energy efficiency • Focus on significant reductions in GHG emissions.

Figure 3: Four Decades of Energy Progress in Copenhagen, Denmark

Since 2009, climate action has been in a full swing in Copenhagen, with the establishment of Copenhagen Climate Plan up to 2015, several initiatives and policies have contributed to substantial CO2 reduction with the integration of renewable energy.

Danish Energy Agreement for 2012-2020

This agreement was set in a national level in 2012, establishing a framework for the policy on climate and energy up to 2020. A comprehensive strategy of establishing intelligent energy system Smart Grids is required for large electricity consumption by wind power. A total of DKK 100 million will be committed to the funding of new renewable energy electricity production (solar, waves. etc) and additional DKK 25 million to wave power demonstration facilities. (IEA)

CPH 2025 Climate Plan

Back to 2009, Copenhagen became the first capital city in the world that has the major ambitions and set the goal to become the first carbon neutral capital in 2025. With an expected 20% growing population next decade, Copenhagen wants to show the growth and development of the city and increased living standards together with the reduction of carbon dioxide emission. To reach this goal, the city adopted the CPH 2025 Climate Plan that based on four pillars: energy consumption, energy production, mobility, and city administration initiatives. Renewable energy plays an essential role in all four pillars that assist the city to reach the goal of carbon neutral.

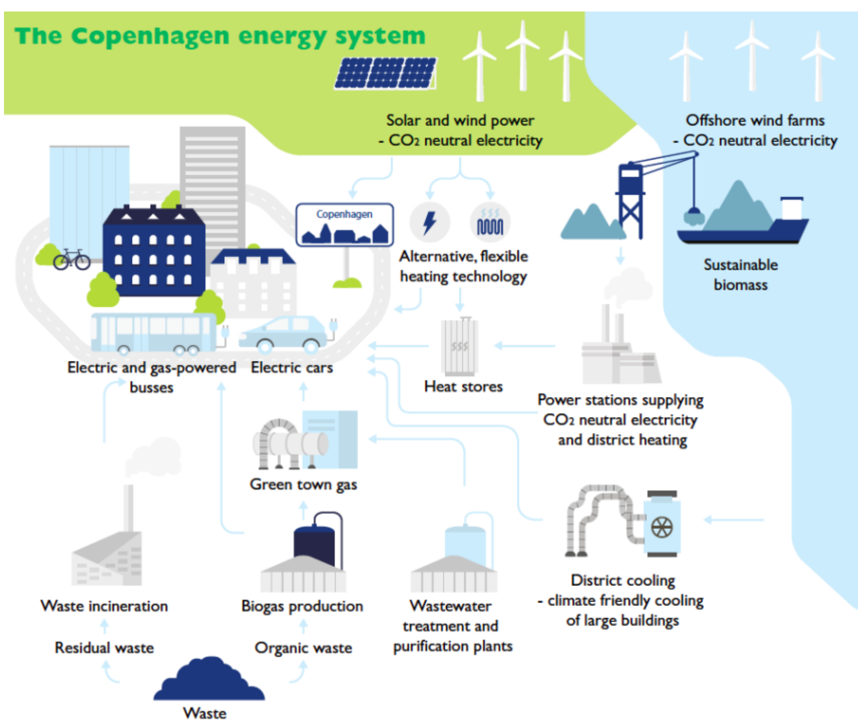


Figure 4: The Copenhagen Energy System

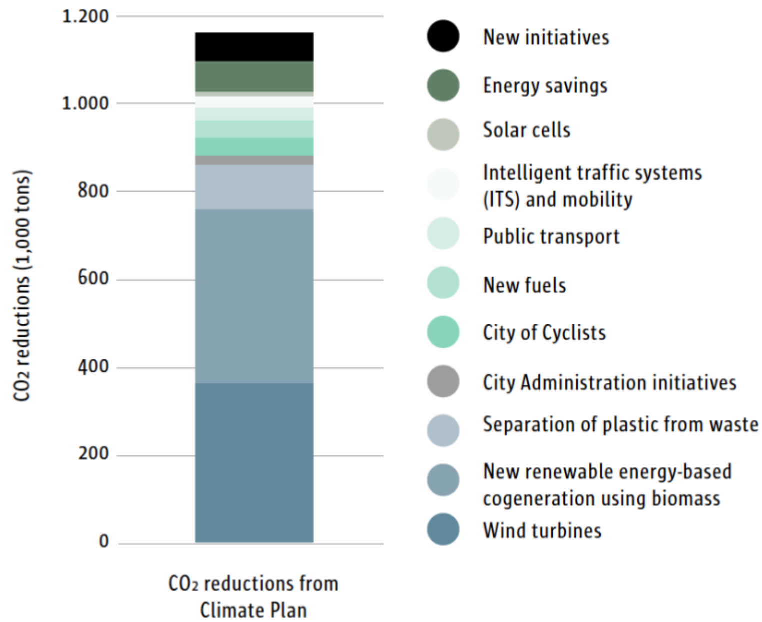


Figure : CO2 reductions resulting from initiatives in the CPH 2025 Climate Plan

<u>Energy Consumption – Solar Cell</u>

Energy consumption accounts for 7% of the total share of greenhouse gas emissions reduction. In 2010, heat and electricity consumption in Copenhagen produced 75% of the total CO2 emissions. Reducing energy consumption by using resources as efficiently as possible is the one of the foremost methods of reducing emission. The plan paves the way for strategies in both residential and commercial constructions, mainly about energy saving and energy efficient buildings.

Renewable energy for sure is an important factor in most strategies. First of all, national policies encourage the flexible energy consumption by stipulating 50% of electricity demand be covered by wind power by 2020. Large share of renewable energy means more flexibility on the selection of the source. And also, similarly, on the consumer side, there would be an increasing demand for renewable energy that made the intelligent energy system able to balance the energy production. An example could be recharging of electric car when there is a surplus in renewable energy or whenever the consumption is low.

Secondly, increasing the uses of solar cell is another major initiative proposed by the plan. As market trends for solar cell shows annual growth of 40% with increased efficiency and substantial drop in price, the city is managed to install the solar cells on all newly built municipal properties. Copenhagen City Administration wants to take a proactive role in promoting the renewable energy technology through providing architectural design guidelines for solar cells on roofs, information about scope of installation, and making use of renewal funding to develop solar cell solution to fit current city's buildings in a cost-effective way. Furthermore, Copenhagen Energy will work on business concept that is commercially viable to accommodate the solar cell installation on most city buildings.

Thirdly, there is a continuous need for sharing the knowledge on low-energy construction and retrofitting the existing buildings. Lighthouse projects provide an opportunity for establishing partnership with developers and contractors on the innovation of new technology, including renewable energy integration, to design energy efficient buildings that will comply with strict energy requirements and optimize energy supply.

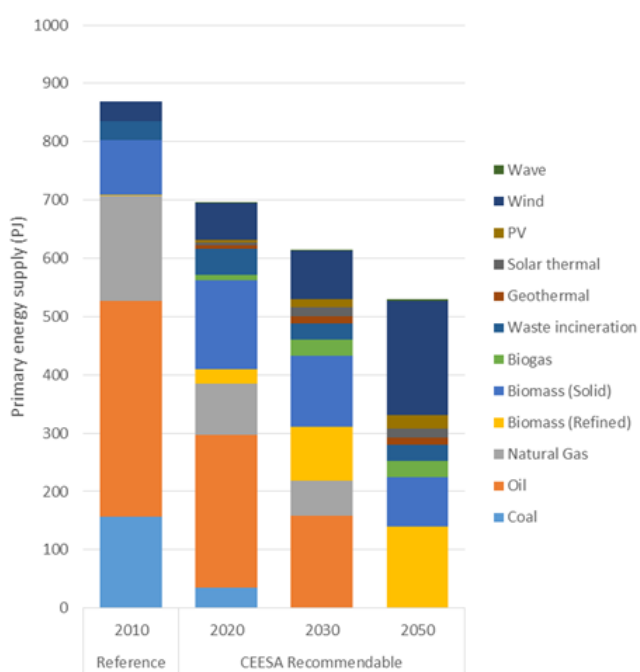


Figure 5: Primary energy supply and Future prediction if strategies are implemented

Energy Production – Wind, Biomass, Waste

Energy production accounts for 74% of total share of reduction of greenhouse gas emissions. The plan expects that by 2025, the production of electricity, heating and cooling in Copenhagen will primarily be based on wind, biomass, geothermal energy and waste. To achieve this, several strategies and initiatives are taken to ensure flexible energy supply and high conversion of green energy in already developed energy technologies.

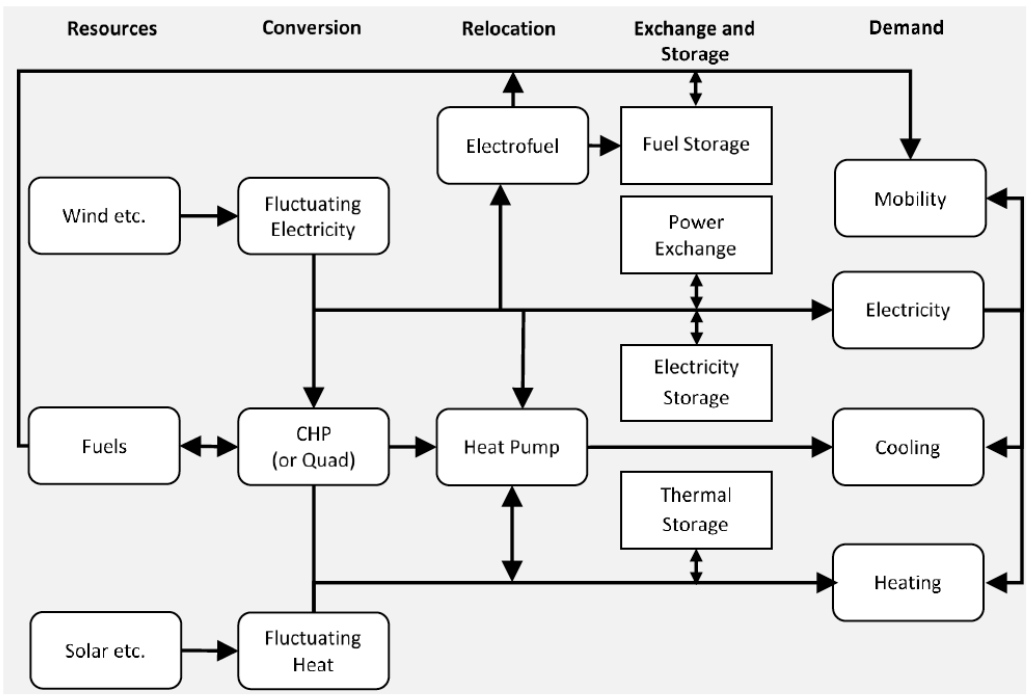


Figure 6: Energy System in Copenhagen in 100% Renewable Energy

First of all, Copenhagen has initiated a number of wind turbine projects and windmills that gives Copenhageners the possibility of directly using real green electricity generating from wind. The plan proposed to construct more than 100 wind turbines with total capacity of 360MW by 2025. This work should include installations both outside and inside the municipal boundaries as well as both offshore and onshore. Copenhagen has already found suitable sites for offshore costal wind turbines in Øresund and established Energy Agreement 2012- 2020 that promised a total of

500 MW wind turbines. Four suitable locations have been selected for land-based wind turbines within municipal border, and seven wind turbines were built on Prøvestenen and Kalvebod Syd in 2013. Partnership of joined ventures between Copenhagen Energy and Copenhagen City Council was proposed to tender for public contracts of government offshore wind turbine projects with guaranteed loans to finance cost-effective projects within a framework of DKK 5.5 bn. In addition, City Administration also wants to incorporate the local communities as well as involving citizens in advocating the wind energy. The City of Copenhagen and Copenhagen Energy will open the opportunity for Copenhageners to buy wind turbine shares as a way of actively expanding the renewable energy market through investing the city business.

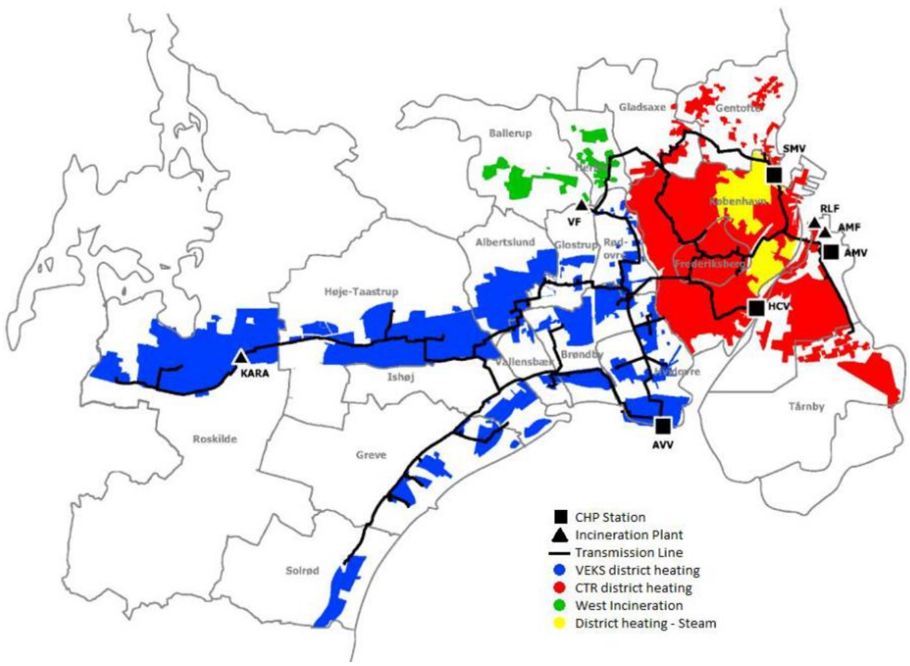


Figure 7: Map of District Heating areas in the Greater Copenhagen Area

Secondly, in continuation of the first climate plan dating from 2009, Copenhagen has worked on converting the combined heat and power plant from fossil fuels to biomass. One of the major strategies is focused on the district heating. Copenhagen has the largest cogeneration system in a city – a heating network where waste heat from combined heat and power plants (CHP) is utilized to keep buildings warm with district heating. One of the main goals of the plan is to develop new sources for district heating to reach carbon neutral by 2025 and for Copenhagen to help secure the generation of renewable surplus power. The system is primarily switching from coal to biomass and waste that mainly consists of wood pellets and straws. At present, the combined heat and power plants at Amager and Avedøre will be converted to biomass and an additional biomass-fired/wood chip-fired combined heat and power plant with capacity of 115-350 MW will be established in the city.

To diversify the energy sources needed and increase the flexibility of the system, Copenhagen also proposed the 4th generation district heating in CEESA, which tests the possibility of using large heat pumps to capture the heat from geothermal wells, cleaned wastewater, solar thermal, and industrial surplus heat as well as utilization of wind power. A geothermal demonstration facility at Amager Power Station has been operated since 2005 that can give sufficient operational knowledges when building plants. Copenhagen wants to create an energy system that can supplement with each other to provide flexible electricity and heat supply. This means that the biomass-fired combined heat and power plants need to adjust to increase its energy production when the wind turbines work at low efficiency, while reducing the electricity production when there is ample wind power available in the system. This strategy prevents peak-load production on single energy source and opens scope for growing consumption of carbon neutral fuels. This system is flexible for varying proportions of heat and electricity production, and also has built-in heating storage that allows for continuing the heat supply.

In addition to the heat generating using biomass, waste can also be seen as a renewable resource to district heating supply. Copenhagen is currently setting a framework for separating plastics from waste incineration to prevent excess emissions of carbon dioxide and increasing recycling rate of plastics. By building new incineration plant at Amager for production of biogas and heat generation, the city would be supported by a high flexibility energy system based on municipal solid waste heat.

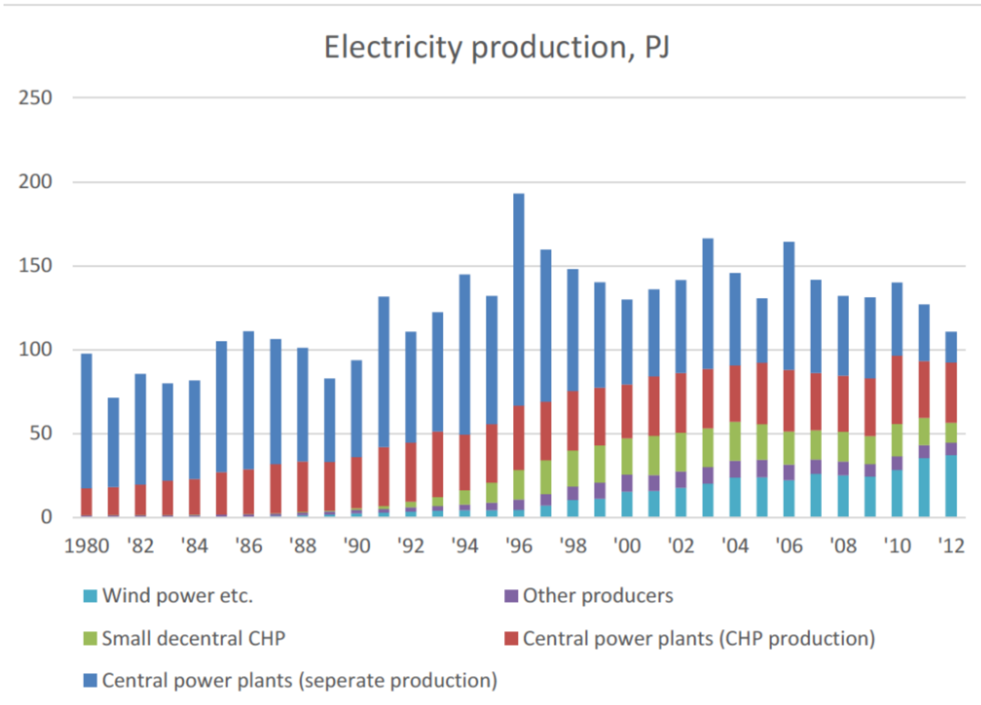


Figure: Energy Production 1980 - 2012

<u>Green Mobility</u>

Regarding transport, Copenhagen has been put a lot of efforts into developing transport pathways in terms of renewable energy integration. The City of Copenhagen strives to increase the use of electric cars, hydro-electric cars, and cars powered by biofuels. As 96% of all car journeys in the Denmark are less than 50km, it creates a large market for electric cars that relatively suit short-distance vehicles. Hydrogen-electric car is expected to develop into the market after implementing adequate infrastructure and conducting more hydrogen technology test. Biofuels such as biogas and bioethanol are promoted in heavy vehicles for both technical and economic perspective that biofuel could be mixed with up to 20% of ordinary petrol. The city is able to collaborate with research institutions and business to establish secure supply and infrastructure for biofuel in a national level. According to Danish Energy Agency in 2012, the cost of electric cars and cars powered by biogas will be similar with petrol and diesel driven cars already by 2020 and will be much cheaper than conventional cars in both purchasing and running costs.

Public Policy Objectives of the Local Governance

According to the Danish Energy Agreement 2012-2020, the plan aims to reach 35% share of renewable energy in gross energy consumption in 2020. It secures the expansion of wind power by 50% of total consumption and encourages development tool to build total capacity of 1800MW offshore wind turbine within the country. Regarding the public policy objectives in the City of Copenhagen, in 2009, the city wanted to reduce its greenhouse gas emissions by 20% by 2015 compared to 2005, and 75% of the reduction would come from initiatives related to city's energy system, which is equivalent to 375,000 tons of CO2. In the same year, City Council agreed to set a goal of reaching carbon neutral (100% renewable energy) and reducing 1.6 million tons of CO2 by 2025. The CPH 2025 Climate Plan was published in August 2012 suggesting and listing detailed objectives on how to meet this target.

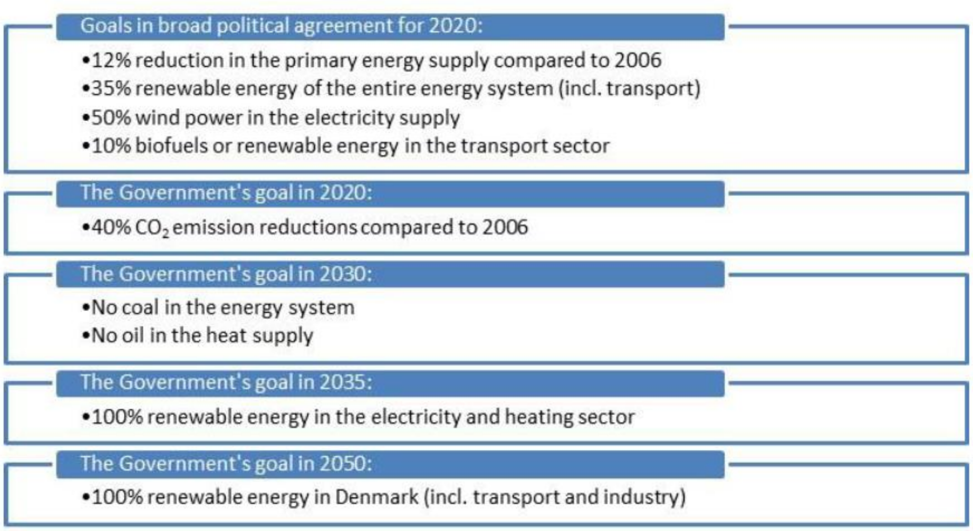


Figure 8: Important goals in the Danish energy planning to reach 100% renewable energy

The goal that the CPH 2025 Climate Plan set for the energy consumption is the reduction of total CO2 emission by around 50%. There will be 20% reduction in heat consumption, 20%

reduction of electricity consumption in commercial and service companies, and 10% reduction of electricity consumption in households compared to 2010. Energy savings and the installation of solar cells will provide a total CO2 reduction of 80,000 tons and the installation of solar cells will correspond to 1% of electricity consumption.

For the energy production pillar, the major goals are carbon neutral district heating in Copenhagen, electricity based on wind and biomass exceeding the city's electricity consumption, separation of plastic, and bio gasification of organic waste. The plan sets the goals for 2025 of installing offshore and land-based wind turbines for 360 MW (100 turbines) and establishing guilds for selling wind turbine shares to citizens and businesses in Copenhagen. Additionally, the city has the goal of converting combined heat and power (CPH) production to biomass with the establishment of new wood-fired CHP plant. A geothermal facility of at least 50 MW has been established together with an additional one before 2030. Peak-load production is expected to convert to carbon neutral fuel by 2025. In total, wind pwoer and biomass in heat supply will reduce 360,000 and 395,000 tons of CO2 respectively.

SPECIFIC INITIATIVES

ENERGY INITIATIVE 1:
Renewable energy replaces coal at Amager power station Unit 1, which converts 100% to biomass (wood chips)

ENERGY INITIATIVE 2:
Renewable energy replaces coal at Amager power station Unit 3, which converts at least 40% of its coal consumption to biomass (wood chips)

ENERGY INITIATIVE 3:
A new combined heat and power station is constructed, based on renewable energy.

ENERGY INITIATIVE 4:
New windmills give Copenhageners the possibility of directly investing in real green electricity.

ENERGY INITIATIVE 5:
Heating with geothermal energy is increased six-fold by expanding the demonstration geothermal facility at Margretheholm.

ENERGY INITIATIVE 6:
Heating efficiency is improved at waste incineration plants by introducing flue gas condensation units.

ENERGY INITIATIVE 7:
The district heating network is modernized to reduce heat losses from the pipes.

FULFILLING VISION 2025
A new, integrated energy system is needed to fulfil the vision of a carbon neutral Copenhagen. Copenhagen's power infrastructure is ideally suited to adding a diversified selection of renewable energy sources. What is still needed is a system for storing energy over days and seasons and which can operate regardless of wind and weather conditions.

Figure 9: Specific Energy Production Initiatives in CPH 2025 Climate Plan

The initiatives and major goals for green mobility focusing on the sustainable energy and implementation of new fuel. Public transport will be completely carbon neutral by 2025, and more than 500 electric cars parking spaces will be established before 2015. Copenhagen expects to have 20%-30% of light vehicles and 30%-40% heavy vehicles powered by electricity and biofuel, and 500-1,000 charging stations with public access have been installed together with 5,000 charging stations for electric and hybrid cars with restricted public access. Taken as a whole, new fuels in the transport sector will contribute to reduction of 30,000tons of CO2.

Copenhagen also set major targets on city administration initiatives. The City of Copenhagen has as its goal that 85% of the city administration vehicles must be powered by electricity or hydrogen by 2015, and all of them run on electricity, hydrogen or biofuel by 2025. Furthermore, a total of 60,000 square meters of solar cell panels on existing municipal buildings and new build have to be installed by 2025.

Category	Initiative
Energy Consumption	Energy renovation and refurbishment of existing buildings to reduce heat demand Promotion of low energy standards in new buildings Improving flexibility of demand to accommodate fluctuations in production from renewable energy sources
Energy Production	Development of new sources for district heating supply Construction of wind turbines, on and near shore including locations in other municipalities Conversion from coal and natural gas to biomass fired power plants Sorting out fossil based material from waste Bio-gasification of organic waste fractions
Green Mobility	Improving conditions for bikes and public transport Assessment of potentials for renewable fuels Intelligent operation of public transport
City Administration Initiatives	Reduction of energy consumption in municipality owned buildings Construction of solar PV on municipality buildings Municipality owned cars run on electricity, hydrogen or biofuel
New Initiatives	Undefined new projects that will reduce CO_2 emissions are expected to be initiated.

Figure10:Summary of initiatives in the CPH 2025 Climate Plan for reductions of CO2 emissions

Local Governance, Agencies and Stakeholders

Copenhagen has pledged to be the first carbon-neutral capital in the world by 2025, and it has emerged as an innovator in clean, renewable energy at the metropolitan and district scale. Its success runs deeper than having progressive ideas. It is rooted in fundamentals of sound governance. The central partners/stakeholders who will contribute to the plan's initiatives are:

- The Government
- Companies owned, wholly or in part, by the City of Copenhagen
- The business community, investors and knowledge institutions
- The people of Copenhagen

Denmark has a relative decentralized government system that lets municipalities operate with considerable independence from the national government. Local governments in Denmark account for over 60 percent of government spending. Local authorities receive an annual block grant from the national government. Therefore, Copenhagen's municipal government is powerful, and that enhances the city's ability to make strategic decisions that span decades and mayoral terms.

The civic capacity is reinforced by the city's mellemformstyre or "mini-mayor" system, which resembles a parliamentary arrangement. The government of the City of Copenhagen consists of its supreme body, the City Council, followed by seven standing committees (the mini mayor). City Councill elects from varying parties with the concept of several "mayors per expertise," such as a technology and environmental mayor, an employment and integration mayor, a health and care mayor. The mixed-party cabinet can lead to mayors with different priorities, and it can also increase the incentive to collaborate and produce policies that enjoy a more widespread support than the term of a single mayor. With strong civic capacity and local power, the capacity of the local capacity in public sector is also strengthened by improvements in education workforce. Collaborations are common between government and universities that can facilitate the energy strategies to target problems.

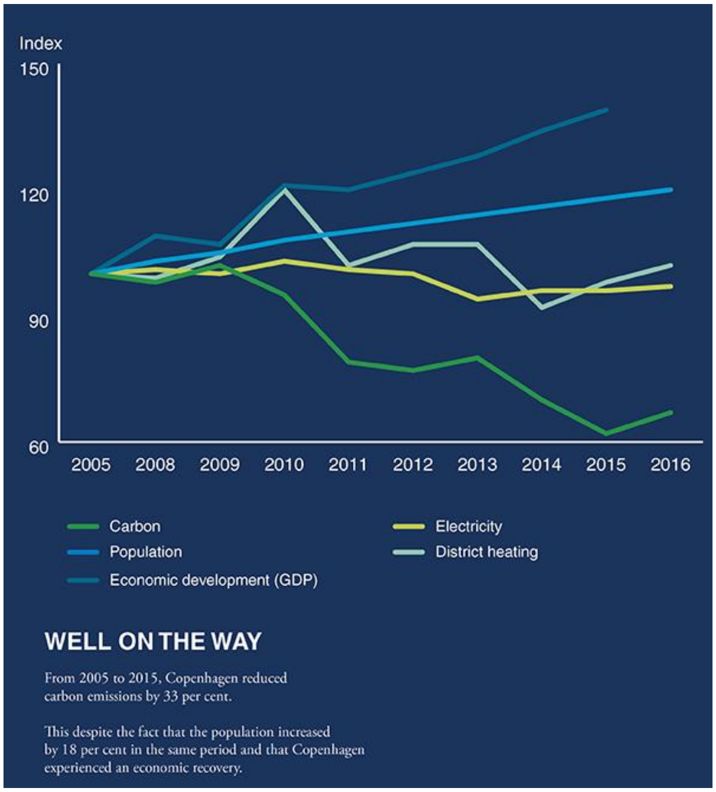
The strong civil and local capacity are further revealed by the government's ability to establish publicly owned corporations with specialized areas of responsibility and authority regarding the stakeholders and agencies that are responsible for the energy infrastructures. In terms of city's corporation, Copenhagen Energy is designated as the major government agency responsible for the development of wind turbines, solar thermal and geothermal energy as stated in CPH 2025 Climate Plan. Additionally, the city and surrounding seven municipalities have together establish the co-owned Greater Copenhagen Utility (HOFOR), which the City of Copenhagen own 73% of the company. HOFOR controls the major operation and maintenance of building, the wastewater system, district heating and cooling, and gas supply for the city and metro region with more projects involving solar panels and smart district heating system with large electric heat pumps. It focuses on the sustainable supply and renewable energy in corporation with municipalities, other companies and consumers. Another publicly owned corporation is CPH City and Port Development that is a joint federal and city organization focusing on the development of waterfront areas. The benefit of these corporations lies on the large scale with strong market force to influence majority of the public toward sustainable development.

While public-owned corporations play important roles in energy infrastructures, private energy companies also have their own strategies contributing to implementation of renewable energy. City will offer business communities to invest, and knowledge institutions are able to explore the possibilities for storing wind energy or developing solar cells integrated into buildings. Ørsted (former DONG Energy) is a private company that develop, construct and operate major offshore and onshore wind turbines, solar farms, energy storage facilities, and bioenergy plants in Copenhagen and also other cities. It operates the Avedøre Power Station, which has been able to use biomass since 2002. As one of the most energy-efficient plant in the world, it is able to produce district heating based on 100% wood pellets in the main boiler and straw in the bio boiler.

People living in Copenhagen will be the direct customer that affected by the strategy implemented since their everyday life depends on the use of energy. As stated in the CPH 2025 Climate Plan, Copenhageners will actively interact with climate initiatives such as solar panel installation through co-ownership and involvement. They may have direct ownership by purchasing wind turbines and have the opportunity to join the discussion of green solutions.

Performance Measures

Since 1995, Copenhagen has reduced carbon emissions by 50 percent. At present, Copenhagen, Denmark has cut CO2 emissions by about 42% compared to 2005 levels, and annual CO2 emissions were reduced to approximately 2.12 million tons. The city has already reached the midterm target that was set in 2009 Copenhagen Climate Plan of reducing 20% of greenhouse gas emissions by 2015 in 2011, with four years earlier. From 2005 to 2015, as population was increased by near 20%, Copenhagen is well on the way of reducing the greenhouse gas emission by additional 33% at the same time experiencing a constant growth in economic development. Right now, the city is on a four-part mission, including achieving 100% renewable energy.



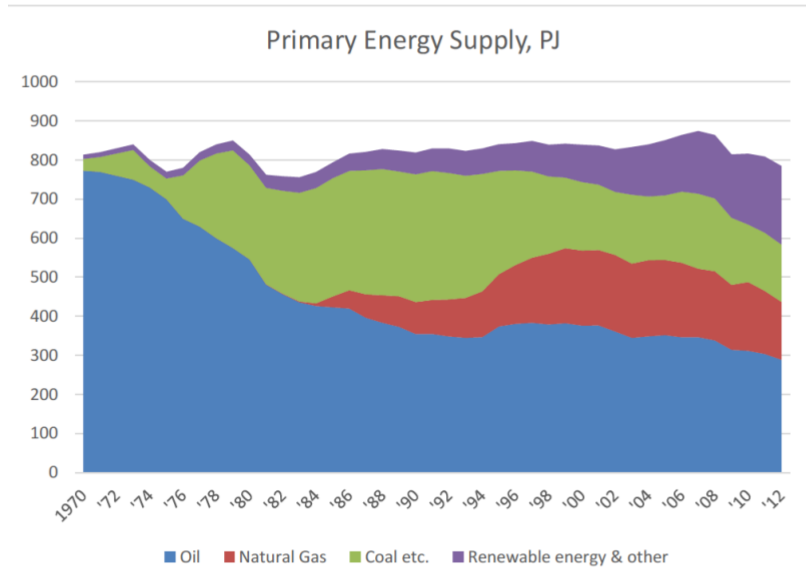


Figure 11: Emission vs. Population and Primary Energy Supply in Copenhagen over time

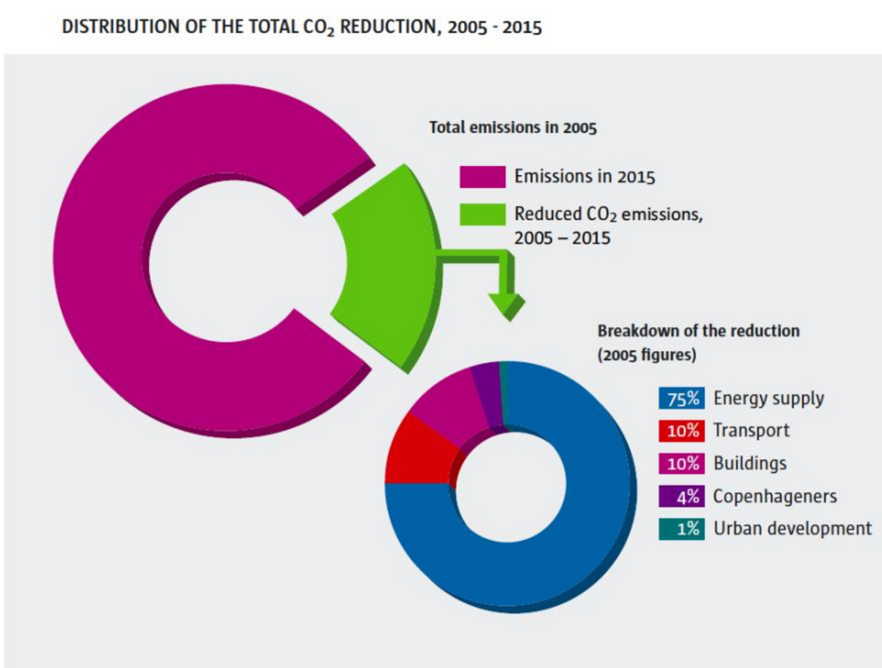


Figure 12: Distribution of the total CO2 reduction from 2005 to 2015 in Copenhagen

During the period of 2005 to 2015, 75% of carbon dioxide emissions was reduced in energy supply sector, 10% from transport sectors and 10% from buildings. By 2019, Copenhagen has 72% of electricity generated from renewable energy, with 55% of electricity from wind energy, 18% from biomass, and 17% from coal. By 2013, Copenhagen has capacity of 7MW solar panel, 12MW onshore wind and 40MW offshore wind turbines. The city has installed 40 solar power units (approx. 5,000 m2) on municipal buildings by the end of 2015. While the share of wind power in electricity consumption in 2012 was around 23%, wind power was continually developed in last several years that reaches 55% of shares in 2019. Copenhagen has its largest offshore wind farm at the Middelgrunden in 2001 with 20 turbines, annually producing 4% of the total electricity consumption of Copenhagen. In 2012, Municipality of Copenhagen completed the planning process of the first two wind turbine parks with seven large wind turbines within the city limits. The city-owned Greater Copenhagen Utility (HOFOR) has installed 23 onshore and offshore wind turbines with total of 64 MW of electric power capacity by 2017. Three 2-MW wind turbines were erected at Prøvestenen in the port of Copenhagen and supply power to 3,400 households. The company is also involved with a number of companies from other countries to bid for government tenders for near-shore wind farms and the offshore wind farm at Kriegers Flak in 2018. It is planned to install 100 offshore and land-based wind turbines for 360MW according to CPH 2025 Climate Plan.

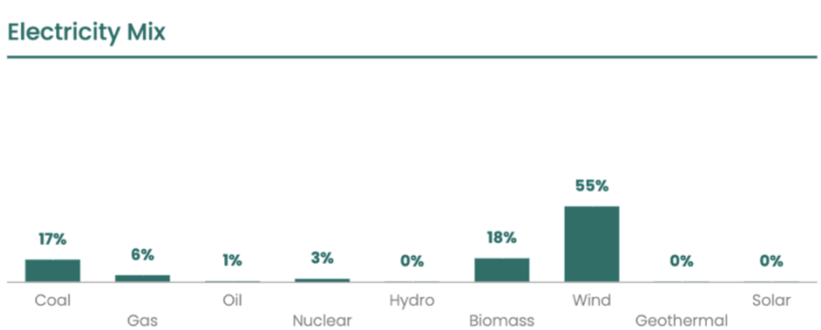


Figure 13: Electricity Mix in Copenhagen (2015)

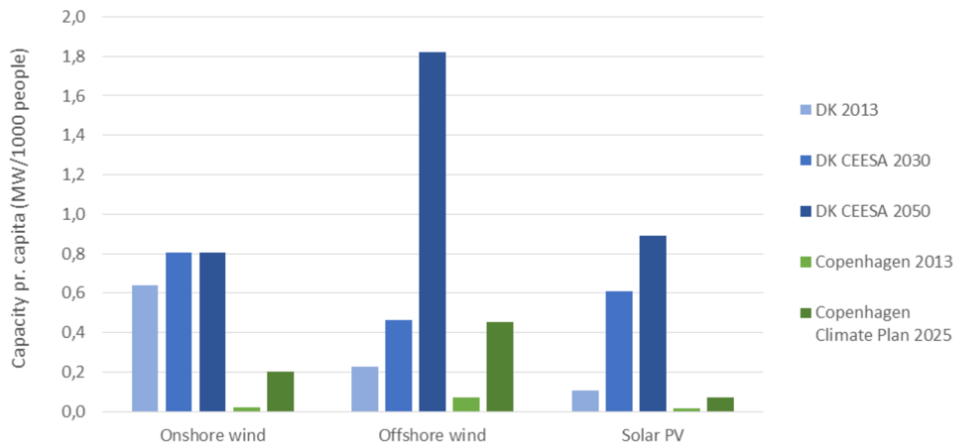


Figure 14: Capacity per capita of onshore wind, offshore wind and solar PV (2013)

Copenhagen's district heating system plays an important role regarding the integration of the renewable energy resources. The Copenhagen district heating system is a heating supply system that uses waste heat from refuse incineration plants, and combined heat and power plants (CHPs). The city explores the biomass fueled combined heat and switches from coal to biofuel using wood pillars and straw in district heating system. Due to high heat efficiency and increasingly based on renewable energy, district heating results in 50% lower CO2 emissions than individual gas boilers and more than 60% lower CO2 emissions than individual oil boilers. Today the system provides 98% of the city with clean, reliable and affordable heating with the annual use of up to 300,000 tons of wood pellets and 150,000 tons of straw. Units of power plants in Amager and Avedøre were already shifted from coal to biomass. The unit 2 at Avedøre Power Station is able to produce district heating based on 100% biomass for almost 150,000 Copenhagen homes as well as power corresponding to the annual consumption of 450,000 households.(Ørsted) In 2015, the renewable share is already close to 50 percent of the district heat production mainly and will be increased significantly towards 2025 as shown in figure 16.

CHP plants		Fuel	Capacity (heating) MJ/s	Capacity (electricity) MW
Amagerværket Power Station (AMV)	Unit 1	Biomass, coal, oil	250	80
	Unit 3	Coal, oil	331	250
Avedøre Power Station (AVV)	Unit 1	Coal, oil	330	250
	Unit 2	Natural gas, biomass, oil	570	570
H.C. Ørsted Power Station (HCV)		Natural gas, oil	500	120
Svanemølle Power Station (SMV)		Natural gas, oil	256	0
Waste incinaration plants				
Amager Ressource Center (ARC)		Waste	120	25
Vestforbrændingen (VF)		Waste	204	31
KARA/NOVEREN		Waste	104	32

The major CHP and waste incineration plants in the Greater Copenhagen area.

Figure 15: The major CHP and waste incineration plants in the Greater Copenhagen area (2015)

Other than district heating system, waste recovery also contributes to the electricity production. Commissioned in 2019, the Amager Bakke waste-to-energy facility takes 500,000 tonnes of waste and generates enough electricity to power 62,500 homes at a 99% efficiency rate, recovers 100 million tonnes of water and and recycles 100,000 tonnes of bottom ash to be used as road material. Additionally, Copenhagen captures the biogas from sewage treatment plant and mix it with natural gas after removing ammonia and sulfides. Almost one third of gas used for cooking in Copenhagen is now biogas.

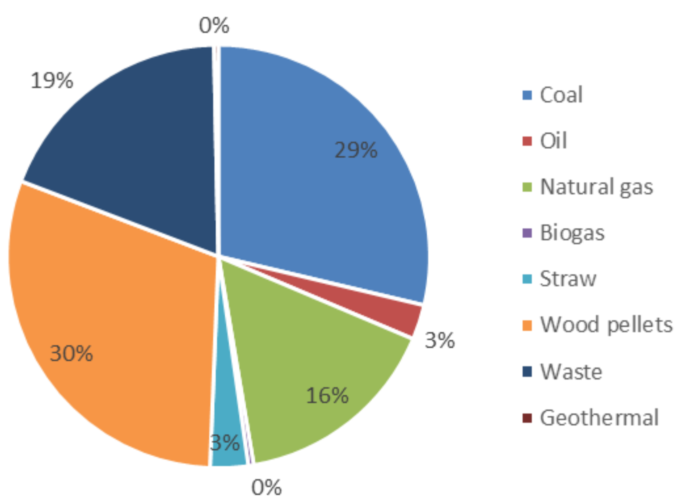


Figure 16: The shares of different fuels in the energy consumption at the plants for electricity and district heating production in The Greater Copenhagen Area (2015)

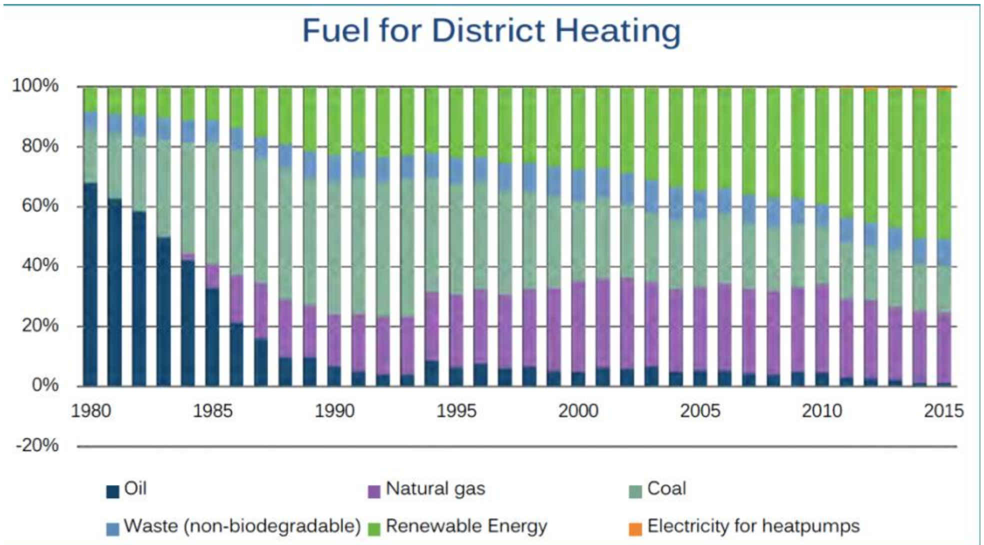


Figure 16: Trend of Fuel for District Heating in Copenhagen

Institutional Regulatory Frameworks and Decision-making process

The framework for the CPH 2025 Climate Plan will integrate and connect to other plans and strategies of the City of Copenhagen. Municipal Master Plan 2011 "Green Growth and Quality of Life" and The Climate Adaptation Plan 2011 are closely connected with this plan, in which the strategic framework for planning in Copenhagen and climate adaptation at decision-making level are already addressed in these two plans. In addition, the plan will be able to link to local master plans, including the Agenda 21 plan, the Action Plan for Green Mobility, and other related strategies as supplements.

The overall political framework relies on the goals set by both Denmark and EU for reducing the greenhouse gas emission by 20% by 2020 for EU, and 40% for Denmark. Denmark also adopted the most long-range and extensive Energy Agreement to make the whole country independent from fossil fuels by 2035. The legislative framework for green transition in Copenhagen takes place at national level; however, Copenhagen plays an important role due to its size and status as a capital. Copenhagen has the ability to share the knowledge and technology to the whole nation when setting the regional initiatives for sustainable development. Vice versa, the City of Copenhagen can collaborate with decision makers on both national and international level for the development of new methods and further increase the local capacity to support the strategies proposed.

New Technology Solutions & Monitoring Systems deployed

Smart Energy System/Smart grid

The smart energy system concept focuses on the collaboration of two key forms of energy production which are bioenergy and intermittent renewable energy such as wind and solar power. The goal is to accommodating large amounts of intermittent renewable energy and bioenergy resources to a sustainable level between the electricity, heat, and transport sectors, especially through thermal storage, heat pumps, electric vehicles etc. A more flexible energy system will be presented with multiple choices of energy resources for infrastructures.

4th Generation District Heating

In the future, there will be more heat suppliers for CHP plants available, including wind power through large-scale heat pumps, solar thermal and geothermal. The 4th generation district heating research project focuses on the transition to low temperature district heating in order to lower the delivery temperature from 80-100 degree to approximately 50-60 degree and reduce the heat lost in the pipe. Three specific areas are analyzed, which are the evolvement of grids and components, the role of low-temperature district heating in the energy system, and the planning and coordination of its implementation. (2050 Energy Vision)

Societal, Economic, Environmental and Operational Impacts Assessment

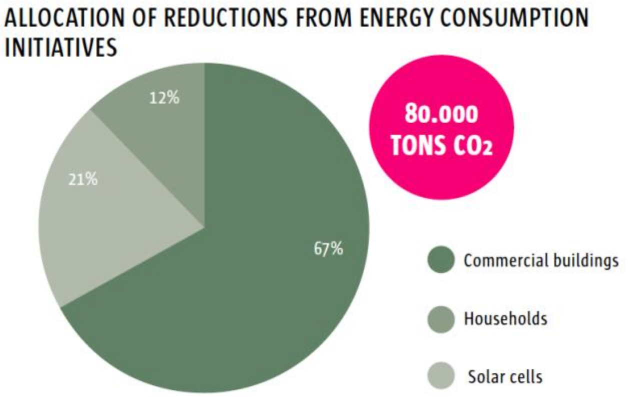


FIGURE 7 // Reduction of CO2 emissions from energy consumption as part of total reductions broken down into initiatives

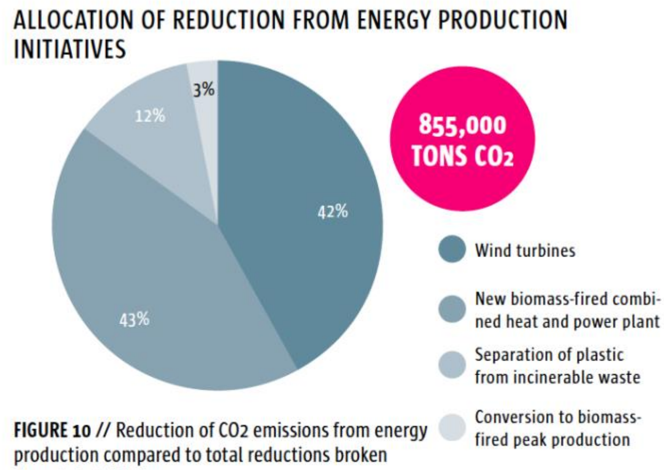


FIGURE 10 // Reduction of CO2 emissions from energy production compared to total reductions broken down into initiatives.

Figure17: Allocation of reductions from energy consumption and production initiatives

From the environmental perspective, above pictures shows that the energy consumption and production initiatives including solar cells, wind turbines and biomass CHP plant will bring up to 21% of 80,000 tons of CO2 and 88% of 855,000 tons of CO2 reduction. In the period up to 2025, the population of Copenhagen is expected to increase by nearly 110,000, and more jobs will be created. The CPH 2025 Climate Plan will not only benefit the environment of the city but also the quality of life of every citizen when developing the city to a greener and smarter city experiencing growth. When renovating the building and reducing the energy consumption, people are able to cut their electricity and heating bills at the same time prevent rising energy prices in the future. Cheap heating is secured as district heating is only half of the price of oil or gas-fired central heating. The CHP is twice as efficient as compared to separate production. Also, they are getting healthier home with better indoor climate. As Copenhagen is recognized internationally as one of the most livable cities, substantial environment improvements have been seen in cleaner water supply and more cycling with less air pollution.

In the meantime, Copenhagen experiences green growth in economic. Since 1990, CO2 emissions have been reduced by more than 40% and during the same period, there has been a real volume growth of around 50%. (CPH 2025 Climate Plan) The green sector in Copenhagen is growing as in 2009, green sector exports rose significantly reaching DKK 10.5 bn. In 2010, the economic growth rate of the Capital Region was 3% compared with the national rate of 1.3%, attracting more new businesses to the city. In terms of economic consequences of energy savings and conversion, overall, it will bring an economic gain of approximately DKK 1.735 bn as shown in figure 18 below.

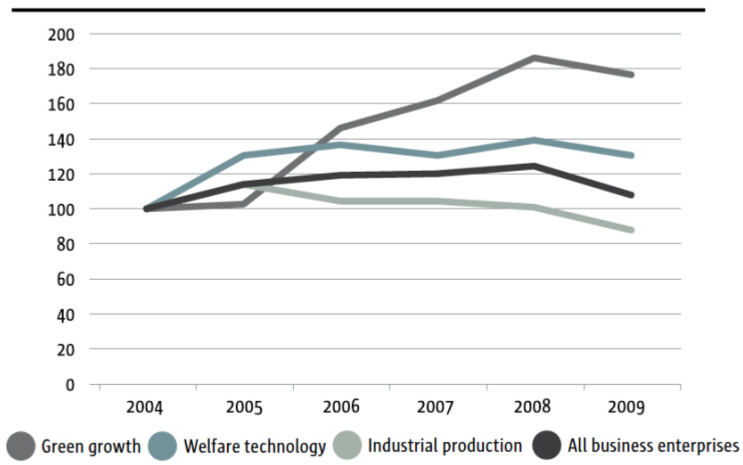


Figure 18: Growth in exports from key sectors compared to total growth in Copenhagen

ECONOMIC GAIN/COST FROM ENERGY INITIATIVES IN DKK MILLION (NET PRESENT VALUE)

Conversion to biomass	-725
Peak-load production from biomass	- 80
Geothermal energy (preliminary calculation from KE)*	-500
Heat savings	1.015
Electricity savings	600
Wind turbines	1.425
IN TOTAL (DKK M)	**1.735**

Figure 19: Economic gain/cost from energy initiatives of CPH 2025 Climate Plan

Financing Strategies & Public-Private partnerships

According to CPH 2025 Climate Plan, the city would require an estimated need for municipal investments of approximately DKK 2.7 bn up to 2025. It is crucial that there will be no increase in the overall expenses for Copenhagen city dweller as the plan will limit impact on the private economy of Copenhageners. A household is estimated to save approximately DKK 6,500 per year if they invest in energy saving measures. The financing of the energy production will not come from City Administration's budget, which implies that they will primarily find in transport and energy consumption.

Private investment accounts for large part of financing strategy. It is estimated that within the areas of energy and mobility, there will be approximately DKK 200-250 bn private investments, and the plan will further encourage 20-25 bn. There are planned investments carried out by energy companies of DKK 5.5 bn in wind projects, DKK 1.5-4.0 bn in a wood chip-fired combined heat and power plant, roughly DKK 1 bn in geothermal energy. Private investments in solar cell are expected to be DKK 0.5 bn by 2025.

Public-private partnership is an essential element in the strategic energy planning. Copenhagen has the ability to leverage local power and in collaboration with government and private and civic sectors. Since 1990, the city has focused on people-centered planning and created environment for innovative businesses to grow. As one critique of the city's plan noted, "private enterprises are to a greater extent included in decision-making, while the public sector has embraced entrepreneurial forms of organization and behavior." The public-private partnership encourages the mutual growth for both parties as it benefits the growth of the companies as well as assisting the city to reach carbon neutral. North Harbour Energy Partnership is an example that engage businesses and citizens into innovative development. Some stakeholders are City & Port Development, DONG Energy, Copenhagen Energy and the Ministry of Climate and Energy.

Case Performance Assessment

The role of municipalities in renewable energy system is quite different than traditional fuel system. While traditional fossil fuels can be transferred from outside and distributed to consumers, renewable energy will take place locally in the countries. In municipal energy planning, the city should grasp the utilization of local renewable energy resources and implement projects that will contribute to the national target. In this case, Copenhagen has done really well in terms of constructing, operating, and implementing the renewable energy such as wind turbine, solar thermal, geothermal energy into the CHP district heating and electricity generation.

From the performance measure, we can see that Copenhagen is on the right way of being the first carbon neutral capital by 2025. The renewable energy has been largely implemented in major public infrastructures such as the electricity and the district heating. The objectives and initiatives are detailed and cleared enough for the city to implement in both energy consumption and energy production sectors in the upcoming years. Overall, City administration acts as a front role to set up and reach the initiatives first in municipal buildings and energy sectors, which create a great model for the whole city to reference on. Although not so much was completed in the transport sectors using renewable energy, due to high energy demands for transport today, Copehangen has great potential on integrating the renewable generating electricity and biofuel to achieve green mobility.

Case Study – San Francisco

Problem Domain Definition in the Urban Context

San Francisco, officially the City and County of San Francisco, is a renowned city in central coast of California and the second most densely populated city in the US with a population of approximately 881,549 as of 2019. Located on the West Coast of the United States near Pacific Ocean, San Francisco has long been a leader in environmental, social, and economic prosperity. Today, the city confronts the greatest challenge of the ear – Climate Change and faces the reality that climate change is already affecting their lives. Sea level rise, reduced snowpack and more fires in the Sierra Nevada Mountains, and extreme weather events include heat waves and intensive rainstorms that lead to flooding all make the living environment in Bay area really vulnerable. Looking from the extended fire season in 2017 and 2018 that brought poor air quality and 2019 flood caused by heavy rain fall and high tide, climate change is a crisis that is directly impacting residents and adding burden to infrastructures. With the recent scientific projections showing the increasing of sea level by 11 to 19 inches by 2050, corresponding actions need to be taken as soon as possible to mitigate the climate impacts by reducing the greenhouse gas emissions.

According to the latest data from 2018 GHG emissions inventory at a glance, in 2018, San Francisco's community-wide greenhouse gas emissions was totaled 5.14 million mtCO2. According to the figure below, transportation sectors account for the largest emissions with 72% from passengers' vehicles, followed by commercial and residential sectors with 88% and 75% from the use of natural gas and 10% and 18% from the electricity respectively.

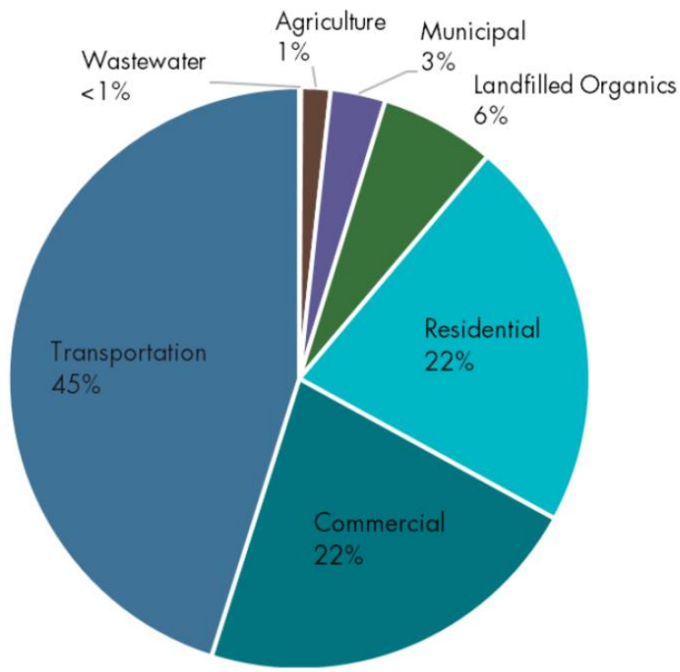


Figure: GHG emissions by sector in San Francisco in 2018

Though overall electricity use in San Francisco increased 11% between 1990 and 2010, the past two decades still shows a steady decline of emission, which is primarily depended on the cleaner supply of electricity with continuing replacement of fossil fuels power generation with renewable sources as well as the State of California's Renewables Portfolio Standard and the closure of two of the state's dirtiest and most inefficient fossil fuel power plants in San Francisco's southeast neighborhoods. In addition, the implementation of clean electric grid, increased building efficiency and transition of transportation fuels have also led to the emission reduction over time.

Historical Context and City Policies

The city and county of San Francisco has a strong commitment to protecting its environment and combating the climate change as early as 1996 when the first San Francisco's Sustainability Plan was published and adopted by Board of Supervisors. Following the plan, in 2002, California passes the Renewable Energy Portfolio Standard requiring that 20% of all power delivered by Pacific Gas & Electric (PG&E), San Francisco's investor-owned primary power provider, come from eligible renewable resources. This percentage was raised to 33% in 2008 and 50% by 2020 in 2017. In 2004, San Francisco became one of the first US cities to adopt the Climate Action Plan. The San Francisco Department of Environment (SF Environment), under Mayor Gavin Newsom, published the plan as part of its commitment to the U.S Conference of Mayors Climate Protection Agreement.

By 2008, the city has already reached the target of reducing GHG emissions to 7% below 1990 levels set by Kyoto Protocol, an international agreement binding targets for greenhouse gas reduction. In 2010, after implementing California's largest municipal solar project at sunset reservoirs comprised of 24,000 solar panels, San Francisco is leading in the renewable energy market and Mayor Newsom announced the goal of 100% renewable electricity by 2020. In the following two years, the 100% renewable goal was supported by the San Francisco Mayor's Renewable Energy Task Force Recommendations Report published in 2012 that outlines the major strategies to be technically and economically feasible for achieving the goal. As 41% of electricity supply was already renewable by 2012, in 2013, SF Environment updated the 2004 Climate Action Plan as Climate Action Strategy under Mayor Edwin Lee with the core of the strategy focusing on sourcing 100% of residential and 80% of commercial electricity from renewable sources, coupled with energy efficiency improvements to reduce usage. (SF Environment)

In 2015, Mayor Lee announced San Francisco's 0-50-100-Roots climate action strategy and further modified in 2018 to 0-80-100-roots Climate Action Framework aiming for 0 waste, 80% sustainable trips, 100% renewable electricity by 2030, 100% renewable energy with emission reduction of 80% by the year of 2050. At the same year, Mayor Mark Farrell announced historic commitment to net-zero GHG emissions by 2050. And in last year, SF Environment collaborated with the Mayor's office and city agencies to develop the technical report "Focus 2030: A Pathway to Net Zero Emissions" detailing a path for achieving emissions reductions by 2030 and pursuing city's 0-80-100 Roots goals. In the past twenty years, San Francisco has been a climate pioneer setting ambitious goals by designing strategies toward reduction of emissions with the major efforts on integration of renewable energy in city's infrastructures.

Figure: 0-80-100-roots Climate Action Framework

Strategies Implemented

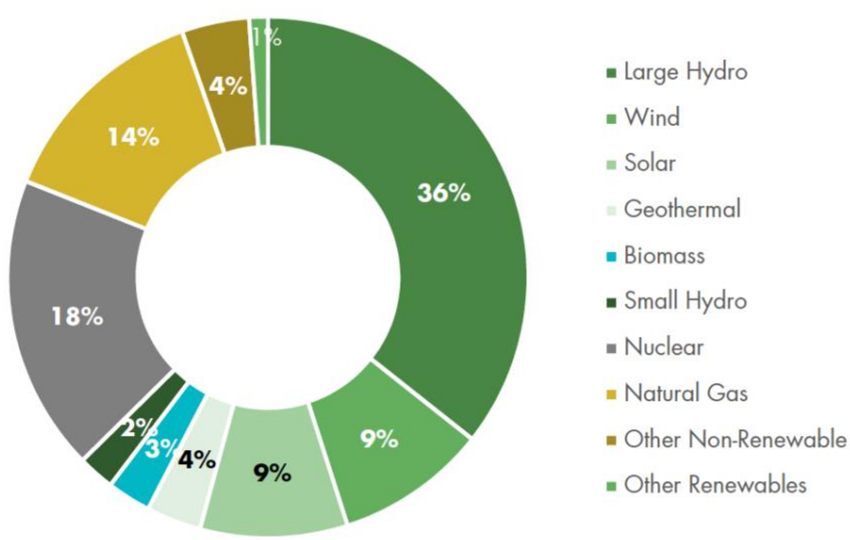


Figure: San Francisco Electricity Grid Mix in 2017

As mentioned in the previous section, in 2018, the city was directed to achieve net-zero emissions by 2050 though four sub-goals: 0 waste, 80% sustainable trips (walking, biking, transit), 100% renewable energy, and urban greening for carbon sequestration. San Francisco is now following the 0-80-100 Roots Climate Action Framework with strong emphasis on achieving 100% renewable electricity and energy by 2030 and 2050 respectively.

San Francisco is stepping on removing fossil fuels in the energy production, known as the decarbonizing the electric grid, and the electricity generation gradually become cleaner. As of 2017, the electricity grid mix was made up of 38% large and small hydroelectric energy, 25% wind, solar, geothermal, biomass energy and other renewables, 18% nuclear energy, and 18% natural gas and other non-renewable energy. City-owned buildings are also powered by 100% GHG-free electricity. San Francisco is efficiently using the renewable resources as renewables accounted for 64% of all the electricity generation. To achieve the further 100% renewable energy by 2050, the city must continue to focus on supplying energy from emission-free and renewable sources. Several strategies are implemented or plan to be implemented according major climate action report provided by SF environment and mayor's office.

San Francisco Climate Action Plan 2004

This plan is one of the first climate action plan published in United States. Among all of the strategies listed to reduce the greenhouse gas emissions, renewable energy actions are grouped into three categories to achieve estimated CO_2 reduction of 548,000 tons per year including developing renewable energy projects (solar, wind, biomass energy), conducting pilot projects for emerging technologies, and supporting green power purchasing.

San Francisco Climate Action Strategy 2013 Update

The SF Climate Action Strategy was updated in 2013 from its first version in 2004. Focusing on increasing use of renewable energy in buildings, San Francisco intends to continue the trend of a cleaner, greener electricity supply by expanding the options for purchasing 100% carbon-free power on municipal properties, businesses, and homes. The renewable energy section of the plan specifically focuses on energy use in buildings. Following graphs and tables show the expected GHG emission reduction from the strategies implemented

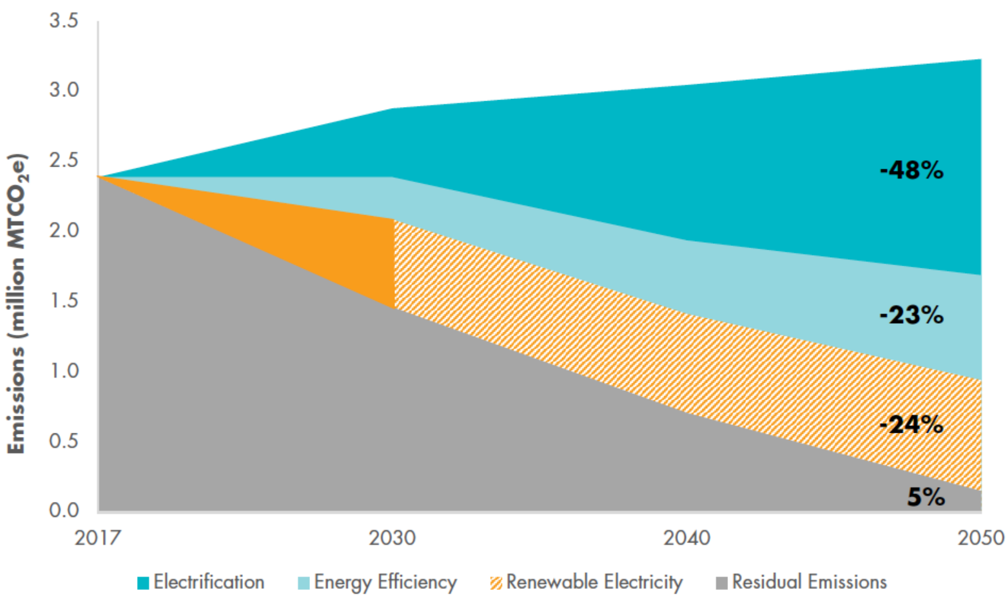


Table 7. **CAS Goals for Residential Participation in 100% Renewable Energy and Associated GHG Reductions**

Year	Participation Rate	Anticipated GHG reductions/mTs
2012	0%	0
2017	5%	96,994
2020	10%	134,256
2025	45%	328,094
2030	80%	521,485

**Commercial* includes industrial and other usage.

Table 8. **CAS Goals for Commercial Participation in 100% Renewable Energy and Associated GHG Reductions**

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**Commercial* includes industrial and other usage.

Figure: Distribution of strategies in the path to zero emissions in buildings and GHG emissions reduction for commercial and residential participation in 100% renewable energy

In-City Renewable Generation – Solar

Although most electricity is produced outside of the city, increasing in-city renewable energy sources is an important strategy to reduce the GHG emissions as well as promote local economic development. San Francisco has very great solar resource potential due to its clearest weather in spring, fall and winter; therefore, it has largely supported the use of solar energy in terms of photovoltaic system installations to generate electricity and solar water heating projects in both residential and commercial rooftops. As of 2017, solar system accounted for 9% of total renewable energy. City has three municipal solar installations with 1.2 MW capacity, and San Francisco Public Utility Commission (SFPUC) developed the 675 kilowatts PV system on the Moscone Convention Center's roof, which was the largest municipal installation in the country at the time of 2012. Photovoltaic can provide up to 7% of city's current electricity needs. The solar water heating projects were also introduced to several residential areas using sun energy to heat domestic hot water. City also launched the SF Solar Map, which is the go-to resource for solar information for property owners that help them to find their home or buildings' potential for solar electric and heating.

In addition to physical installations, city also promote the solar energy by offering incentives and financing opportunities. SFPUC has launched a successful project in 2008 called GoSolarSF, which is the first municipally operated incentive program for solar energy. It offers financial incentives to residents as well as low-income residents to install rooftop solar systems and have the one-time payment to reduce the cost of installation and energy bills. By reducing cost, it also helps community-based organization to increase their funds and jobs. Residents who are saving money from utility bills can also spend more on local economy that further promoting vitality of city's green economy.

Wind Energy

Wind is an excellent and abundant renewable resource to generate energy using modern wind turbines at very low cost. The estimated potential for wind development in the greater Bay Area for San Francisco's use could exceed 150 megawatts (2014). While currently San Francisco has moderate medium to large scale wind onshore resources, the best wind source in San Francisco lies offshore over the waters of Pacific Ocean with high speed and low turbulence. Unfortunately, the water is too deep for conventional turbine foundation designs. The city tries to address the issue by creating long-term plan on floating turbines or turbines installed on platforms (similar to offshore oil and gas rigs) along the deep California coast as well as the wave energy technologies. Besides that, SF environment is also exploring the "urban wind" that focuses on the small-scale wind turbines appropriate for urban use, which shows a great potential for the renewable future.

City also plans to support options for those who cannot install renewable energy projects in their homes. By enabling "community solar gardens" or "community wind" projects, residents could invest to the multifamily properties and receive power from local, off-site renewable energy sources.

Hydro Energy

Located near Pacific Ocean, hydropower accounts for 36% of total electricity generation. All the municipal facilities' hydropower is generated at the Hetch Hetchy reservoir in Yosemite. The Hetch Hetchy power system is operated by SFPUC and generates 1.6 billion kilowatt-hours (kWh) of clean, hydroelectric power annually for the San Francisco's municipal tenants and retail customers as well as additional energy for residents and businesses in the 662 square-mile service area of the Modesto and Turlock Irrigation Districts. It would also provide solar and biogas energy to customers. With the benefit of its location near the sea, the city is also searching for the tidal and wave energy in place such as Golden Gate that has 400 billion gallons of water rushed through every. 15 to 17 average megawatts (MW) are potential to be extracted from the site.

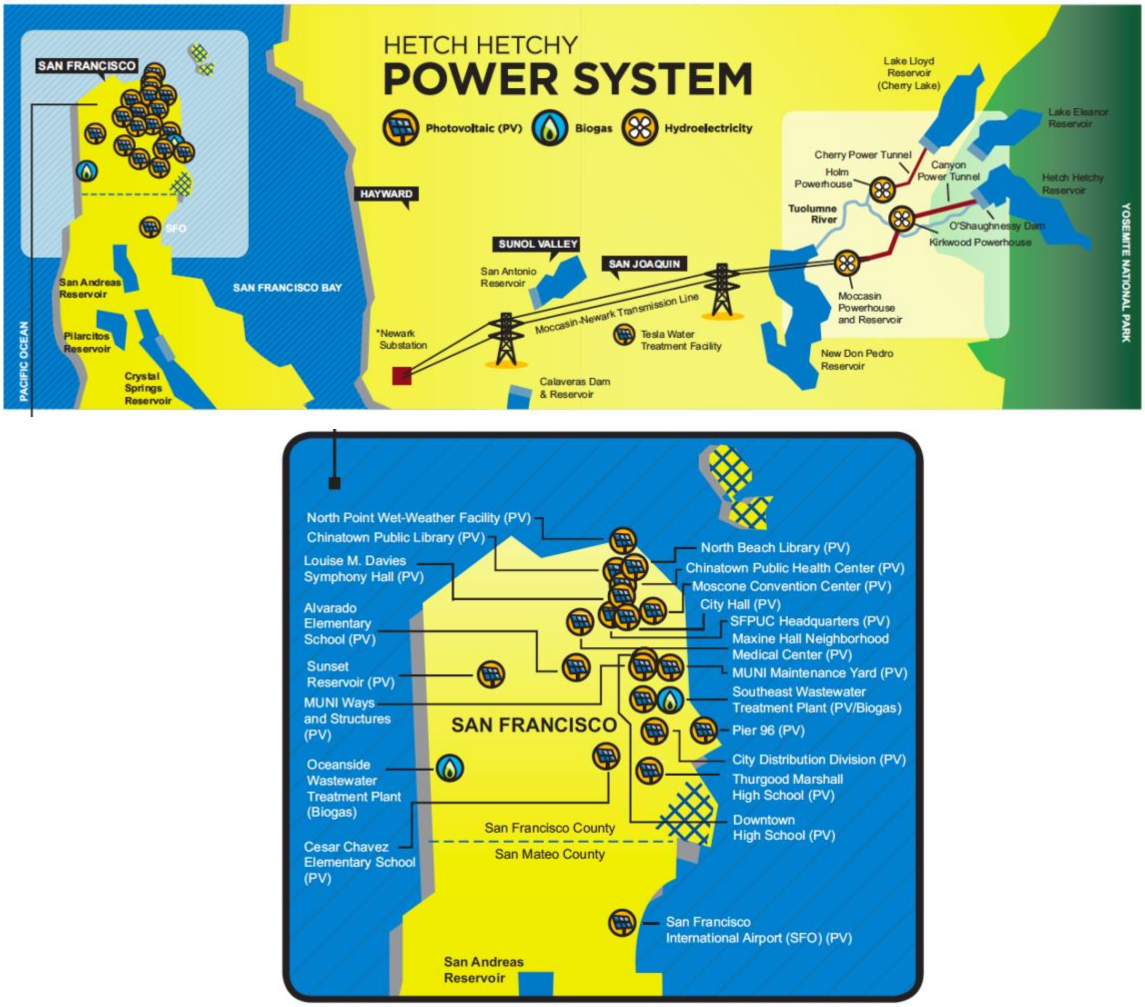


Figure: Distribution of Hetchy Hetchy power system in San Francisco and surroundings

<u>Biomass and Biofuel Energy</u>

Sewage treatment and landfill biogas can be collected for use in combustion to generate electricity. Biogas is continuously growing in energy market as a renewable source. In San Francisco, biogas, mainly methane that produced from sewage as by-product powers the SFPUC's Oceanside and Southeast wastewater treatment plant. By generating up to 3.2 megawatts of renewable energy from capturing and combusting the methane gas, it provides both heat and electricity for wastewater treatment plant operations.

CleanPowerSF

CleanPowerSF is launched in 2014 by San Francisco Public Utilities Commission as a form of Community Choice Aggregation (CCA). It is unique because it was formed to serve San Francisco exclusively, and benefits from being nested within a public utility. It expands access for all income level residents by allowing communities to aggregate the purchasing power of its citizens to buy electricity on the wholesale market or directly from power generators. It offers customers a new option to purchase their electricity from renewable and low-carbon sources at competitive rates. "CleanPowerSF buys your electricity from sources such as wind and solar, and that electricity is delivered to your home via PG&E's existing poles and wires." While PG&E still retain the transmission and distribution system and delivers the renewable energy, communities will be enrolled in the basic "Green" service with at least 50% renewable energy and have the option to upgrade to "SuperGreen" service with 100% renewable blend by paying $6 a month or opt out and stay with Pacific Gas & Electric (PG&E), San Francisco's investor-owned primary power provider.

COMPARISON OF TYPICAL MONTHLY BILL—RESIDENTIAL

E1	CleanPowerSF Green	CleanPowerSF SuperGreen	PG&E Default
Renewable Energy Content	50%	100%	38%
Electricity Generation	$21.88	$24.61	$32.08
PG&E Electricity Delivery	$51.65	$51.65	$51.65
Additional PG&E Fees*	$9.28	$9.28	–
Taxes and Fees	$0.08	$0.08	$0.08
AVERAGE TOTAL COST PER MONTH	$82.89	$85.62	$83.81

Figure: Comparison of typical monthly bill for residential sector

Through the program, city has more control over the ability to increase the cost-effectiveness of renewable energy, and it is also required to create more local jobs, be municipally owned and located, be rate competitive with PG&E and protect low-income residents.

CleanPowerSF expects to enroll 55,000 customers by the end of 2016. The proposed renewable projects to be implemented and estimated emission reduction by the program are shown in the graphs below:

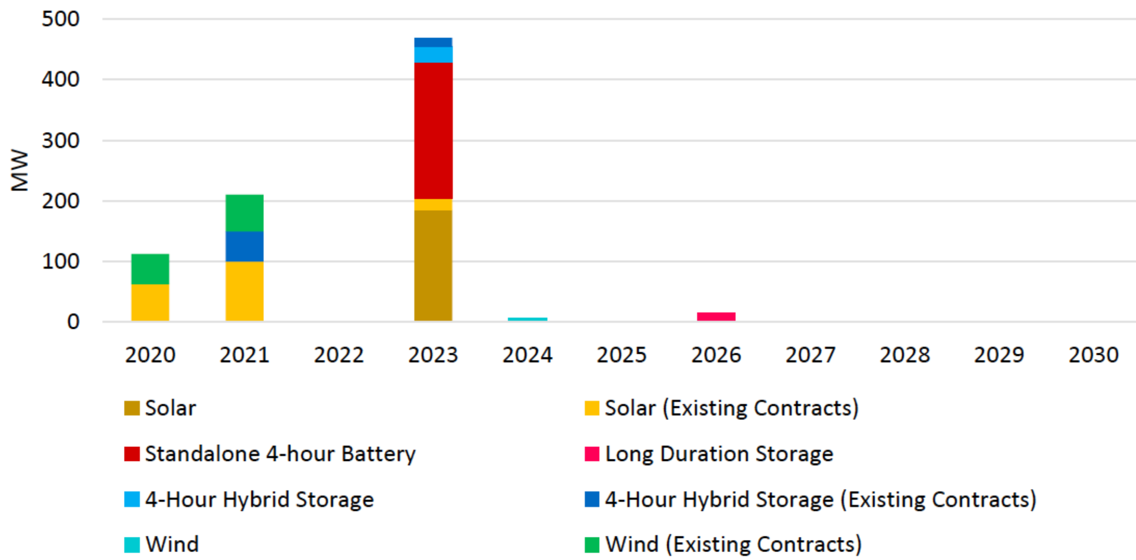


Figure: CleanPowerSF's current and expected projects

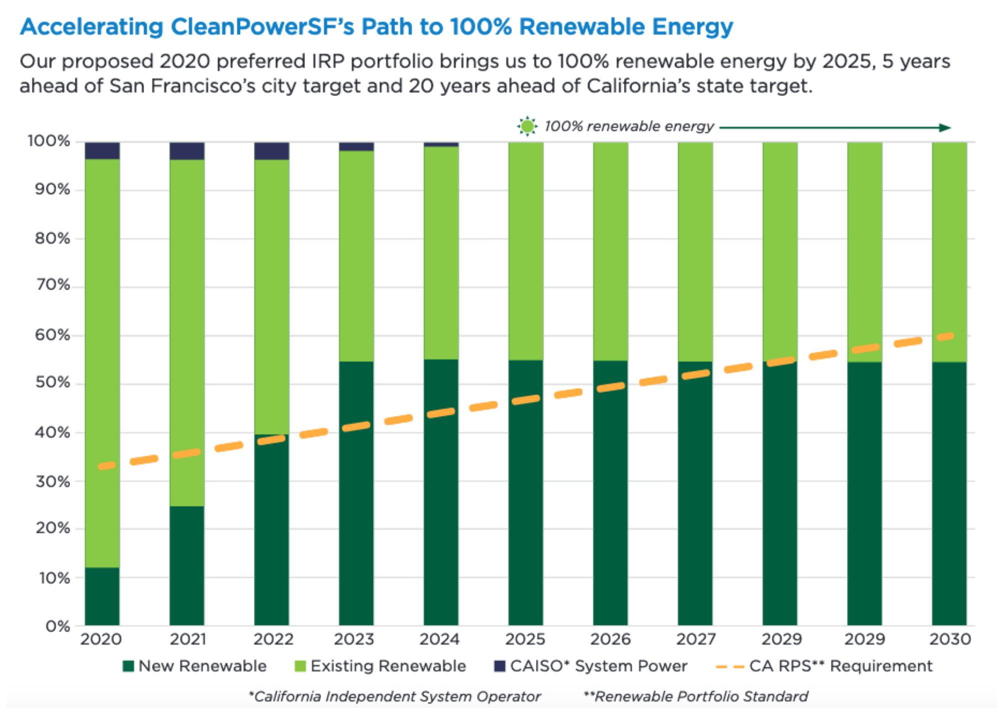


Figure: CleanPowerSF's path to 100% renewable energy

Public Policy Objectives of the Local Governance

Mayor's Renewable Energy Task Force

In 2011, San Francisco mayor Edwin M. Lee announced the goal of reaching 100% renewable electricty supply within 10 years. In the following year, the report was published with 43 recommendations focusing on three main areas: Energy Efficiency, Local Distributed Generation, and Utility-Scale Generation. The primary strategies related public policy objectives described in the report are also referenced by the SF Climate Action Strategy 2013 as follows:

Shrink the pie with increased energy efficiency

The city aims to increase the energy efficiency by promoting energy audits and retrofits through local and state programs, using building energy data to strict the building code energy requirement.

Break down barriers for multitenant buildings and occupants

This strategy enables property owners to share the costs and savings of renewable energy with their tenants, which make up more than 60% of SF citizens, and encourage green leases by democratizing the local renewable energy economy. Virtual Net Programs will be expanded for owners to distribute credits from a single solar electric system to multiple tenants.

Expand access to local renewable energy

This strategy tackled on expanding customer's ability to install solar system on-site or invest in a community-owned solar system off-site and receive electricity credits on their utility bills. It is mainly operated through the CleanPowerSF project as described above in the strategy section.

Encourage local renewable energy

Encouraging local renewable energy could reduce the transmission needs and improve local energy security. In order to implement the strategy, the task force recommend standardizing and streamline solar permitting and addressing solar system shading. It is also critical to have stable contracts that allow renewable energy projects to sell their power to the grid such as funding for GoSolarSF program as well as developing local renewables under CleanPowerSF.

<u>Provide 100% renewable power purchasing options – Community Choice Aggregation</u>

This strategy aims to develop and encourage green purchasing programs by implementing Community Choice Aggregation (CAA) program such as CleanPowerSF that allows participating customer to buy power wholesale directly from producers. City has also expanded deliveries of 100% renewable municipal power by making SFPUC the default power provider for city properties and tenants and by providing renewable SFPUC power for transit providers and new development.

<u>Encourage private-sector investment in renewable energy</u>

In order to expand and reduce the cost of clean energy financing, private sector investment can be encouraged by leveraging city resources include CAA and consumer demand for renewable energy. Create financial incentives and opportunities such as low-interest bonds and funding for local projects and energy efficiency can also promote the renewable energy investment and project development.

Local Governance, Agencies and Stakeholders

San Francisco and Bay Area's political standings are relatively progressive with Democrats and Greens dominated the political representation since the 1960s. The State of California has fully-fledged legislative powers in many areas, including the environmental and energy policy, although some of them are coordinated at Federal level. The political system in Bay Area is organized through Counties and Cities. San Francisco is both a City and a County, and therefore it has a Mayor's Office and a Board of Supervisors as the major local government in the area. Cities tend to be more independent while counties are usually more powerful in less urbanized areas. In the case of San Francisco, Mayor's office has strong powers than the county. Mayor's office Mayoral Task Force also work together with Mayor's office to give more detailed plans and recommendations on the strategies and policies.

California is one of the eleven states in United States that allow for "legislatively-referred and direct initiatives statues, constitutional amendments and referenda" (CARVALH, Luís, 2014), which means that other than elected legislative bodies, citizens can also propose laws at local and state level as an important stakeholder. This creates more participation from residents as a form of direct democracy as well as understand voters' preferences in city and states' policies. Also, energy utilities companies can act just as regular citizens to raise proposals and provide incentives or recommendations on city's regulations on the energy operation. Under the City and County of San Francisco, San Francisco Department of Environment (SF Environment) generally manage the visionary policies and innovative programs that promote social equity, protect human health, and lead the way toward a sustainable future. The department is currently in charge of the 0-80-100-roots climate action that follows the policies and strategies planned for achieving 100% renewable by 2030.

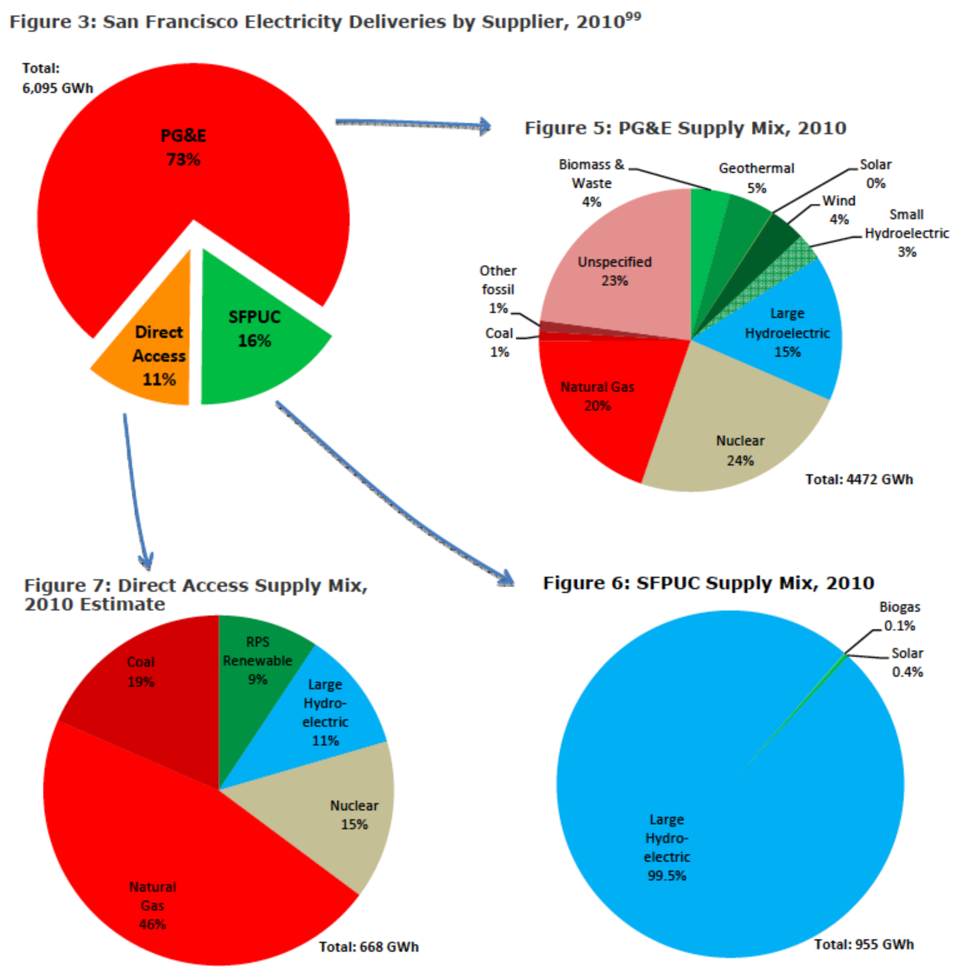


Figure: Electricity Mix of San Francisco Electricity Deliveries by Supplier in 2010

Besides local government structures and stakeholders, there are two main types of electric power utilities in San Francisco that play critical roles in providing energy and electricity to citizens. The first type is investor-owned utilities, which private companies provide electricity generation, procurement and distribution to a monopoly service area. Pacific Gas & Electric (PG&E) is by far the biggest investor-owned utilities in San Francisco Bay Area, delivering natural gas and electricity to most of Norther California, including San Francisco, and serves roughly 5 million electricity customers. Over 60% of the electricity delivered by PG&E is generated from either renewable resource or GHG free resources (nuclear). As of 2014, it operates 100,000 direct solar panels connection in their service areas.

The second type is municipal-owned utilities, which are the companies owned and operated by a local jurisdiction. Two examples in San Francisco would be Pal Alto Municipal Utility and San Francisco Public Utilities Commission (SFPUC). SFPUC delivers electricity to all municipal operated facilities such as public buildings, hospitals, port and airport and shares the market with PG&E. It is also the administrator of the CleanPowerSF that acts as major program contributing to the 100% renewable energy goal by providing plans to more than 380,000 customers of SF citizens to incorporate renewable energy.

There are also other relevant actors beyond state and municipal level agencies, utilities and citizens, including the number of local authorities that pursuing the community action aggregation, independent energy providers for both whole and individual consumptions, and active communities of academic researchers, grassroots associations and organized movements that take actions to influence energy regulations through experiments and research.

Performance Measures

Facing these climate challenges, San Francisco has made remarkable progress in dealing with it by developing number of innovative policies and programs to move the city toward its goal of 100% renewable energy to become a cleaner, healthier and more secure city. In 2017, San Francisco achieved a 36% reduction in GHG emissions below 1990 levels, largely surpassing the goal of 25% set by San Francisco Board of Supervisors, while economy has still grown 78 percent over same time. This put San Francisco well head of targets set by California’s Assembly Bill 32, the Global Warming Solutions Act as well as the international Kyoto Protocol as early as in 2013.

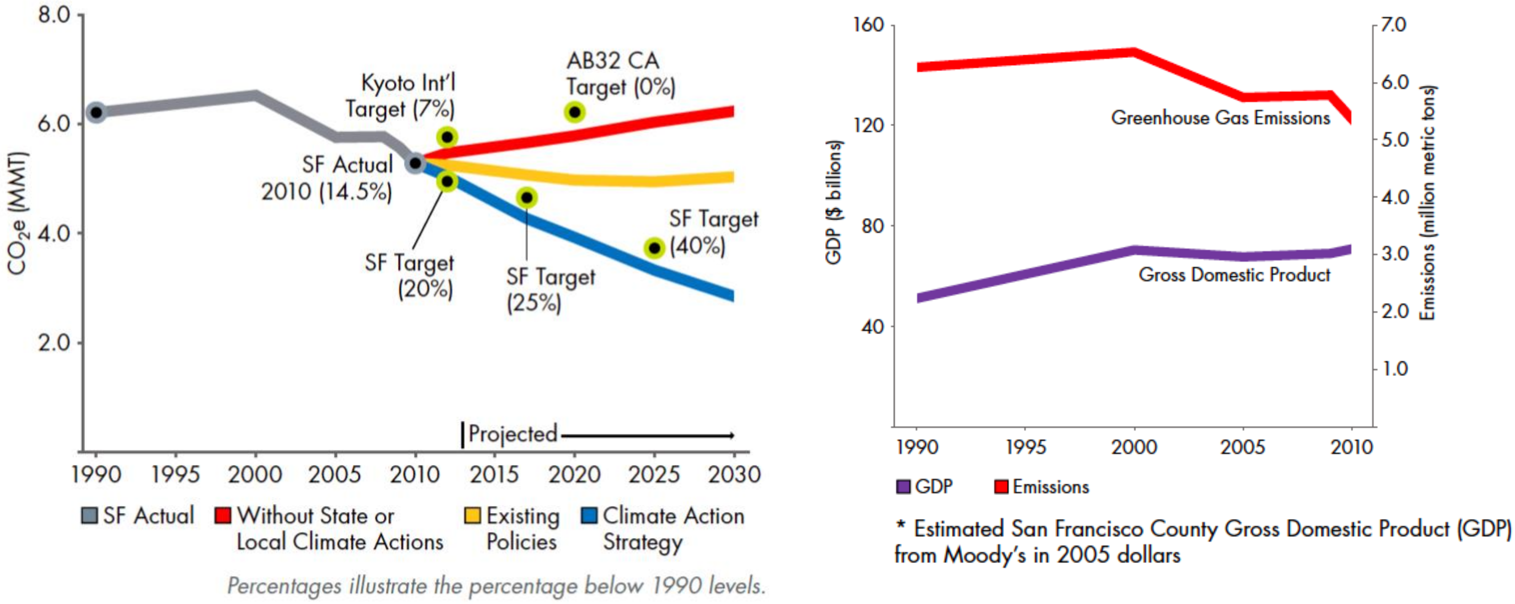


Figure: San Francisco GHG emissions related to various targets and its economy grew

More than 18.5 MW of in-City renewables had been installed, with 15 MW of solar PV (more than 2,000 systems) citywide and 3.5 MW of biogas cogeneration at the City’s wastewater treatment plants. Including the three major municipal solar installations with 6 MW capacity on Moscone Convention Center (675kW), Sunset reservoir (5MW), and San Francisco International Airport (500kW), SFPUC installed photovoltaic panels on 23 sites which generate approximately 8.6 MWh of renewable energy in San Francisco. More than 500 residential and commercial solar installations with approximately 1.8 MW in capacity. As of 2014, GoSolarSF program has provided $16.9 million in incentives towards more than 2,000 solar installations, with a combined capacity of nearly 7 MW. It reduced GHG emissions by 1,900 mT annually and saved participants roughly $2 million annually on their electricity bills. Furthermore, it offered $11 million to low-income households and non-profits and created more than 100 green jobs through workforce development program. Besides, the largest solar hot water installation in St. Francis Square has a total of 227 solar collectors covering 9080 ft2, along with thirteen 1000-gallon storage tanks. (SF Environment)

<u>CleanPowerSF</u>

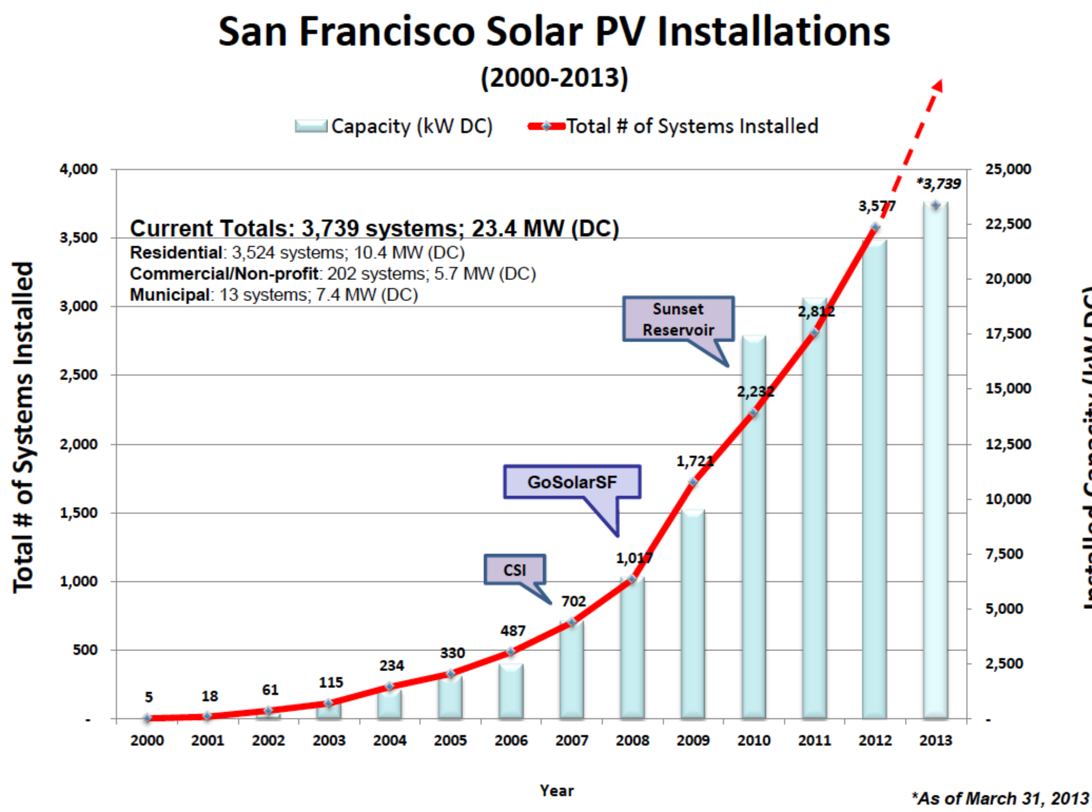


Figure: San Francisco Solar PV Installation Trend as of 2013

Since CleanPowerSF launched in 2016, it has saved San Francisco ratepayer more than $3.5 million in reduced electricity bills as well as reducing the citywide electricity supply-related greenhouse gas emissions by approximately 258,000 metirc tonnes in 2018 relative to 1990 level. CleanPowerSF now offers 35% of renewable energy of total electricity mix with its own energy mix shown in the graph below. Currently, the program is consisted of energy from wind, solar, hydroelectric, geothermal and biomass sources, which generated from Shiloh Wind Farm with 25 MW of energy from the facility, Sunset Reservoir Solar Array, The Geysers that has a net generating capacity of about 725 MW from geothermal. Other new renewable energy projects that CleanPowerSF invested are Blythe Solar with 62MW photovoltaic solar energy, 47 MW Terra-gen voyage wind project and 100MW SPower San Pablo Raceway Solar Project. Not all of them located in San Francisco, but they all contribute to the electricity that CleanPowerSF provided to the local residents in San Francisco. (CleanPowerSF)

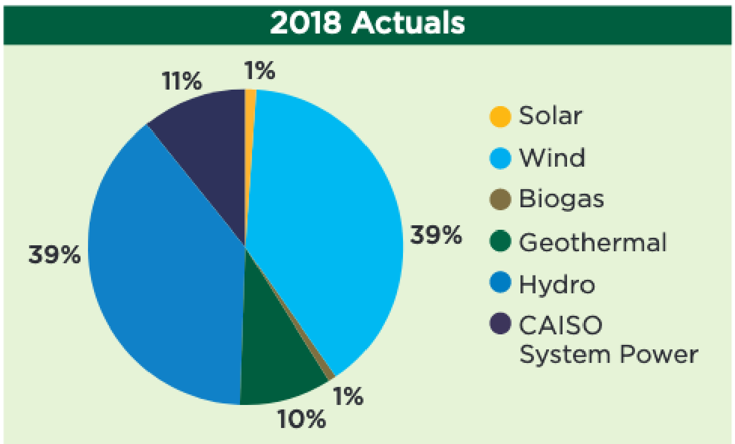


Figure: CleanPowerSF Actual energy mix in 2018

Figure: Distribution of CleanPowerSF new renewable energy projects

<u>Hetchy Hetchy Power System</u>

Together, SFPUC's Power programs provide more than 70% of the electricity consumed in San Francisco with clean power. The Hetch Hetchy power system generates 1.6 billion kilowatt-hours (kWh) of clean, hydroelectric power annually for the San Francisco's municipal tenants and retail customers generate up to 3.2 megawatts electricity from biogas in wastewater treatment. Following table shows a more detailed contribution of each renewable energy sites toward the program. (SF Environment)

HYDROELECTRIC GENERATION	Approximate Hydroelectric Capacity: 380.5 MW			
Powerhouse	Date On-Line	Unit 1	Unit 2	Unit 3
Holm Powerhouse	1960	82.5 MW	82.5 MW	—
Kirkwood Powerhouse	1967	39.5 MW	39.5 MW	36.5 MW
Moccasin Powerhouse	1969	50 MW	50 MW	—

SMALL HYDROELECTRIC GENERATION	Total Small Hydroelectric Capacity: 3.8 MW		
Project	Date On-Line	Location	Output
Moccasin Low Head Unit	1987	Moccasin Powerhouse	3.8 MW

BIOGAS GENERATION	Total Biogas Capacity: 3.1 MW		
Project	Date On-Line	Location	Output
Oceanside Wastewater Treatment Plant	1995	3500 Great Highway	1 MW
Southeast Wastewater Treatment Plant	2002	750 Phelps St.	2.1 MW

PHOTOVOLTAIC (PV) GENERATION *	Total Solar Capacity: 7.9 MW		
Project	Date On-Line	Location	Output
Moscone Convention Center	Oct, 2003	747 Howard St.	676 kW
Southeast Wastewater Treatment Plant	Oct, 2005	750 Phelps St.	255 kW
Pier 96	Jan, 2007	Pier 96	245 kW
SFO	Nov, 2007	Terminal 3	496 kW
Maxine Hall Neighborhood Medical Center	Nov, 2007	1301 Pierce St.	36 kW
City Distribution Division	Dec, 2007	1990 Newcomb Ave.	111 kW
North Point Wet-Weather Facility	Dec, 2007	110 Bay St.	222 kW
Chinatown Public Library	Dec, 2007	1135 Powell St.	11 kW
Sunset Reservoir	Dec, 2009	2000 24th Ave.	5006 kW
MUNI Maintenance Yard	Nov, 2011	1095 Indiana St.	106.9 kW
Chinatown Public Health Center	Dec, 2011	1490 Mason St.	24 kW
SFPUC Headquarters	Jun, 2012	525 Golden Gate Ave.	165 kW
Tesla Treatment Facility	Jun, 2012	900 West Vernalis St.	32 kW
Alvarado Elementary School	Jan, 2013	625 Douglass St.	50 kW
MUNI Ways and Structures	Nov, 2013	700 Pennsylvania Ave.	101 kW
Louise M. Davies Symphony Hall	Mar, 2014	201 Van Ness Ave.	251 kW
North Beach Library	Aug, 2014	850 Columbus Ave.	11 kW
Thurgood Marshall High School	Jun, 2015	45 Conkling St.	87 kW
City Hall	Jul, 2015	1 Dr. Carlton B. Goodlett Place	82 kW
Downtown High School	Aug, 2015	693 Vermont St.	47 kW
Cesar Chavez Elementary School	Feb, 2016	825 Shotwell St.	53 kW

** Sourced from the California Energy Commission.*

Figure: Measures of renewable energy generation in Hetchy Hetchy Power System

Institutional Regulatory Frameworks and Decision making process

In the institutional regulatory framework, the urban experimentation and piloting of new energy solutions is the central building block that refers to city's history and efforts in promoting energy and green related initiatives. These experiments would be carried out by local agencies such as leading utility companies and other stakeholders such as government tiers, knowledge institutes, and the most importantly, citizens. (CARVALH, Luís, 2014) In the decision-making process in San Francisco, the city has the benefit of local control by incorporating opinions from citizens including important stakeholders, as mentioned in the local governance section before.

The Community Choice Aggregation acts as method to facilitate the participatory framework. CCA programs enable local governments to purchase and/or develop power on behalf of the local community. Through CCA, the city can focus more on consumer choice with local control at the same time help communities to reach their climate and economic goals. The energy supply would be more efficient and much cleaner with local energy resources and programs. Revenues would be reinvested in the community rather than distributed to shareholders and promote the development of new renewable energy projects. (CCA)

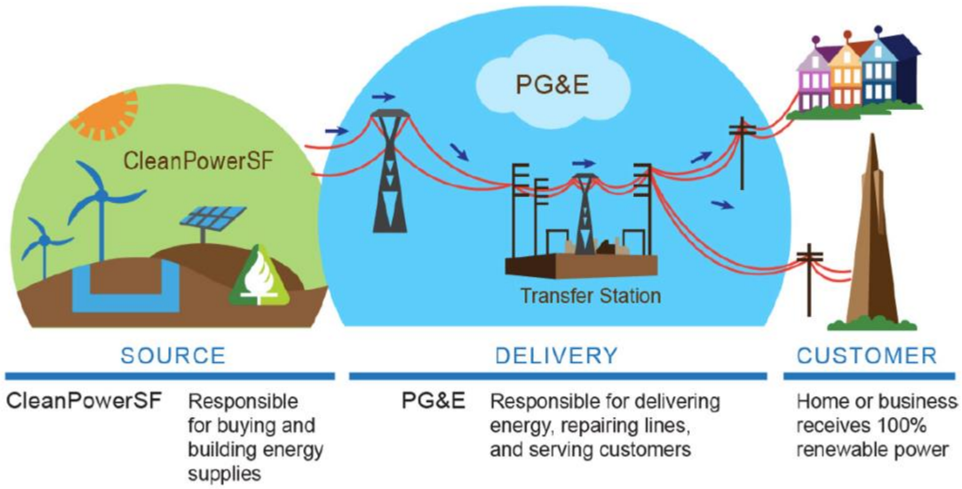


Figure: Process of Community Choice Aggregation (CleanPowerSF)

New Technology Solutions & Monitoring Systems deployed

<u>Offshore Wind Energy and Urban Wind</u>

As mentioned in the strategy section, San Francisco has major obstacles on installing the offshore wind energy as it was limited by the water depth, with shallow water being more economically preferred. For example, the wind speeds near the Farallon Islands west of San Francisco are around 8.0m/s, but depths (over 50 meters) are deeper than any commercial wind farm in operation today. However, San Francisco Bay and Pacific Ocean has a great potential for the wind farm construction. The solution is proposed in a report by Stanford University that estimated that 1.4–2.3 GW, 4.4–8.3 GW, and 52.8–64.9 GW of deliverable power could be harnessed from offshore CA using monopile, multi-leg, and floating turbine foundations, respectively. (Dvorak et al.) Besides offshore wind farm, urban wind is also explored by using small wind turbines, rated at 100 kilowatts or less. Now new "micro" or "urban" wind turbines are being designed for residential and commercial buildings with less space and lower wind speeds. Small wind turbines usually have vertical-axis turbines that are generally less efficient than horizontal turbines, but offer some advantages for urban areas, including lower wind start-up speeds, better ability to handle winds from various directions, and possibly fewer impacts on wildlife. City policies are provided in Mayoral Task Force recommendations that required SF Environment to take fluid dynamics modelling of the city's urban wind resource.

Monitoring System

The SFPUC operates 25 monitoring stations throughout San Francisco and in outlying areas where the City may develop renewable energy projects. These stations measure wind speed and direction to more fully understand the urban wind potential in San Francisco as well as monitoring the solar resources for the area. SFPUC also uses the data from the monitoring stations to create a Solar Map that shows the average annual solar energy received by every square meter in San Francisco and all PV and SWH installs in city, with estimated rooftop PV potential (KW and KWh), electric bill savings, CO_2 reduction, cost estimator / financial analysis and link to solar installers. Solar Water Heating Calculator is embedded in the solar that helped residents to evaluate their buildings' solar resource potential. (SF Environment) Wind Map was also deployed together with the solar map that shows the wind installation and related resources.

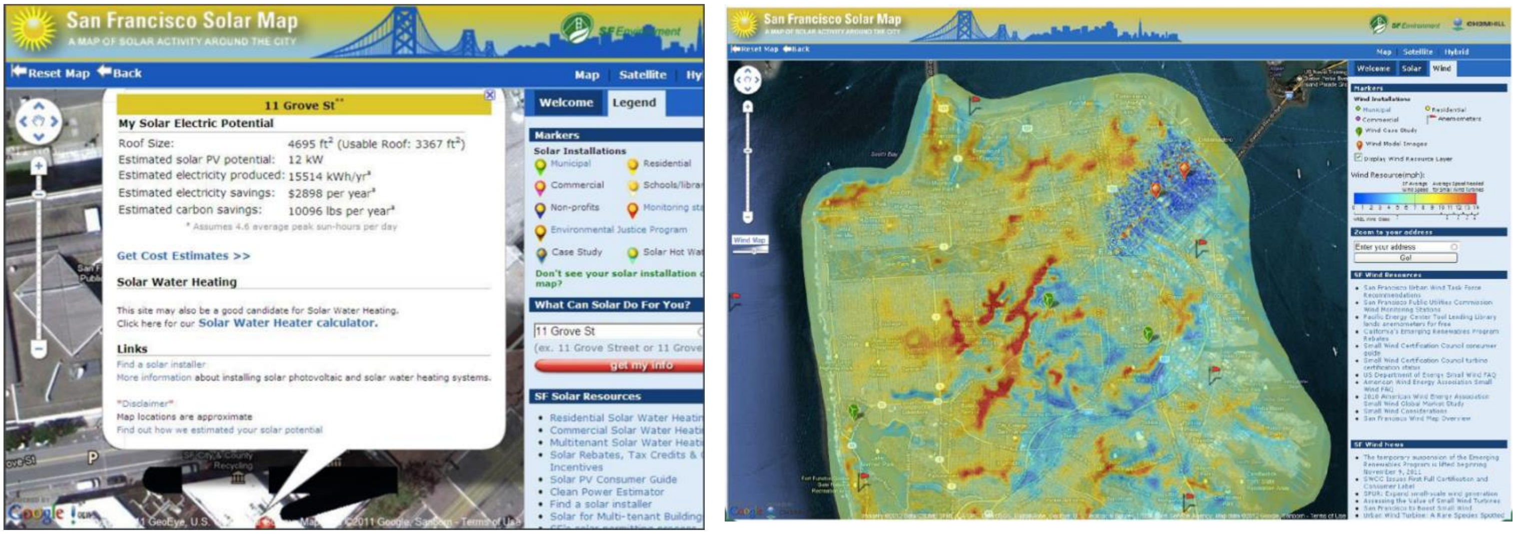


Figure: San Francisco Solar Map and Wind Map

Societal, Economic, Environmental and Operational Impacts Assessment

San Francisco aims to provide local accessible clean energy to the citizens. In the societal aspect, the city increasing aims to make participation available to all residents living in San Francisco regardless of income level. Through the programs such as CleanPowerSF and GoSolarSF, it considers the obstacles individuals in low-income and underserved communities that may face to access the energy efficiency and renewable generation programs, and minimize the barriers to entry. Cash incentives are available to qualified low-income homeowners that install solar electric system. Federal solar tax credit is also provided to homeowners that install the system, and the credit is valued at 30 percent of the net system cost for systems placed in service by December 31, 2019. (Mayoral Task Force)

In economic aspect, the CleanPowerSF plans to invest revenues in reducing residents' electricity bills and the development of new clean energy infrastructures with the potential to create 8,000 to 9,000 jobs between 2018 and 2030. $186 million was invested in projects within the 9 Bay Area Counties, which includes 81 MW of new solar and 27 MW energy storage. It estimates these projects will create 1,394 job per year. For the environmental and health impacts, the CleanPowerSF primarily sources its power from renewable and greenhouse gas emission free energy sources as shown in above sections that do not contribute negatively to air quality. The program's policies also prohibit the sourcing of power from coal, therefore preventing the emissions of damaging particulate matters. The program aims to reach 100% renewable energy on content goals and 100% GHG emission free electricity by 2030. (SF Environment)

Financing Strategies & Public-Private partnerships

Development of public-private partnerships as well as private sector investments are critical to make the renewable energy projects more technically and economically feasible. According to the Mayoral Task Force recommendation, "the City can facilitate and encourage the expansion of low-cost financing options for renewable energy by supporting standardization to lower transaction costs, engaging potential lenders, and leveraging its own resources, both financial and operational."

San Francisco's financing strategy of renewable energy is primarily based on GreenFinanceSF which is a partnership with the Clinton Climate Initiative and the San Francisco Department of the Environment that facilitates the public-private partnerships. This initiative is a Property Assessed Clean Energy (PACE) program that provides access to new forms of financing for commercial building owners. The PACE acts as an open market that enable the property owner to hire a contractor for implementation of an energy efficient retrofit while private investors compete to provide funding for the project. The City of San Francisco has authorized up to $100 million of financing for this energy efficiency initiative.(SF Environment) The city is also exploring other opportunities to spur the financing for renewable energy such as financing enhancements, revolving loan funds, and interest rate buy-downs to attract and, stretch private capital, and expansion of mortgage-backed energy efficiency financing instruments. Private investments are encouraged by feed-in tariffs for local renewables that fairly compensate small scale local, renewable distributed generation projects. Another form of financing is through the on-bill financing or third-party on bill repayment with local utilities and the city is also exploring the potential of on-bill through SFPUC through CleanPowerSF.

Case Performance Assessment

San Francisco is one of the pioneers in the clean, renewable energy market that sees its path to achieve the 100% renewable electricity by 2030. With all the renewable energy projects ranged from solar photovoltaic panels to hydro powers being implemented, the city has a great potential to increase the share of renewable sources in energy generation by developing and innovating new projects on urban wind, offshore windfarm, and wave energy. San Francisco clearly benefits from a number of environmentally progressive and high-impact Californian laws and regulations that provide opportunities to develop new business models and adoption of new technologies. In order to utilize the regulatory framework well, San Francisco's key stakeholders including mayors, local government and energy utilities (SFPUC) play a key role on designing and implementing the energy strategies.

The Community Choice Aggregation, CleanPowerSF, that allows cities and counties to pool their electricity loads, and purchase and/or generate power on their behalf expands citizens' access to renewable energy and encourages the local renewable energy. Another advantage is that San Francisco raises a lot of financing incentives that give all citizens chance to incorporate renewable energy. With these strategies, cities can look more into long-term polices that require partnerships with other private sectors and further assessment of costs and other factors is needed.

<u>Case Study – Munich</u>

Problem Domain Definition in the Urban Context

Having over 1.5 million residents, Munich, the capital of Bavaria, is the third largest city and one of the country's most important economic hubs in Germany. Today, Munich is a global center of art, science, technology and culture that enjoys a high quality of living standards and being rated as the world's most livable city by Monocle's Quality of Life Survey 2018. Lies on the elevated plains of Upper Bavaria with the oceanic climate, Munich's general trend of climate change is observed with a rise of medium yearly temperatures of about 1 degree Celsius in Germany over the last 120 years. In November 2016, the city council concluded officially that a further rise in medium temperature will happened with a rise in the number of hot days and nights with temperatures higher than 20 degree Celsius. Change in precipitation patterns and rise in the number of local instances of heavy rains are also expected as part of continually climate change. Munich's city administration decided to support a joint study with German Meteorological Service to gather data and create an integrated action program for climate protection (IHKM) with a strong emphasis on renewable energy.

Figure: Map of Germany and location of Munich

On the national level, Germany's climate and renewable energy policy is developed under the concept of "Energiewende" adopted in 2010, which is the planned energy transition to a nuclear-free and low-carbon energy economy. The nuclear phase-out was very controversial in German politics between 1980 and 2011, but the "Energiewende" has gained broad political support in recent years. Germany is unique in terms of its energy policies as "Energiewende" aims to transform country's energy system based on two main pillars of renewable energy and energy efficiency, together with markets and system integration through support from energy sector research and development (R&D)(Sait, Mohammed, 2018). Germany is on track to reach its Kyoto Protocol targets with more efforts on achieving the Energiewende's long-term GHG emission target to cut 40% by 2020 and 80% by 2050 as shown in figure. While "Energiewende" is a policy system that has been developed at national level, Munich shows how municipal and other actors at the local level have incorporated the energy transition to renewable energy and adopted the Energiewende approaches to energy policy.

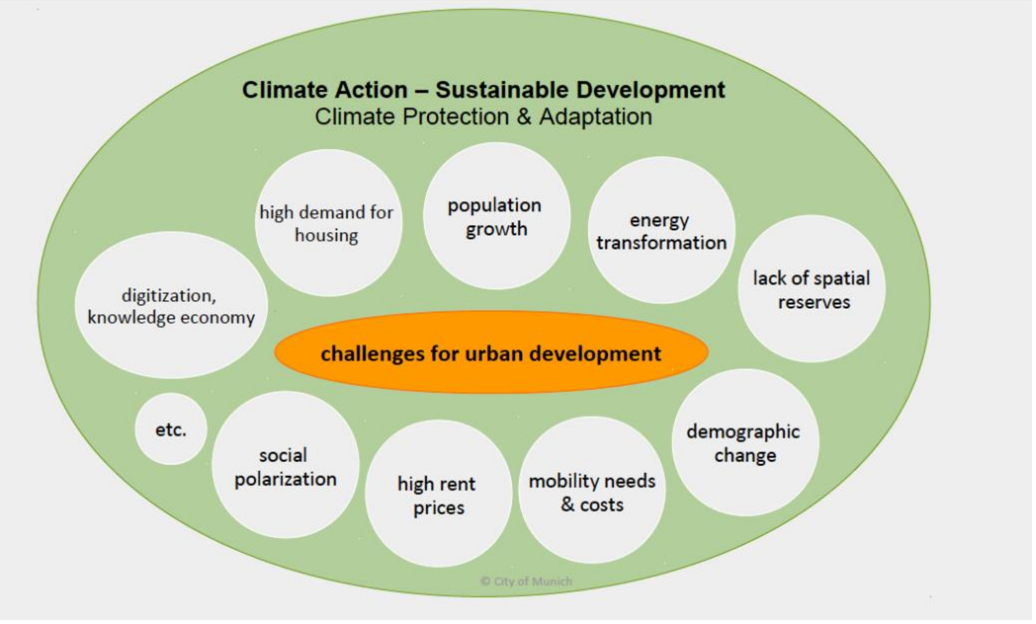


Figure: Challenges for urban development in Munich

Historical Context and City Policy/Strategies implemented

Munich is one of the most well-known cases that associated with Energiewende approach with its own goal of reaching 100% renewable energy by 2025. Munich's energy path had four main periods of development. Its beginning history can be traced back to the 1980s when the Energy Commission was established consisting of several local stakeholders to perform decentralized energy allocation and network building at local level. In 1982, the city council asked the administration to push the use of renewable energy. As early as 1997, Munich installed the largest roof-top solar panel in Europe, and from 1989 to 1998, Förderprogramm Energieeinsparung (Energy Conservation Support Programme) started to monitor CO2 emissions and the data was reported to the City Council through the Local Agenda 21 process. With more attention being put on the greenhouse gas emission and strategic urban development during 1998 and 2008, there was a shift in energy thinking in Munich to integrating renewable energy in infrastructures with the concept of Perspektive München. Until 2008, the city set the goal of supplying all municipal facilities and households with 100% renewable energy and adopted the Integrated Action Program on Climate Protection (IHKM) which climate change and energy policies within local governance structures (Sait, Mohammed, 2018).

Integrated Action Program on Climate Protection (IHKM)

The Integrated Action Program on Climate Protection was launched in 2008 following the decision of City Council with the target defined by the European local network Klimabündnis e.V.: a reduction in carbon emissions by 10% every 5 years and a 50% reduction in carbon emissions per capita compared to the reference year 1990 to be achieved by 2030. The carbon emissions should be decreasing to 3.15 tons per inhabitant per year. The first climate protection programme under IHKM was approved in 2010 managed by Department of Health and

Environment and would be renewed every two years. The IHKM is organized in a cross-department fashion with new measures and initiatives ranging from environmental-friendly traffic planning to housing construction and changing behaviors of individuals. The program will report about all climate protection activities, develop new measures and provide financing. The strategy structure of the program focuses on eight fields of actions taken by the interdepartmental Steering Committee and project groups with new measure. The eight topics are shown in the figure below:

1. **Housing (refurbishment and construction)**
   Reduction of energy demand in new and existing buildings
2. **Urban development, land use planning, landscape planning**
   Strategical measures, basics for future energy savings
3. **Mobility**
   Enhance public transport and sharing concepts
4. **Energy efficiency (industries & commerce)**
   Activate energy saving potentials within the sector industry & commerce
5. **Energy production**
   Mostly activities of the Public Utility Company (SWM GmbH)
6. **Energy management (municipal sector)**
   Reduce energy consumption and increase renewable energy production within the municipal buildings and traffic infrastructure
7. **Public procurement, municipal fleet, business trips**
   Climate neutrality of business trips
8. **Awareness raising**
   Activate citizens in Munich for climate protection

Figure: Eight topics focused in IHKM

From the first package of measures in 2010 there has been a special focus on expanding electricity generation from renewable sources and on improving energy efficiency in housing construction, heating systems and city-owned buildings. In this field of energy supply and distribution, the municipal energy supplier Stadtwerke München (SWM) plays an important role in implementing related strategies by establishing the "Renewable Energies Expansion Campaign".

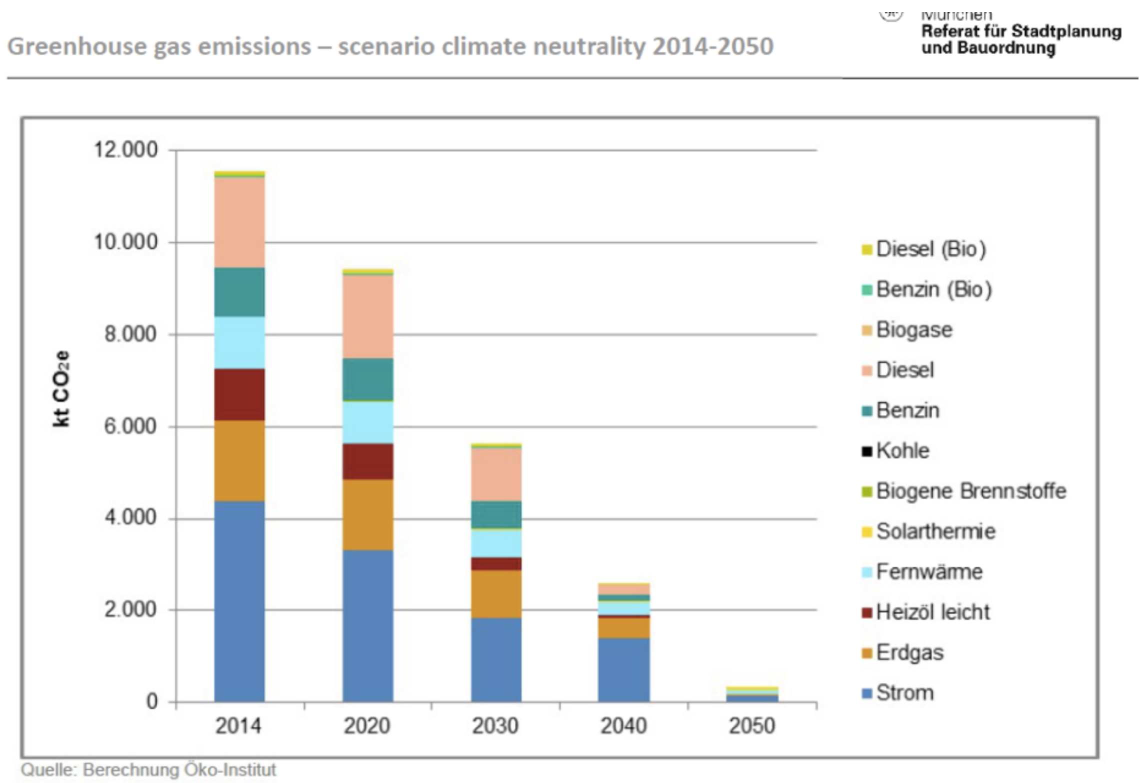


Figure: GHG emissions in Climate Neutrality scenario under IHKM plan

Renewable Energies Expansion Campaign - SWM

In 2008, Stadtwerke München (SWM) launched the Renewable Energies Expansion Campaign and set the goal of reaching 100% renewable electricty by 2025. A budget of around €9 billion to pursue Munich's 100% renewable energy goal was established and thus far SWM has focused exclusively on cost-efficient projects that are self-sustaining. The campaign has three major strategies to achieve the goal by utilizing a range of renewable sources, which are green electricity/energy, green heating and green cooling.

As Munich and its region are densely populated, the renewable energy source include wind and solar are limited of use here so that it is hard to generate as much green electricity regionally as required. Consequently, SWM are also producing green electricity together with partners at other locations in Europe. (SWM)

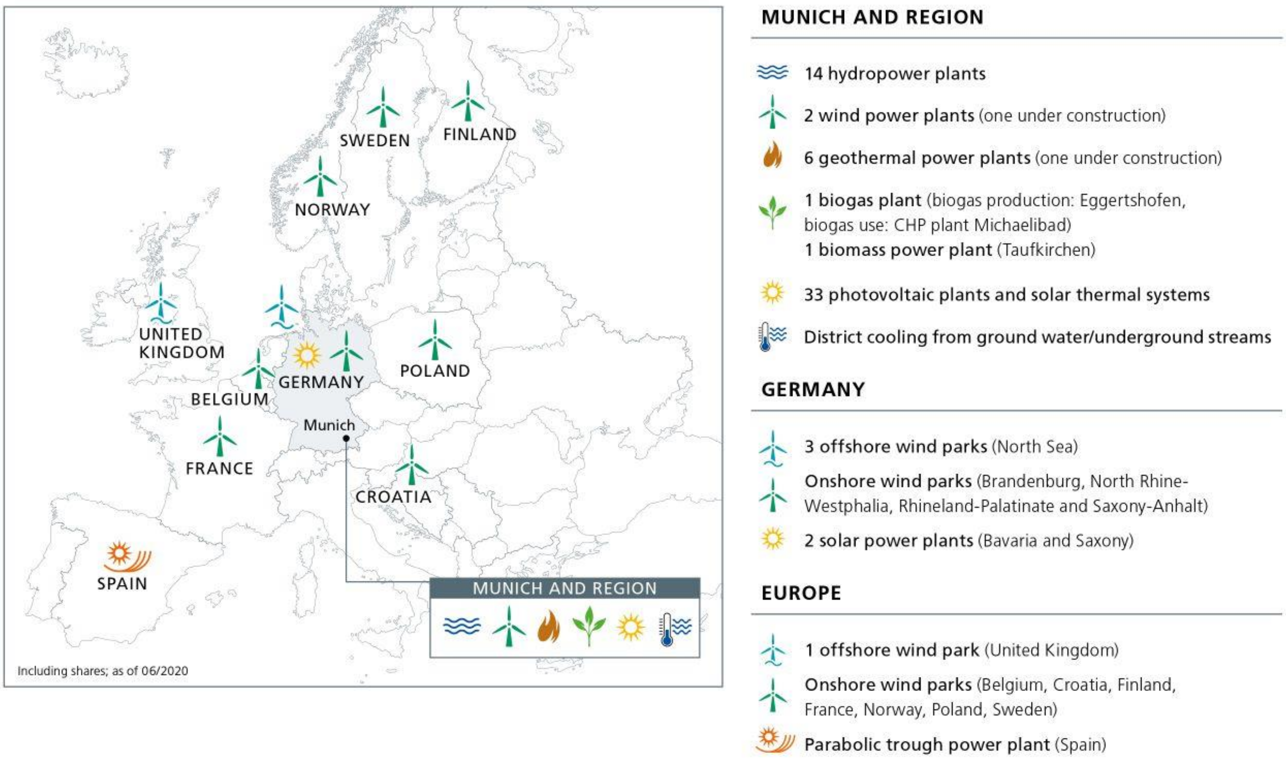


Figure: Distribution of SWM's Renewable Energy Projects as of 2019

<u>Green Electricity – Wind, Solar, Biomass</u>

SWM currently operates wind, solar, biomass, hydropower and geothermal energy to generate more than 50% of Munich's electricity requirement. Wind energy is still the most productive as well as the most profitable technology for the generation of green electricity from renewable sources in Munich. It accounts for by far the largest share of 80% of SWM's green energy mix according to current forecast.

However, since the regional potential of renewable energy is limited, SWM is unable to generate as much renewable power in the region around Munich as it required. That is why the company participates in projects in the rest of Germany and Europe. With two local wind power plants in Munich, SWM's investments focus more on onshore and offshore wind parks in other areas. As there is no need to generate electricity in the immediate vicinity of where it will be consumed, SWM's systems are exploring places that have best use of renewable power on a large scale to generate electricity for Munich's citizens. By investing and building onshore wind parks in Poland, the 39 wind turbines will have a generation capacity of 132 megawatts that would satisfy approximately 170,000 Munich households. It also acquired more than 15 wind parks in Norway, France, Sweden, Belgium, Finland and other areas in Germany. DanTysk wind farm, operated as a joint venture between Vattenfall and SWM, is one of the largest German offshore wind installations in the North Sea.

In addition to wind energy, SWM also use potentials of other renewable energy sources such as water, geothermal, solar and biomass. The company aims to invest in economically profitable regional projects. Biomass combined heat and power plants are implemented to generate electricity from region sources located in surrounding forests. In terms of solar energy, the company has the new M-Solar Sonnenbasuteine busines model that enables 92% Munich's inhabitants that live in multi-family building, who are hard to have their own roof to install solar plant, to make contribution to the renewable energy. With the financial investments, citizens could help increase the number of solar systems on city's other rooftops and contribute directly to the green energy. In addition, similar to wind farm, SWM invests solar heat plant in other places such as Andalusia, Spain that could be added to the integrated European grid.

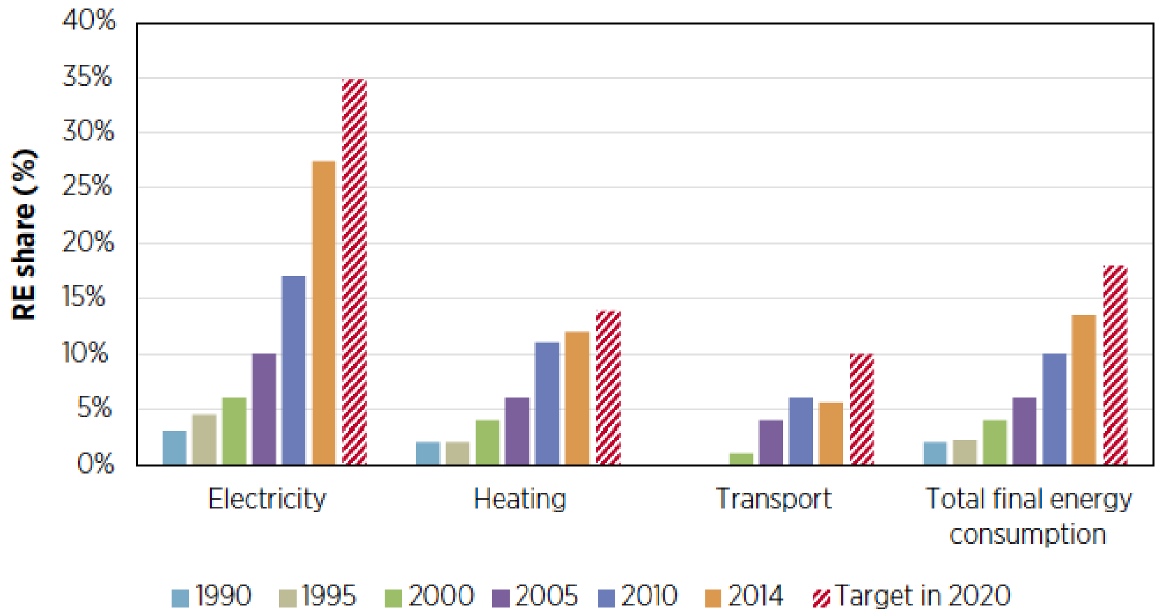
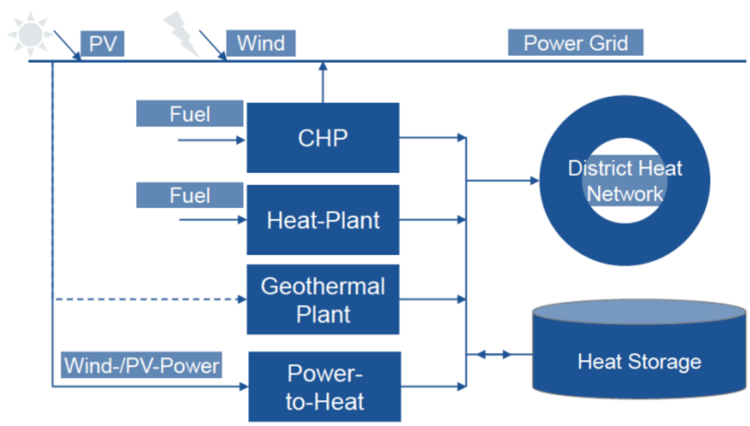


Figure: Renewable energy share of Germany's final energy consumption, 1990-2014 and 2020

<u>Green District Heating – Geothermal energy</u>

In Germany, heating sector accounts for roughly 40% of the total energy consumption, with more striking picture in private households that has 90% of energy consumed in heating and hot water production. Today around 30% of the overall heating market in Munich is covered by district heating, and additional of 10,000 householders were supplied with district heating in 2018. With an investment volume of 200 million euros, SWM pursues an ambitious goal to achieve CO2 neutral coverage of all of Munich's district heating requirements from renewable energies by 2040. (Annual Report SWM, 2019) The key technology to achieve this goal is deep geothermal energy by tapping vast hot water reserves located thousands of meters under the Munich's surface. Thanks to Munich' s unique location right on top of a huge reservoir of this natural energy source, the larger baseload capacity of deep geothermal energy has the potential to be the heat source with the lowest production costs and provide renewable heat to the whole city. Currently, Munich has 5 geothermal power plants and 16 geothermic wells. Another plant has been constructing on the site of "Heizkraftwerk Süd" power station since 2017 and would make a major contribution to our district heating vision by supplying more than 80,000 Munich citizens. In addition, SWM is also testing other sites for "geothermal suitability". (Annual Report SWM, 2019)

Figure: Interaction of electricity and heating sector



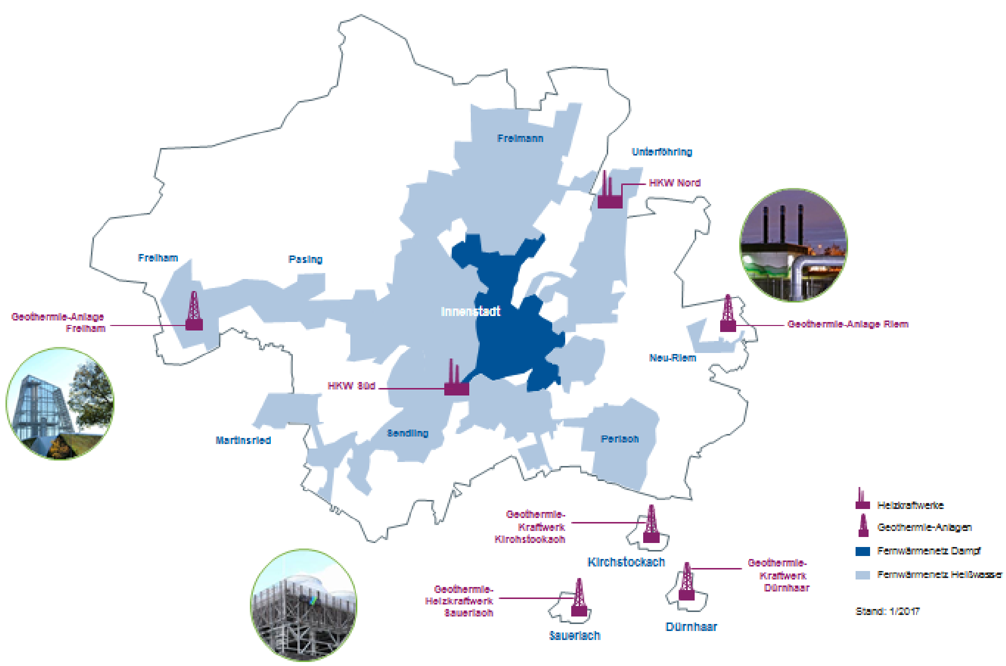


Figure: District Heating Area in Munich

Green District Cooling

SWM also see high growth potential for M-Fernkälte district cooling. In Munich, power consumption in summer is approaching that during the winter due to increasing usage on air-conditioning systems. The concept of district cooling is similar to district heating that centrally cooled water is delivered to customers through a network of pipes. Ground water and underground streams are used for cooling, which makes the process more efficient and environmentally friendly compared to conventional air conditioning. With significantly less electricity is needed for cooling, it is possible to reduce burden on fossil fuels and achieve a total electricity saving of around 70% compared to discrete cooling towers. In total, SWM has invested over 30 million euros in expanding the district cooling network in Munich alone.

Public Policy Objectives of the Local Governance

As a long-standing member of the European Climate Alliance, Munich's City Council has established the objective of achieving 50% CO2 emission reduction by not later than 2030. The related public policy objectives of the local governance to reach this goal is illustrated in the "Integrated Action Program on Climate Protection" (IHKM) reports that would be published every two years starting from 2010. As an interdepartmental management system, the IHKM has elaborated a total of 200 operational and strategic measures for climate protection. With packages of measures updated every 2 -3 years under the Integrated Action Program, the "Climate Protection Program 2010" for the period 2010-2012 has incorporated 55 measures that could be group in to 14 subject categories. These measures are necessary for achieving an ambitious goal of reaching production of eco-power in facilities of the Stadtwerke München for the entire city of Munich by 2025. According to the report, "this amounts to around 7.5 billion kilowatt hours per annum, and will make Munich the first city of over a million people able of satisfying its energy demand relying exclusively on "clean" sources."

No.	Title of the Package of Measures
1	Energy conservation incentive program (*Förderprogramm Energieeinsparung*, FES)
2	Energy-efficiency in city-owned buildings
3	Municipal housing associations
4	Climate protection strategies of Munich's utility company Stadtwerke München GmbH
5	Increasing use of renewables in city-owned buildings
6	Incentives, training courses and environmental education for energy-efficient consumption habits
7	Developing energy concepts
8	Sustainable forestry and promotion of timber construction
9	Procurement of energy-efficient vehicles for the City's vehicle fleet
10	Further development of subway and tramway infrastructure and acceleration of bus and tramway connections
11	Implementation of the bicycle traffic concept
12	Low-energy equipment, computer systems and lighting in the City administration
13	Low-energy street lighting and traffic signals
14	Technical and construction measures of different municipal investment companies

Figure: Measures of Integrated Action Program on Climate Protection

Besides the measures listed in the IHKM report, the city-owned public utility company SWM also set its objective on producing as much green electricity (100%) in its own plants as the entire municipality of Munich requires by 2025 and an 80% reduction in CO2 emissions from the services by 2040 compared to 2008 baseline year. To meet the target, SWM will need to produce 7.5 billion kilowatt hours of green electricity. In addition to the renewable electricity, SWM developed a district heating vision in year 2012 with the objective to achieve 100% green, carbon neutral district heating mainly from geothermal energy by 2040. The expansion of district cooling to replace individual air conditioning systems represents a further strategy. By 2030, bus traffic in Munich will also to be 100 percent electrically driven and emission-free.

Local Governance, Agencies and Stakeholders

Since reunification, Germany's planning system has been essential to the implementation of federal policy. Germany's spatial planning approaches with integration helps rescaling the planning agendas and focusing more on the state level. In Germany today, there are five connotationally distinct and legally independent political levels. From top to bottom, there are European Union, Federal Republic of Germany, 16 Länder as member or subordinate states, districts, and municipalities and towns. Municipalities form a part of state's authority and local government usually regulate development and structure in the municipal areas. The legislation will also link to the federal laws and state structure. Munich as one municipal is governed by a mayor and a city council. It is also the seat to many national and international institutions such as the Bavarian State Parliament, the Federal Finance Court of Germany and the European Patent Office.

In terms of the climate action plan, the stakeholders include several City Departments which have responsibilities to the contribute to the climate protection. The basic decision on the IHKM program is made by an interdepartmental management of the City's climate protection measures. The Department of Health and Environment (DHE) is mainly responsible for developing the IHKM in cooperation with other city departments and offices. Other actors of urban society from business, academia, politics, and associations could be engaged for effective climate protection through the Alliance headed by the Deputy Mayor of the city. Alliance offer its partners a central platform to exchange information and develop innovative role-model projects. More than 100 have joined to develop more than 30 projects including solar covered parking lots.

Besides local government and citizens as the stakeholders for the energy production and consumption, Munich's major approach on energy planning is based on the cooperation with the city-owned energy utility company - Stadtwerke München (SWM). SWM is one of the largest municipal companies in Munich and in Germany that stands for a secure supply of energy and drinking water, urban mobility, forward looking telecommunications services. Its service offeres important part of public communal services and are making major contributions to the economic strength and the quality of life in Munich and the region. SWM owns and operates various forms of renewable energy plants ranging from hydro power, geothermal, wind to solar and biogas. As the City of Munich is the 100% owner of SWM, SWM belongs to the citizens of Munich and is therefore an essential part of municipal public services. The company takes responsibility for individuals, resources and the environment and committed to education and social issues. Other smaller private companies also see the light in working together with the city of Munich in several initiates through the programme "ÖKOPROFIT".

Performance measures

The measures in the IHKM "Climate protection program 2010" show the saving of more than 450,000 tons of CO2 per year. During the process of the program, Stadtwerke München GmbH has a generating capacity of around 2.9 billion kWh of green power from its own facilities, which is equivalent to nearly 39 percent of Munich's power consumption. When the "Climate Protection Program 2013", which continues in 2014, is fully implemented, its 63 measures will probably result in an annual CO2 saving of around 590,000 t CO2. The most recent "Climate Protection Program 2015" that comprises 87 leads to the result of expected CO2 saving of around 1.4 million tons. (IHKM)

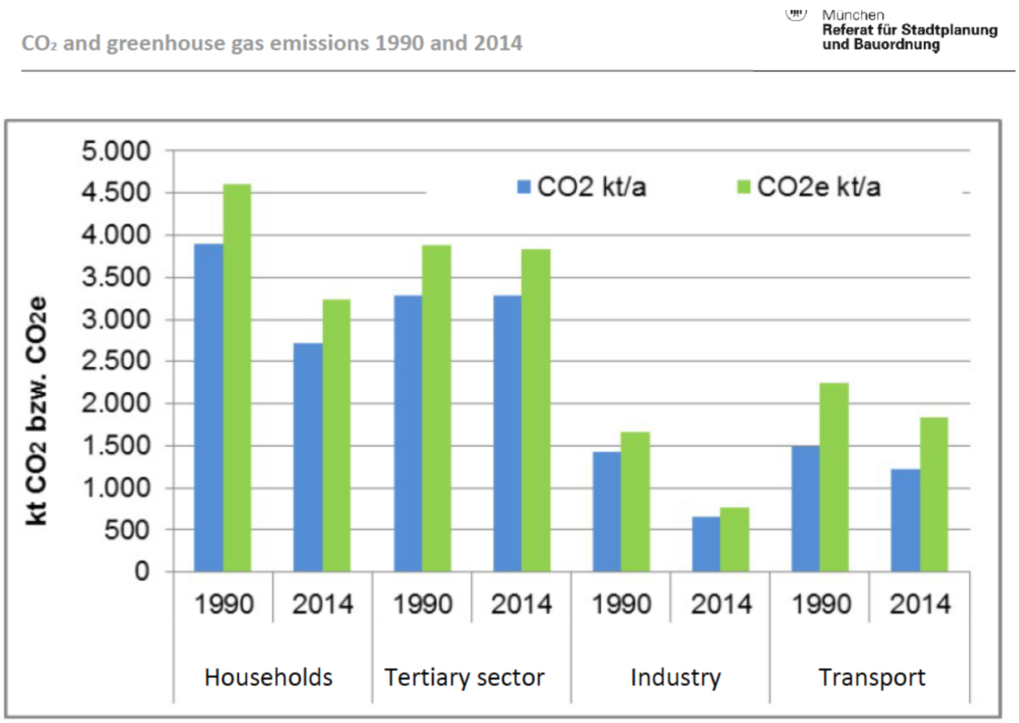


Figure: CO2 and Greenhouse Gas Emissions 1990 and 2014

At the end of 2019, Munich, through the existing plan operated by SWM, has already produce capacities totaling approximately 5.67 billion kilowatt-hours of green electricity from renewable energy to support more than 800,000 households and regular transportation, a figure which already accounts for more than 50% of city's electricity requirement. Munich the with SWM currently operates 33 photovoltaic plants and solar thermal system, 14 hydroelectric power plants, 1 biogas processing plant, 1 biomass power plant, 5 geothermal plants (two of which are used purely for generating heat) and 2 wind turbine plants (one is under construction) in Munich area and region. Other than projects implemented in Munich, 3 offshore wind parks were constructed in Germany at North Sea, including the DanTysk offshore wind farm installed in 2014 where a total of 80 3.6-megawatt (MW) wind turbines generate 1.3 billion kilowatt-hours (kWh) of electricity per year. In addition, together with municipal partner TrønderEnergi, SWM expanded market to Norway to operate four wind parks with a total generation capacity of 120 megawatts that are already up and running. SWM also holds a 33% share of wpd Europe, a worldwide developer and operator of windfarms, that have wind turbines with a total output of 70 MW in Belgium, France, Italy, Croatia and Portugal. Besides wind turbines, the biomass-combined heat and power plant uses the cogeneration process to produce 25,000 megawatt hours of green electricity per year for approximately 10,000 households and 150,000 megawatt-hours of green heating. (Annual Report SWM, 2019)

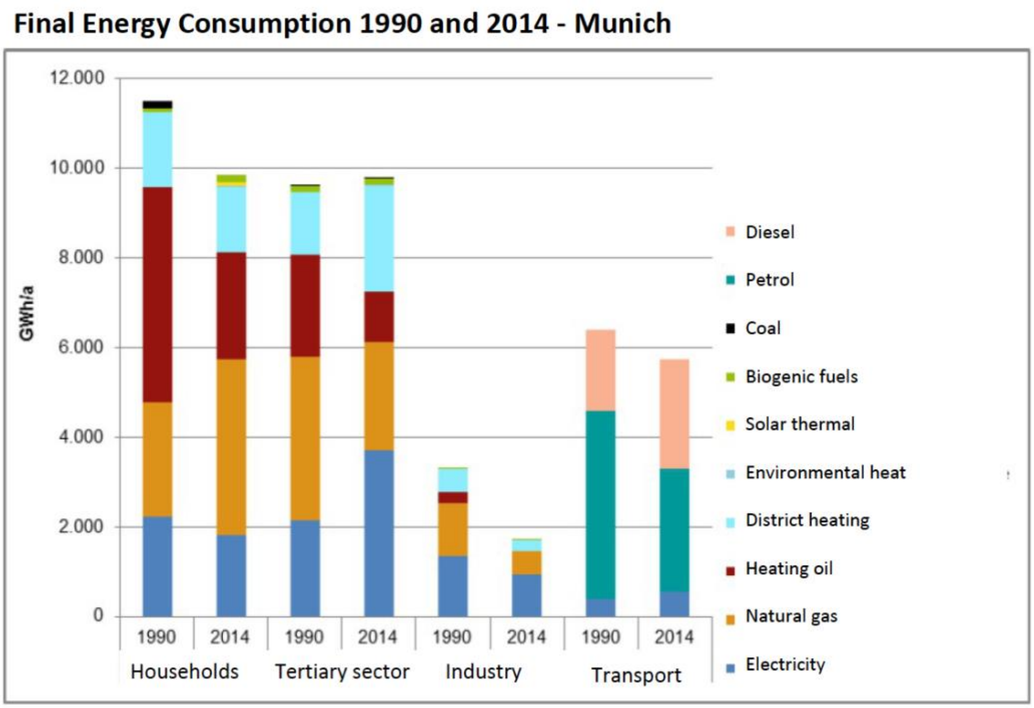


Figure: Final Energy Consumption 1990 and 2014 in Munich

Another vital strategy implemented is the district heating, which as of 2017, district heating covers 30% of overall heating market in Munich and has sales volume of approximately 4.298 GWh with the network around 800 km. Geothermal power is the primary source for the district heating and currently SWM has 5 geothermal plants in operation and one under construction that can supply more than 80,000 Munich citizens. Performance tests at the 5 geothermal wells in "Heizkraftwerk Süd" power station show much higher temperature than expected, and the actual output of the plant would exceed 50 megawatts. Overall, all already initiated or executed projects have prevented the emission of approximately 5 million tonnes of CO2 per year and saved more than 1.1 tons of radioactive waste.

Institutional Regulatory Frameworks and Decision-making

Munich's institutional regulatory framework for local administration, companies and citizens uses the energy commission as a springboard for discussions by exchanging knowledge and experiences across sectors to implement energy concept. (Sait, Mohammed, 2018) The framework for future urban development in Munich encourages city in balance with 10 action areas, 4 strategic guidelines, 16 thematic guidelines and lead projects. The thematic guidelines are illustrated in "Ecology-Climate Change and Climate Protection" report that describes strategies from energy supply, buildings, land use, urban planning and mobility, and lifestyles and health. (IHKM)

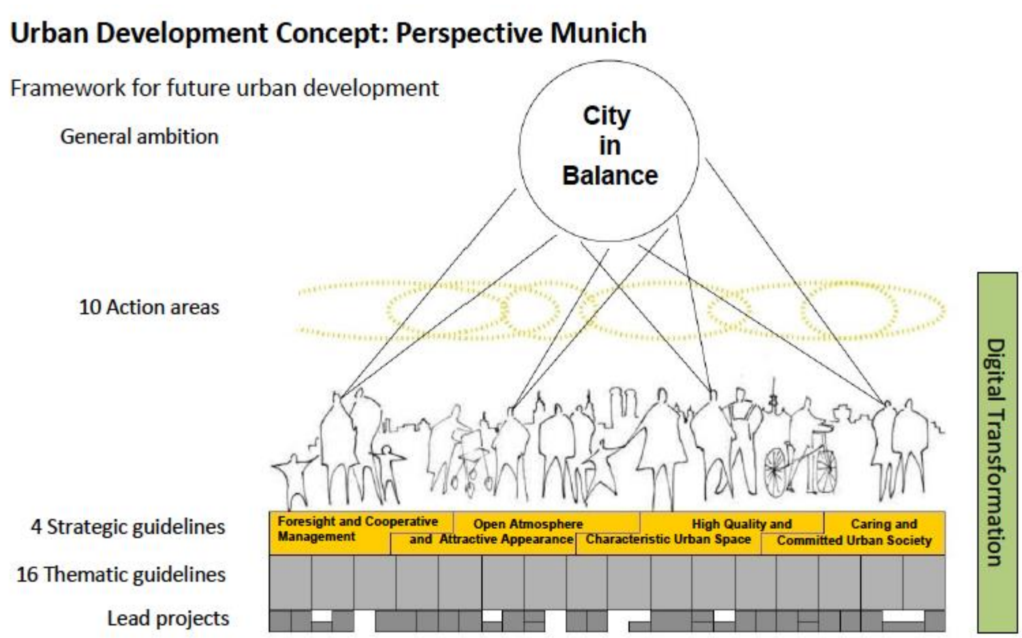


Figure: Urban Development Framework in Munich

For the organization structure of the Integrated Action Program for Climate Protection in Munich (IHKM), three decision-making and working levels were established. The first level is the Steering Committee (Lenkungskreis) which consist of management officials of relevant administrative bodies responsible for coordination. It is headed by the full-time Debuty Mayor of the City of Munich and is responsible for the management of the entire process of IHKM development. The second level is Project Group (Projektgruppe) which coordinates the practical expert work and updates and adjusts the IHKM report until the CO2 reduction target is achieved. The Project Group consists of managers of all City Departments and is heads by Department of Health and Environment. It would develop the suggestions for the Steering Committee. The third level is the seven subject-specific Wokring Groups (Arbeitsgruppen) under the Project Group that are responsible for cross-cutting climate protection measures and standards. It contains people working for the relevant City Departments. Urban Development, Energy generation & distribution and Energy management in city-owned properties and in infrastructure are three groups that mainly tackled on the integration of renewable energy. In addition, external expert institution, Forschungsgesellschaft für Energiewirtschaft mbH (FfE), also supports the IHKM program by analyzing the measures's contribution to CO2 reduction. (IHKM)

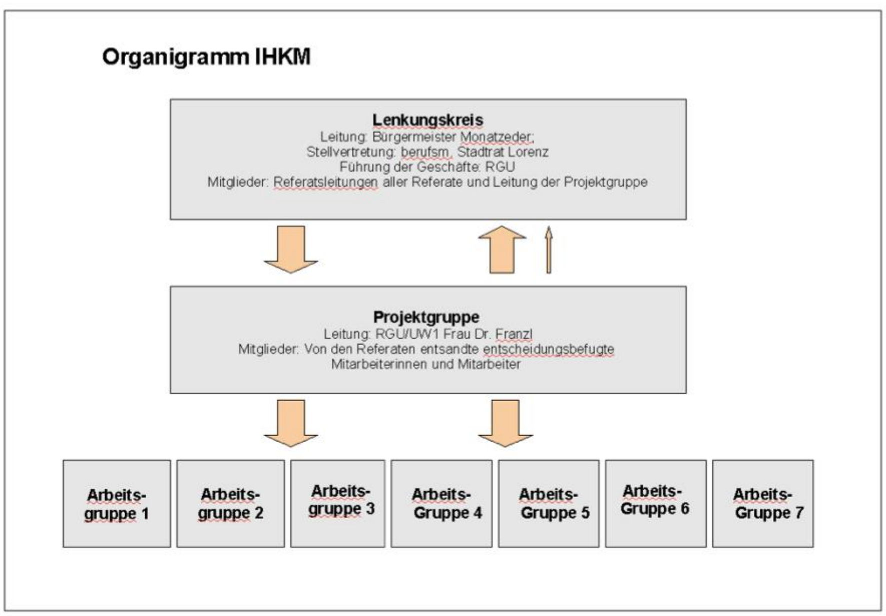


Figure: Organization structure of the Integrated Action Program for Climate Protection (IHKM)

New Technology Solutions & Monitoring Systems deployed

<u>Virtual Power Plant</u>

Munich's municipal utility company SWM has recently opened a virtual power plant with combined output of more than 50MW for the management of decentralized energy supplies. According to SWM, "the virtual power plant is a network of several small-scale power plants which are pooled and operated like a single system." It helps to meet electricity demand based on green electricity production and enables reliable and cost-effective operations of small-scale power plants for SWM to better plan and forecast these power generation. (SWM)

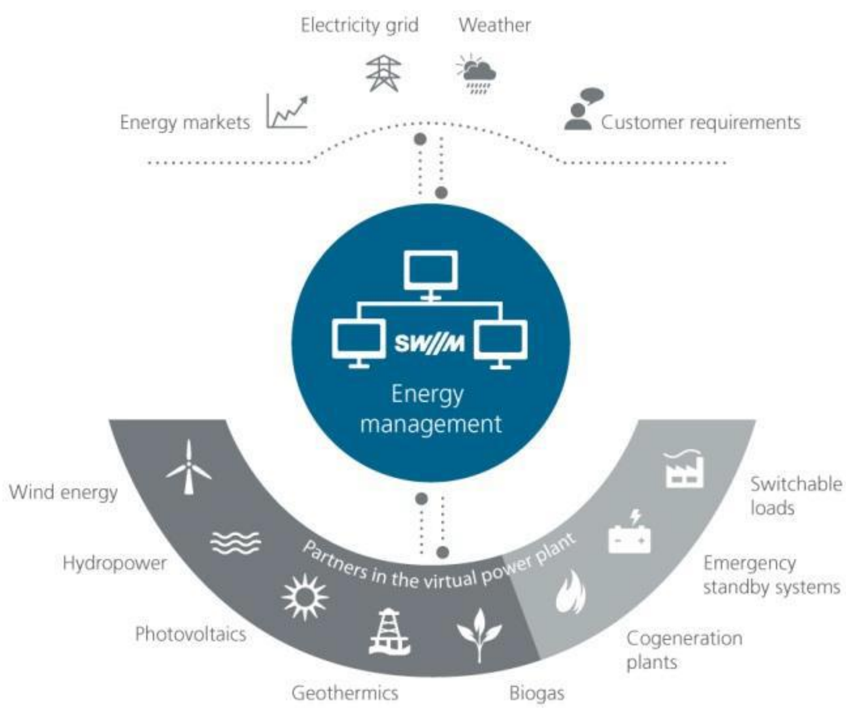


Figure: Virtual Power Plant

Financing Strategies & Public-Private partnerships

As the major master plans are conducted under the local government and municipal utility company, most of the funding are received from Climate Initiative of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Total investment by the "Climate Protection Program 2010" with its 55 measures came to 25.6 billion EUR. A total of 59.2 million EUR was invested in the updated programme in 2013 with its 63 measures. (IHKM, 2015) Though most financing of the program comes from city's subsidies and funding, in terms of public and private partnership, city established comprehensive consulting services that can encourage private business and individuals to incest in climate protection measures themselves. City of Munich's municipal construction center is in charge of the consulting service that deals with energy-efficient construction and integration of renewables in existing and new buildings for years.

SWM also established a budget of around €9 billion to pursue Munich's 100% renewable energy by launching the Renewable Energies Expansion Campaign. The major financing strategy SWM managed is through the value chain of energy in terms of sales, trade and generation. Developments in energy markets are key influencing factor for SWM, which include, in particular, the contribution margins of power plants and the prices of emissions.

Societal, Economic, Environmental and Operational Impacts Assessment

The environmental impact of the integration of renewable energy can be directly reflected on the reduction of CO2 emission of up to 1.4 million tons after implementing the Integrated Action Program on Climate Protection in Munich. The city has additional reductio potential on the district heating system and existing energy conservation incentive programs for private building owners. Munich aims to set the annual primary energy requirement of 60kWh/m2 for refurbished existing buildings that could be implemented on apartments of the municipal housing associations as a compromise between Munich's high accumulated demand for affordable housing and the climate change challenge.

Case Performance Assessment

Overall, with the development of the Climate Protection Program by the City Council and Renewable Energies Expansion Campaign by SWM, Munich set an ambitious goal in reaching 100% clean, renewable electricity by 2025. Integrated Action Program on Climate Protection (IHKM) also receives attention on the national level. With the help of the municipal owned energy utility company SWM, Munich is able to implement the green strategies quickly and comprehensively through the public sector. The major takeaways from Munich's strategies are that bundling the urban development measures and activities under an interdepartmental project group is critical for success, and renewable energy generation should not be limited by the city's existing resource. SWM acts as a great example showing the opportunity for city with less renewable sources to invest and develop renewable projects in other places near the city. The ultimate goal is to provide green, clean energy to the citizens in order to combat the ongoing climate change.

Conclusion

With the ever-growing urbanization rates in megacities worldwide, large cities are of great importance in energy consumption. Large cities with large populations have the highest energy consumption rates, which can have a spillover effect by contributing to high pollution rates. Pollution as a result of the high carbon emissions with increasing urbanization in large cities. With increased rates of carbon emissions come adverse climate change. Catastrophic climatic conditions are being experienced all over the world as pollution rates in large cities soar. Reduction of carbon emissions is crucial in mitigating the effects brought t about by climate change. Increasing the energy efficiency levels and managing the energy consumption rates is of great importance for energy security in large cities and the world.

Lesson Learned from Beijing, Boston, and Shanghai

The paper analyzed three megacities: Boston in the United States, Shanghai, and Beijing, both in China. For a long time, Boston has been involved in mitigating climate change, focusing on reducing carbon emissions. The Boston Municipality has been at the forefront of integrating renewable energy resources in the city's infrastructure to lower carbon emissions (City of Boston, 2008). Incorporating renewable resources into the city's operations moved towards getting rid of conventional fossil fuels as energy sources. Implementation of strategies geared towards making Boston a greener city are majorly drawn and implemented by the mayor's office. Apart from the Boston Municipality, the state government is also another major stakeholder in implementing greener projects. Other stakeholders in the city's objectives of being a 100% clean environment by 2050 include the energy and electrical companies and generally the city's residents. Other organizations are involved in the city's efforts to integrate renewable energy that are not necessarily from the city or the state. These are organizations concerned with green energy, such as installing solar panels and harnessing wind power energy and ocean wave energy into electricity.

The implementation of renewable energy resources in Boston is mainly guided by the Climate Action Plan established by the city's former mayor. The mayor devised the plan, which is usually revised every three years. Documented in the plans include strategies on installing solar panels in buildings across the city, a strategy that has been primarily implanted, cleaning up electrical grids to go green, and reusing renewable energy for energy efficiency. Boston's Climate Action Plan envisions the city's strategy to be a 100% green city by 2050 (City of Boston, 2020). Projects on lowering carbon emission rates by incorporating renewable energy instead of fuel oil in the city's operations drive the city to be greener. Substituting fuel oils with renewable energy is also a measure of increasing the city's preparedness for climate change while mitigating its effects.

Converse to how Boston implements renewable energy integration strategies, Shanghai and Beijing cities draw most of their plans from the country's Five Year Plans. The paper reviewed strategies implemented in the two cities from the 11th FYP to the 13th FYP. Beijing, as the capital city of China, with one of the biggest populations in the country, has one of the highest energy consumption rates in the world. The city's pollution had also been skyrocketing before measures on the use of clean energy were implemented. Air pollution was at staggering levels before the Five Year Plans included strategies to transform its energy sector. With the Olympic Games held in Beijing, the city was pushed to integrate renewable energy sources for a cleaner and greener city. The efforts bore fruit as air pollution in the city reduced. Beijing has continued carrying out projects on installing renewable energy in the city, such as wind power energy, hydropower, and solar power energy. The Beijing city government is the primary governing authority in implementing green programs with other stakeholders, including energy companies and the central government. The city residents are also part of the stakeholders, for they inform the Beijing Municipality on the energy consumption levels and energy efficiency for the necessary programs to be implemented.

Like Beijing, Shanghai borrows heavily from the Five Year Plans to integrate renewable energy resources in the city. The plan acts as a framework through which the city sets up green projects. There has been installing energy-efficient systems in new buildings with the retrofitting of green energy mechanisms in old ones. Other projects on renewable energy include the installation of solar panels for energy and tapping of wind power. The World Bank has mainly been involved in implementing the projects, especially in the Changning district, making it one of the significant stakeholders alongside other banks, development institutions, and the city residents. The integration efforts of renewable energy in Shanghai's infrastructure have seen remarkable results with the drop in the carbon emission levels in the city. The city also has a higher capacity in energy security with the use of clean energy sources, which are easier to tap into and convert green energy into electricity. With the installations that have been made and the green projects still underway, it can be said that the city has successfully taken measures to make Shanghai a green city. Buildings are more energy efficient as the strategies in the Five Year Plans are rolled out. The city has seen a drop in the city's energy intensity, and energy consumption as the Municipality does away with polluting energy sources to the climate.

Lesson Learned from Copenhagen, SF, and Munich

Form the three case studies, we could see that all three cities have represented great planning strategies and performance measures for integration of renewable energy in urban infrastructures. They all have a comprehensive climate action plan that focuses on the implementation of renewable sources into the energy production and energy consumption. One key takeaway from all three cities is that they all have their city-owned municipal energy utility company that are actively involved and helped the renewable energy integration in the city's infrastructures. While Munich is more following the state and country's law and legislation on the policy and is relatively subjected to federal support and governance, Copenhagen and San Francisco have more space for the participation of local private sectors and citizens either from the Community Choice Aggregation in San Francisco or the public-private partnership in Copenhagen. There are more financial incentives provided in San Francisco to the citizens and private business to incorporating renewable energy into their properties.

Citie's local energy planning has become more comprehensive to include more energy sectors as well as take more policy goals into account. However, the institutional framework is more effective at place in which local authorities and local energy companies have the executive powers; it comes a little difficult to implement projects with less clear responsiveness and less power of local authorities. In a more strategic energy system, rather than limited coordination between the country and the city, the central and local energy planning must be strongly integrated to better reach the national target.

Key lessons I learned from these three case studies are that first renewable energy must be implemented and planned locally. Local governance including mayor, city administration and different departments should work together to bundling the urban development measures and activities under an interdepartmental project. This creates an integrated platform for city officials to implement the project with better communication of information and new ideas. Secondly, as renewable energy is relative a locally planned strategy, the public sector can partner with private energy companies to get both technical and economic support. Thirdly, as energy is ultimately distributed to and consumed by citizens, it is critical that consumers can participate in the energy planning in terms of financial incentives, technical knowledges or just simply community recommendations. Since the ultimate goal is to mitigate ongoing climate change issues and create a more livable city environment for citizens, cities should be well aware of citizens' needs and city's ability to address and implement the corresponding strategies.

References (Yichen)

Asia Pacific Energy (2012). China: 12th Five Year Plan of Renewable Energy Development. Retrieved from https://policy.asiapacificenergy.org/node/40 on 19 October 2020.

Asia Pacific Energy (2016). China: 13th Five Year Plan for Renewable Energy Development. Retrieved from https://policy.asiapacificenergy.org/node/2837 on 19 October 2020.

Bloomberg (2020). Beijing Energy International Holding Co Ltd. Retrieved from https://www.bloomberg.com/profile/company/GGI:GR on 30 October 2020.

Bloomberg (2020). Beijing Enterprises Clean Energy Group Ltd. Retrieved from https://www.bloomberg.com/profile/company/1250:HK on 30 October 2020.

Bloomberg (2020). Shanghai Laogang Renewable Energy Co Ltd. Retrieved from https://www.bloomberg.com/profile/company/CNCENZ:CH#:~:text=Shanghai%20Laogang%20Renewable%20Energy%20Co.,treatment%2C%20and%20power%20generation%20projects on 30 Oct 2020.

Bloomberg (2020). Shanghai Renewable Subsidies to support Solar and Offshore Wind, *Bloomberg Green*. Retrieved from https://www.bloomberg.com/news/articles/2020-06-09/shanghai-renewable-subsidies-to-support-solar-and-offshore-wind on 30 Oct 2020.

Bloomberg (2020). Shanghai Topsolar Green Energy Co Ltd. Retrieved from https://www.bloomberg.com/profile/company/STGECZ:CH on 30 Oct 2020.

Boston Business Journal (2019). The largest clean energy companies in Massachusetts. Retrieved

Integration of renewable energy resources in major cities' infrastructure

From https://guidehouse.com/-/media/www/site/downloads/energy/2019/largest-clean-energy-companies-in-massachusetts.pdf on 19 October 2020.

Boston government, (2020). 2014 Climate Action Plan: July 2019 Progress Report. Retrieved from www.boston.gov on 19 October 2020.

China National Renewable Energy Center (CNREC) (2020). Center for Renewable Energy Development. Retrieved from http://www.cnrec.org.cn/english/aboutcnrec/overview/ on 30 October 2020.

City of Boston (2008). Climate: Change, The City of Boston's Climate Action Plan December 2007. Retrieved from www.cityofboston.gov on 19 October 2020.

City of Boston (2020).Boston Climate Action. Retrieved from www.boston.gov on 19 October 2020.

City of Boston (2014).Greenovate Boston: 2014 Climate Action Plan Update. Retrieved from www.cityofboston.gov on 19 October 2020.

Government of Shanghai (2006). Eleventh Five-Year Plan – Shanghai, China. Retrieved from http://wap.sh.gov.cn/shanghai/node27118/node27386/node27408/node27500/node27521/u26ai26725.html on 19 October 2020.

Massachusetts Clean Energy Center (2020). Local Industry Groups. Retrieved from https://www.massec.com/local-industry-groups on 19 October 2020.

Onag, G. (2020). Shanghai Electric: 5G and IIoT essential to wind power strategy, Futureiot. Retrieved from https://futureiot.tech/shanghai-electric-5g-and-iiot-essential-to-wind-power-strategy/#:~:text=Shanghai%20Electric%20is%20riding%20on,world%2Dleading%20renewable%20energy%20solutions on 30 Oct 2020.

Reuters (2014). China's Shanghai aims for cleaner energy, lower CO2 growth. Retrieved from https://fr.reuters.com/article/china-energy-environment-idUSL3N0MG1B920140319 on 30 Oct 2020.

Rogers, J. (2016). Where Does Massachusetts Get Its Electricity? The Bay State's Energy Scene by the Numbers,

Union of Concerned Scientists. Retrieved from https://blog.ucsusa.org/john-rogers/where-does-massachusetts-get-its-electricity-by-the-numbers on 30 Oct 2020.

The Shanghai Hub (2020). Shanghai – Cleantech Hubs. Retrieved from

https://uk.reuters.com/article/china-energy-environment/chinas-shanghai-aims-for-cleaner-energy-lower-co2-growth-idUSL3N0MG1B920140319 on 30 October 2020.

https://cleantechhubs.se/hub/shanghai/ on 19 October 2020.

The World Bank (2019). ICR- World Bank Document- World Bank Group. Retrieved from

http://documents1.worldbank.org/curated/en/998261563296152552/pdf/China-Green-Energy-for-Low-carbon-City-in-Shanghai-Project.pdf on 19 October 2020.

The World Bank (2020). Supporting Low-Carbon City Development in Shanghai, the World

Bank, IBRD, IDA. Retrieved from https://www.worldbank.org/en/results/2020/10/12/supporting-low-carbon-city-development-in-shanghai on 19 October 2020.

USC US-China Institute (2007). National Development and Reform Commission; 11th Five Year Plan on Energy Development. Retrieved from https://china.usc.edu/national-development-and-reform-commission-%E2%80%9C11th-five-year-plan-energy-development%E2%80%9D-april-2007 on 19 October 2020.

Wasser, M. (2019). Boston Aims To Be Carbon-Free By 2050. Here Are 5 Takeaways from a New Report**,** *WBUR News*. Retrieved from https://www.wbur.org/news/2019/01/29/carbon-free-boston-report-takeaways on 30 Oct 2020.

Wu, J. and Y. Zhang (2008) 'Olympic Games promote the reduction in emissions of greenhouse Gases in Beijing', Energy Policy 36: 3422–3426.

Xinhuanet (2018). Beijing sees renewable energy growth, Xinhuanet app. Retrieved from http://www.xinhuanet.com/english/2018-09/08/c_137454885.htm on 19 October 2020.

Zhang, Y., Gu, A., Lu, H., & Wang, W. (2017). Hydropower Generation Vulnerability in the Yangtze River in China Under Climate Change Scenarios: Analysis Based on the WEAP Model, *Sustainability MDPI.*

Integration of renewable energy resources in major cities' infrastructure

Doi: 10.3390/su9112085.

Zhao, J. (2011). Climate Change Mitigation in Beijing, China. Retrieved from

https://uni.unhabitat.org/wp-content/uploads/2012/06/GRHS2011CaseStudyChapter05Beijing.pdf on 19 October 2020.

Reference (Jingjing)

Copenhagen

Copenhagen Capacity. "Cleantech in Greater Copenhagen." *Copcap.Com*, 2017, www.copcap.com/set-up-a-business/key-sectors/cleantech. Accessed 22 Sept. 2020.

International Renewable Energy Agency (IRENA). *History and Evolution of tHe Policy and Regulatory Framework for Wind Energy*. 2013.

Renewables 100 Policy Institute; Go100%.org. "Go 100% Renewable Energy : City of Copenhagen." *Go100percent.Org*, 12 Apr. 2015, www.go100percent.org/cms/index.php?id=70&tx_ttnews%5Btt_news%5D=20.

"Copenhagen – CNCA." *Carbonneutralcities.Org*, 2012, carbonneutralcities.org/cities/copenhagen/.

"Copenhagen's Four-Fold Path to Carbon Neutrality - Renewable Energy World." *Renewable Energy World*, 3 Aug. 2017, www.renewableenergyworld.com/2017/08/03/copenhagens-fourfold-path-to-carbon-neutrality/#gref.

"CPH 2025 - Climate Plan Roadmap 2017-2020." The Technical and Environmental Administration The City of Copenhagen, 2016.

Mathiesen, B. V., Lund, R. S., Connolly, D., Ridjan, I., & Nielsen, S. "Copenhagen Energy Vision A Sustainable Vision for Bringing a Capital to 100% Renewable Energy." *Department of Development and Planning, Aalborg University.*, 2015.

"The CPH 2025 Climate Plan." The Technical and Environmental Administration The City of Copenhagen, 2013.

"C40: 98% of Copenhagen City Heating Supplied by Waste Heat." *C40*, www.c40.org/case_studies/98-of-copenhagen-city-heating-supplied-by-waste-heat. Accessed 11 Nov. 2020.

"Danish Energy Agreement for 2012-2020 – Policies." *IEA*, www.iea.org/policies/606-danish-energy-agreement-for-2012-2020.

"Denmark's Energy Revolution: Past, Present, and Future." *The Solutions Journal*, www.thesolutionsjournal.com/article/denmarks-energy-revolution-past-present-future/. Accessed 11 Nov. 2020.

"Denmarks Largest Power Station Becomes Greener." *Orsted.com*, orsted.com/en/media/newsroom/news/2014/10/denmarks-largest-power-station-becomes-greener. Accessed 11 Nov. 2020.

Noring, Bruce Katz and Luise. "Why Copenhagen Works." *Brookings*, 17 Feb. 2016, www.brookings.edu/research/why-copenhagen-works/. Accessed 11 Nov. 2020.

"Smart District Heating in Copenhagen with Heat Pumps." *State of Green*, stateofgreen.com/en/partners/hofor-utility-company/solutions/smart-district-heating-in-copenhagen-with-heat-pumps/. Accessed 11 Nov. 2020.

"The CPH 2025 Climate Plan." The Technical and Environmental Administration The City of Copenhagen, 2013.

Mit.Edu, 2020, web.mit.edu/nature/archive/student_projects/2007/cherryj/urban-nature/copenhagen/index.html. Accessed 11 Nov. 2020.

San Francisco

CITIES ARE READY FOR 100% CLEAN ENERGY 10 CASE STUDIES. Edited by Sierra Club, 2016, content.sierraclub.org/creative-archive/sites/content.sierraclub.org.creative-archive/files/pdfs/1352%20RF100%20report%2005_web-08-2016.pdf.

"2018 SAN FRANCISCO GEOGRAPHIC GREENHOUSE GAS EMISSIONS INVENTORY AT A GLANCE." 2018.

CARVALH, Luís. "Energy Transitions in Cities. Lifestyle, Experimentation and Change Seventh Case Study: San Francisco." *European Institute for Comparative Urban Research (EURICUR)*, 2014.

Climate Action Plan 2014. San Francisco Department of Environment, 2014.

Focus 2030: A Pathway to Net Zero Emissions. San Francisco Department of the Environment, July 2019.

Jones, Christopher, and Coolclimate Network. *Consumption-Based Greenhouse Gas Inventory of San Francisco from 1990 to 2015*. 2020.

"Mayor Lee Announces Bold New Target of 50 Percent Renewable Energy by 2020 | Office of the Mayor." *Sfmayor.org*, sfmayor.org/article/mayor-lee-announces-bold-new-target-50-percent-renewable-energy-2020. Accessed 12 Dec. 2020.

San Francisco Climate Action Strategy. San Francisco Department of the Environment, 2013.

"San Francisco Mayor's Renewable Energy Task Force Recommendations Report." 3 Dec. 2012.

"C40 Knowledge Community." *Www.C40knowledgehub.org*, www.c40knowledgehub.org/s/article/Cities100-San-Francisco-s-community-choice-aggregation-programme-fuels-the-transition-towards-a-renewables-powered-city?language=en_US. Accessed 12 Dec. 2020.

"CleanPowerSF." *CleanPowerSF*, www.cleanpowersf.org/. Accessed 12 Dec. 2020.

"Go 100% Renewable Energy : Project Detail - North America." *Www.Go100percent.org*, www.go100percent.org/cms/index.php?id=77&tx_ttnews. Accessed 12 Dec. 2020.

"GreenFinanceSF." *San Francisco Chamber of Commerce*, sfchamber.com/resources/economic-development/tax-incentives/greenfinancesf/. Accessed 12 Dec. 2020.

"GreenFinanceSF: Commercial PACE Program." *Sfenvironment.org - Our Home. Our City. Our Planet*, 17 Oct. 2011, sfenvironment.org/article/financing/greenfinancesf-commercial-pace-program. Accessed 12 Dec. 2020.

Impact – CalCCA. cal-cca.org/cca-impact/. Accessed 12 Dec. 2020.

"Mayor Lee Announces Bold New Target of 50 Percent Renewable Energy by 2020 | Office of the Mayor." *Sfmayor.org*, sfmayor.org/article/mayor-lee-announces-bold-new-target-50-percent-renewable-energy-2020. Accessed 12 Dec. 2020.

"Renewable Energy." *Sfenvironment.org - Our Home. Our City. Our Planet*, sfenvironment.org/energy/renewable-energy.

"San Francisco Public Utilities Commission : Installations." *Sfwater.org*, sfwater.org/index.aspx?page=403. Accessed 12 Dec. 2020.

"Sfenvironment.org - Our Home. Our City. Our Planet." *Sfenvironment.org - Our Home. Our City. Our Planet*, sfenvironment.org/.

Integrated Resource Plan — CleanPowerSF. "CleanPowerSF." *CleanPowerSF*, 2014, www.cleanpowersf.org/resourceplan.

"Top Ten U.S. Cities Ranked For Climate & Renewable Energy Policies | Sustainability Roundtable Inc." *Sustainround.Com*, 2017, sustainround.com/2017/05/31/top-ten-u-s-cities-ranked-for-climate-renewable-energy-policies/.

"San Francisco Public Utilities Commission : Hetch Hetchy Power." *Sfwater.Org*, 2020, sfwater.org/index.aspx?page=1241.

Dvorak, Michael J., et al. "California Offshore Wind Energy Potential." *Renewable Energy*, vol. 35, no. 6, June 2010, pp. 1244–1254, www.sciencedirect.com/science/article/abs/pii/S0960148109004984, 10.1016/j.renene.2009.11.022. Accessed 12 Dec. 2020.

Munich

ANNUAL REPORT 2019. STADTWERKE MÜNCHEN (SWM), Apr. 2020.

Blasi, M. *Climate Action in Munich Strategies -Concepts -Activities*. 2018.

Frey, Josef, and Andrea Miller. *Munich -a Pioneer in Climate Protection The SWM Renewable Energy Strategy*. 2017.

"Munich: 100% Green Power." *Issuu*, June 2013, issuu.com/siemens_the_crystal/docs/2_munich_muellerl__compatibility_mo. Accessed 12 Dec. 2020.

Renewable Energy Prospects: Germany, REmap 2030 Analysis. International Renewable Energy Agency (IRENA), 2015.

The IHKM in Action. Feb. 2014.

The Integrated Action Program for Climate Protection in Munich (IHKM). Department of Health and the Environment, City of Munich, Dec. 2018.

"C40-Munich." *Www.C40.org*, www.c40.org/profiles/2013-munich.

CNBC.com, Anmar Frangoul, special to. "Munich: The 100% Clean Electricity City?" *CNBC*, 26 Sept. 2014, www.cnbc.com/2014/09/26/munich-the-100-clean-energy-city.html. Accessed 12 Dec. 2020.

"Connective Cities :: Good Practice Details." *Www.Connective-Cities.net*, www.connective-cities.net/en/good-practice-details/gutepraktik/integrated-action-program-for-climate-protection-in-munich-1/.

"Expansion Campaign for Wind Power in Europe: Wpd and SWM to Pool Their Competencies - Renewable Energy Industry." *Www.Renewable-Energy-Industry.com*, www.renewable-energy-industry.com/news/press-releases/pm-3896. Accessed 12 Dec. 2020.

Munich, Germany – 100% Renewable Energy Atlas. www.100-percent.org/munich-germany/. Accessed 12 Dec. 2020.

Welle (www.dw.com), Deutsche. "Munich Embraces Ambitious Strategies to Convert to Green Energy by 2025 | DW | 09.11.2009." *DW.COM*, www.dw.com/en/munich-embraces-ambitious-strategies-to-convert-to-green-energy-by-2025/a-4874301. Accessed 12 Dec. 2020.

reve. "An Offshore Wind Farm Changes Munich's Energy Mix | REVE News of the Wind Sector in Spain and in the World." *Evwind.Es*, 18 Mar. 2020, www.evwind.es/2020/03/18/an-offshore-wind-farm-changes-munichs-energy-mix/74086.

Sait, Mohammed, et al. "Renewable Energy as an Underutilised Resource in Cities: Germany's 'Energiewende' and Lessons for Post-Brexit Cities in the United Kingdom." *Resources*, vol. 8, no. 1, 2018, p. 7., doi:10.3390/resources8010007.

"Mastering the Energy Transition." *Www.Swm.De*, 2012, www.swm.de/english/company/renewable-energies.html. Accessed 22 Sept. 2020.