Sustainable Tokyo 2040

Minato Ward

Japan’s Green Window to the World

MJ2410 - Energy Management

Francisco Beltran
Frida Jalkenäs
Juris Pomerancevs
Lesley Fisher
Maria Cecilia Oliveira
Weimar Mantilla

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KTH Royal Institute of Technology
Stockholm
Sweden
Abstract

After its devastation at the end of the Second World War, Japan achieved an unprecedented economic growth, becoming today the world’s third-largest economy [1]. Since the 1950s, it has been at the forefront in terms of manufacturing industry practices and innovation technologies. It is a role model when it comes to education and health, and has one of the highest living standards in the world [2]. It is also well known for its tradition and culture, and the importance its inhabitants give to nature. Moreover, it is the place where one of the first global measures regarding climate change, the Kyoto Protocol, was adopted.

On the other hand, it is one of the largest energy consumers and importers worldwide [3], and the 5th largest contributor to GHG global emissions [4]. Until 2011, Japan relied mostly on nuclear power to meet more than one quarter of its electricity needs, and this technology was expected to play an even bigger role in the future, putting Japan on track to meet its environmental targets. After the Great East Japan Earthquake in 2011, nuclear power was almost immediately abandoned, causing a drastic change in the primary energy matrix. Coal and gas filled the void, leaving Japan with only 7% energy self-sufficiency, one of the lowest values in the world. Since then, different energy sources and policies have been developed, but have not been sufficient. Currently, Japan relies mainly on fossil fuel imports for more than 90% of the total energy supply and has been strongly criticized for slashing its GHG emissions targets. [3] [5] Thus, one of the major challenges that Japan is facing today is to obtain a high energy security, while increasing the share of renewables and decreasing the share of imports.

In order to transform the Japanese energy sector it is necessary to shake the board and change the perspective on how things have been done so far. That is why, rather than a large scale proposal for the entire Japan, the aim of this project is to present a smaller scale proposal for a ward in Tokyo, to make it a sustainable city in 2040. Although this proposal is meant to be applied for a particular place, the idea is that it could be reproduced throughout the entire country as part of a larger strategy. Within the city of Tokyo there is a district that stands out, because of the complexity and variety of the systems that coexist in it.

Minato is a centrally located ward which opens to the sea through Tokyo Bay. It is directly connected to Haneda International Airport through railway and metro lines, harbors Tokyo’s main ferry terminal, and gives quick access to Tokyo’s main expressways. Minato is a wealthy commercial district, home to the Japanese headquarters of numerous multinational firms such as Honda, Mitsubishi, Sony, Fujitsu, Toshiba, Google and Apple. Almost 80 nations have their embassies or consulates located in Minato, which every year open their doors to thousands of people during the “Minato City World Festival”. It will host events during the next summer Olympic Games, and three of the most emblematic places in Japan, the Tokyo Tower, the Rainbow Bridge and the urban development Roppongi Hills are located within its borders. As if this were not enough, the large amount of commuters and visitors that move in and out of the ward everyday have to coexist in harmony with a large residential population. [6] [7]
In order to improve the life quality of its inhabitants, show the world Japan's commitment to protect the environment, and position itself as a game changer in the global energy sector, what would be a better place where to start from than Minato City, in order to make it Japan’s Green Window to the World.

Four different Key Performance Indicators (KPIs) are used to quantify the accomplishment of the objective of making Minato sustainable by 2040. Based on a qualitative system model for Minato, quantitative models were developed using both HOMER Pro® and the Long-range Energy Alternatives Planning System (LEAP). For these models, three different scenarios are used: one representing a business as usual scenario, another showing what the future would look like if all the existing policies and goals were to be met, and the last one depicting what necessary improvements and investments should be made to achieve a sustainable Minato by 2040. A technical and economic analysis of the results of the models was made, resulting in what is thought to be the best proposal for Minato.

The proposal consists in the installation of 3 195 MW of onshore wind power and 456 MW of solar PV, both to be constructed in three phases. From the 16 364,2 MW of expected necessary installed capacity in Minato for 2040, 61,1% will come from the grid, 19,5% from the wind turbines, 2,8% from solar PV, 11,1% from stored energy in batteries, 5,4% from Hydrogen, and the remaining 0,1% from the already existing incineration plant. The overall proposition has a NPV of ¥ 2,64 Trillion, and decreases emissions in Minato to 1,0 million tonnes of CO₂. The final system has an efficiency of 70,5% and a renewable energy fraction of 59,1%. Even though the KPIs goals are not met with this proposal, a large part of the road is covered towards a sustainable city. The renewable energy fraction increases from 9,5% to 59,1%, the total primary energy supply (per year per person) and the CO₂ emissions are reduced by 66% and 86% respectively, and the crowdedness factor is brought down from 173% to 150%, all with regards to base year 2015. If compared to the goals set by the Japanese Government for 2030, (22-24% renewables in primary energy matrix, 26% emissions reduction and 24% self-sufficiency ratio) it can be seen that the values obtained for Nokko, the horse would largely exceed them.
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1. Introduction

1.1 Overview of Japan

Japan is a volcanic archipelago located in the Pacific Ocean. It consists of more than 6,000 islands, of which the main four, Hokkaido, Honshu, Shikoku and Kyushu, account for more than 95% of the land area and 98% of the population. Japan has a temperate climate with an average annual temperature of 10.5 °C and an average rainfall of 136.2 mm [8]. Due to its location along the “Ring of Fire”, Japan is prone to earthquakes, tsunamis and volcanic activity. [9][10]

![Map of Japan](image)

**Figure 1: Location and general information about Japan [9][11][12][13]**

About 73% of its territory is forested, mountainous and unsuitable for agricultural, industrial, or residential use; only 12% of its land can be used for agricultural purposes. Almost 94% of the 127 million inhabitants in the country live in urban areas. The population is ageing rapidly and is expected to decrease in the following years. [9][14]

Japan has the world’s third-largest economy after the United States and China [1], thanks to the remarkable economic growth experienced in the last 70 years led by the motor vehicle and electronics industries. The service sector accounts for 75% of the GDP, dominated by banking, insurance, real estate, transportation and telecommunications industries. [9]

Japan has been experiencing a period of transition in its energy sector, due to the abandonment of nuclear energy after the Fukushima disaster, on which all the Japanese energy policies were based. The Japanese Government, led by Prime Minister Shinzo Abe, argues that in order to achieve
Japan’s environmental targets it will be necessary to put nuclear power plants back into operation. From the 50 existing nuclear units, 7 have already restarted operation, 12 are expected to do so in 2025 and 18 by 2030. Regardless, the Fukushima accident has risen awareness that it is also necessary to increase the renewable energy fraction in the total primary energy supply. Between 2010 and 2015, solar energy production increased by 207.8% and biofuels and waste by 19.7%. Major Japanese multinational companies such as Toshiba, Hitachi and Mitsubishi have begun to invest in wind, solar and smart-grid technologies. [3][15]

The Japanese transportation network stands out because of its modernity and high development. It consists of extensive networks of paved roads, as well as high speed trains, airways and waterways [16]. Public transportation in Japan is known as one of the most energy efficient, punctual, but also crowded systems in the world [17]. The emblem of this system is the Shinkansen, the Japanese bullet train which started operation in 1964, just in time for the first Tokyo Olympic Games. The Tokaido Shinkansen line, which connects Tokyo, Nagoya and Osaka, Japan’s three largest cities, is the world’s busiest high-speed rail line [18]. The domestic demand has decreased over the last 20 - 25 years, which is something unique for developed countries. In 2014, road transportation accounted for 58.9% of passenger volume and 50.6% of freight volume, being the most widely used transportation system. [19]

![Figure 2: Tokaido Shinkansen bullet train with Mt. Fuji behind][20]

Japan is the 8th major generator of municipal waste worldwide with 45 360 000 tons per year. At the same time, its recycling rate is of only 20.8%, far below the more than 50% already achieved by countries such as Germany, South Korea, or Slovenia [21][22]. Approximately 3% of the 200 million kilolitres of oil that Japan imports annually goes towards making plastic [23]. Due to the increasing population and economic growth experienced by Japan during the last century, waste management has become one of the most important issues in the Government’s agenda. This is why, in an effort to promote proper waste management and an effective use of resources, several laws have been enacted and released, and a cooperation between local governments, private business operators and residents has been developed. [24]
Japan is one of the most visited destinations in Asia, and tourism seems as one of the most promising businesses in the years to come [9][25]. There are several strategies in order to increase the number of tourists in the following years, among which are the Olympic Games to be held in Tokyo in 2020 [26]. Some of the most visited places in Japan include: the city of Tokyo, Mount Fuji, Hiroshima, and Kyoto. [27]

![The Torii in Miyajima-Hiroshima (left) and Pagoda with view of Mt. Fuji (right)](image)

**Figure 3:** The Torii in Miyajima-Hiroshima (left) and Pagoda with view of Mt. Fuji (right) [28][29]

### 1.2 Tokyo

Tokyo is the capital city of Japan, and the center of politics, economy, education, communication and culture of the country [30]. Tokyo Metropolitan area is home to more than 37 million inhabitants which account for 30% of Japan’s total population, making it the largest urban agglomeration in the world [31]. The mainland part of Tokyo is divided into the 23 special wards area to the east, and the Tama area to the west [30].

![Satellite images of Japan and Tokyo metropolitan area](image)

**Figure 4:** Satellite images of Japan and Tokyo metropolitan area [32][33]

The climate in Tokyo is generally warm and temperate. The highest temperatures are reached in August (≈ 30°C), and the coldest in January (≈ 0°C). However, due mainly to the rapid urbanization and industrialization process experienced over the last 100 years, the temperature of the center of Tokyo has risen about 3°C [34] as can be observed in figure 5. This weather effect has been referred to as the “urban heat island phenomenon”, which is also observed in many cities of the world with intensive energy consumption [35][36]. The Tokyo government is working to end this trend.
The city is an important wholesale center, where goods from all parts of the country and the world are distributed. Tokyo has an extensive and varied transport network, and the world’s largest urban railway system. It is home to 76% of the foreign-affiliated companies in Japan, and the city with the most Fortune Global 500 company headquarters in the world after Beijing [31]. It is considered one of the 3 “command centers” for the world economy, along with New York and London [30]. Furthermore, Tokyo is also one of the most visited destinations worldwide, with 12.5 million international visitors per year [38].

1.3 Minato

Minato City is one of the central wards in Tokyo, and is located in the southeast end of the city. It faces Tokyo Bay to the east and has borders with all of the other 4 central wards, Shibuya, Shinjuku, Chiyoda and Chuo, and the southern ward of Shinagawa. It has a total area of 20,37 km², which represents about 3.25% of the 23 special wards total area [39]. It was established on March 15, 1947 when the three former towns of Akasaka, Azabu, and Shiba were merged into one municipality. [6]

Figure 6: Minato-Ku Location [40]
Minato has a residential population of 254,561 inhabitants [41], which is expected to increase 20% over the next 22 years. Figure 7 shows the population forecast for the central wards, where Minato has the largest projected growth, reaching around 304,000 inhabitants by 2040 [42] [43].

![Figure 7: Forecast resident population in central Tokyo](image)

As one of Tokyo’s central districts, Minato is home to a large number of embassies, universities and well-known companies, both national and multinational. Therefore, large populations commute to the district everyday, resulting in a daytime population 3 times larger than the residential population [44]. In order to consider these fluctuations, an average population consisting of all residents and 30% of the commuters is assumed for this project.

One of the most outstanding projects that have been carried out in Minato towards a smart city, is the Roppongi Hills complex. The futuristic idea behind it is “a city within a city”, in which people can live, work, shop and have leisure activities in the same place, to avoid commuting time and reduce energy consumption. It consists of office spaces, apartments, shops, cafes, restaurants, a movie theater, a museum, a hotel, a TV studio and green spaces, all in a 72,400 m² space.

![Figure 8: Roppongi Hills complex](image)
2. Current State

2.1 Energy and Emissions Overview

In 2015, renewable energy sources represented 5.5% of the total primary energy supply (TPES), and 16% of the total electricity generation in Japan [46]. Fossil fuels accounted for 93.7% of the TPES, from which 99.3% were imported. The changes in the primary energy matrix, energy production and imports during the last 40 years can be seen in figures 9 to 11. The effect of the Great East Japan Earthquake after 2011 can be seen clearly in all of them.

Figure 9: *Total Primary Energy Supply by source in Japan (1973-2015)*[3]

![Figure 9: Total Primary Energy Supply by source in Japan (1973-2015)](image)

Figure 10: *Energy Production by source in Japan (1973-2015)*[3]

![Figure 10: Energy Production by source in Japan (1973-2015)](image)
Total greenhouse gases (GHG) emissions in Japan in FY2015 were 1325 million tonnes of CO₂ equivalent [48], making it the 5th largest contributor worldwide [4]. Removal of CO₂ eq by forests, croplands, grazing management, and urban revegetation was of 58.8 million tonnes, representing only 4.4% of the total emissions [48] Because of the increased use of fossil fuels in the last years, CO₂ emissions rose. After the COP21 meeting in Paris 2015, Japan announced that it would reduce its GHG emissions by 26% from 2013 to 2030. Looking only at CO₂ emissions, the power sector is the largest contributor, accounting for 48.6%, which implies that changes within that sector need to be implemented to reach the goal in 2030 [3]. Given this situation, the national government has introduced legislation to increase the use of renewable energy sources. The New Energy Usage Act obligates electric power companies to use electricity generated by new energy in a proportion that exceeds the prescribed level related to the quantity of their electricity sales. A subsidy scheme was also put in place, to expand solar photovoltaic [49]

Within Tokyo, the commercial sector is the largest contributor to CO₂ emissions (Figure 13). Since emissions correlate with energy consumption and the commercial sector is expressive in Minato, the distribution of energy consumed within that sector will have an effect on the proposed reduction measures (Figure 14).
Figure 12: Energy consumption by sector in Tokyo [50]

Figure 13: Energy-derived CO$_2$ emissions by sector in Tokyo [50]
2.2 Transportation

Tokyo metropolitan transportation is considered one of the most dense systems among the world's megacities, offering a variety of transportation means. According to the general transportation census, the trend from 1988 to 2008 shows an average of 2.56 trips/person/day in Tokyo, mainly due to business and commercial activities in the area [51]. Railway usage has increased due to different policies in Japan and Tokyo, supporting privatization of the service and increasing taxation for car ownership and fuels. The trend differs from the city to Minato, where walking represents the main mode of transport, followed by buses, trains and cars (Figure 15) [52].

Minato government has promoted the use of bicycle parking-lots and together with four surrounding municipalities, established a bicycle sharing program [39].
2.2.1 Fossil Fuel Transportation

Diesel and gasoline fuels for transportation in Minato are mainly used by private cars and buses. For this project the transport load curve was assumed to be the same for every month, only differing largely between weekdays and weekends (Figure 16). The shape of the curve is based on a study by the National Renewable Energy Laboratory [53] showing an average trend in fueling events per day.

![Fossil Fuel Transportation - 2018](image16)

**Figure 16: Fossil fuel transport load curve**

2.2.2 Electric Transportation

All of the trains and trams in Minato are powered by electricity, although this technology has not yet expanded to buses and private cars. Only 1% of private cars and none of the buses in Minato are electric. For the electric transportation load curve for base year 2018, it is assumed that the energy consumption for every day of the year is the same (Figure 17). The shape of the load curve is partially based on the timetable of tram and trains passing through Minato.

![Electric Transportation - 2018](image17)

**Figure 17: Electric transport load curve**
2.2.3 Hydrogen Transportation
Currently there is almost no hydrogen based transportation in Minato, but it is predicted to grow in the future. As with electric cars, it is assumed that the hourly load curve is the same throughout the entire year.

![Hydrogen Transportation - 2018](image)

**Figure 18**: Hydrogen transport load curve

A future challenge of the transportation within Minato is to establish a convenient transport network, upgrading the accessibility to the system while taking into account a healthy lifestyle and high efficiency.

2.3 Buildings
As a ward on the cutting edge of technology, developers in Minato have created spaces such as the Roppongi Hills complex, which capitalizes on social, economical, and environmental advantages of mixed-use spaces. However the majority of buildings are still considered the same quality and performance as in the whole of Japan, i.e. outdated if compared to the European standards. Japan’s “build and scrap” mentality means that buildings over 25 years in age are perceived as old and due to frequent natural disasters, lack of durability and consequent cost considerations, the majority of them are demolished and replaced by new ones instead of refurbishing. Building stock in Tokyo has been very dynamic, which is an opposite to the Western cities where urban conservation concentrates on longevity [54]. Changes however are noticed with political discussions about the importance of a building lifespan increase, which is in part due to the need for energy efficiency measures to be rentable. [55]

To understand the nature of Minato as the commercial center, the types of buildings within the ward and their floor area are illustrated in figure 19.
2.3.1 Households

From the previous graph it can be seen that residential buildings account for about 40% of floor area, however the land area they take has the highest share, since much of the commercial floor space is concentrated in high rise office areas. Therefore, the typical Tokyo cozy neighbourhoods are still a large part of the ward and “the rights for the sun” for the residents are not violated heavily like it is other metropolises, which is ensured by the law that sets limits for building height along the western part of Minato. [57]

Several studies about final energy use in households suggest similar numbers, and use per function as shown in figure 20. Because of the fact that households in apartments tend to have a centralised means of heating and cooling generation and on average have less people per dwelling, a difference in measured data is observed between a typical household in detached building and apartment. [58][59]
Energy use behavior in Japanese households has a specific nature, that is somewhat unique if compared to, for example, European practices. To start with, heating is preferred for rooms only not the whole building, as it is considered as energy wasting. Due to the low insulation level this argument is valid [55]. The heating energy concept can be defined as person rather than space orientated. Means of heating range from traditional kotatsu, to outdated kerosene heater utilisation, (the safety manual of which suggests no operation during the night due to risk of carbon monoxide intoxication) and include a very high share for natural gas and LPG boilers [60]. Although one might imagine seeing mostly traditional Japanese wooden dwellings, modern urban areas such as Minato do not offer many of this kind of uniqueness. Despite this, the oldest wooden building in Tokyo, Sangedatsumon, is located in Minato. Only around 5,5% of residential buildings are wooden, with the majority being reinforced concrete structures. [56]

2.3.2 Commercial Buildings

Minato has a reputation of being a hub for business for a reason - more than a half of the total building floor space exists for various commercial activities. Many of the world known companies have their headquarters in one of many Minato’s high-rise buildings, 18 of which are amongst top 47 tallest buildings in Tokyo [61]. Although the number of high rise buildings is the highest in Tokyo, another 87,5% of buildings in Minato are those with between four and ten storeys. [56]

Studies on final energy use have been widely available, and after analysing several sources a common ground has been reached on energy intensity depending on building type and function, which can be viewed in figure 21 [59]. Most of the commercial floor space in Minato is for offices (55%), followed by stores (37%) and hotels (7%). Therefore most the significant energy use reductions can be achieved in these buildings. [56]

![Figure 21: Final Energy Use per m² Floor Area in Different Buildings](image)

In 2010 the Cap-and-Trade (C&T) policy was introduced in Tokyo to mitigate CO₂ emissions in large commercial facilities. Small and medium size facilities are not involved in C&T, but are
obliged to report \( \text{CO}_2 \) emissions and their plan for reductions, which is not a strong incentive in the author’s opinion [62]. “Cool Biz” and “Warm Biz” - a unique campaign kicked off in 2005 by the government had the aim of decrease cooling and heating energy use through encouraging public and private sector workers to dress in casual outfits, increasing the setpoint for cooling to 28°C and reducing it to 20°C for heating. [63][64] With these and other measures introduced there is still a high potential to decrease energy need in Minato commercial buildings, as around 94% of buildings are older than 5 years and the building code in Japan is not strict towards energy efficiency. In addition, energy equipment that has been utilised is in large part fossil fuel driven. To reduce peak electricity demand, which occurs in summertime, the solution used has been to use natural gas engine absorption chillers, with a share of almost 50% [55][60].

To create load profile input for HOMER Pro, preprocessing is required. In the model, lighting, electrical appliance, cooking and ventilation energy use is dependent solely on occupant activity, which follows curve proportional to Japanese lifestyle specifics, including consideration of weekday and weekday schedules [65][66]. Approach of load estimation for space, water heating and cooling involved correlations with ambient temperature, which are based on statistical data for different building types in Tokyo and annual final energy signatures agree with several other studies in Japan [59]. Temperature profile with hourly resolution was used, taking into account climate change scenario A1B by IPCC for 2040. For scenarios where measures are implemented, the applied principle is shown in Appendix 11.5.

Although the energy consumption within the building sector varies throughout the year, the shape of the load curve only suffers slight variations. The average load curve for base year 2018 for the building sector can be seen in the following figure.

![Figure 22: Buildings load curve variations](image-url)
2.4 Industry

The final energy consumption in the industry sector in Tokyo has been decreasing since FY1990, following the same trend as the manufacturing industry, which accounts for the largest share in the sector. The construction industry has had its ups and downs, dependent on the economic situation in the country and region, while the mining, agriculture, forestry and fishery trades have remained almost constant throughout the years. The decreasing trend and the final energy consumption share in this sector can be seen in the following figures. [50]

Figure 23: Final energy consumption trend in the Industrial Sector [50]

Figure 24: Final energy consumption in the Industrial Sector, by industry type [50]
Regarding the final energy consumption by fuel type (Figure 25), the industrial sector has experienced a great change, from one predominantly powered by fuel oil (FY1990), to one in which the percentage of electricity, natural gas, and fuel oil is almost equal (FY2014).

![Figure 25: Final energy consumption in the Industrial Sector, by fuel type [50]](image)

Minato accounts for 1% of the manufacturing establishments in Tokyo [56], which at the same time account for more than 70% of the final energy consumption within the industrial sector [50]. For that reason, it is assumed that the final energy consumption in Minato for the industrial sector is 1% of the one for the entire city. As the predominant type of industry in the ward is the same as in Tokyo, the graphic industry, it is assumed that the final energy consumption by fuel type in Minato is the same as in Tokyo. With these assumptions made, a summary of the energy consumption in the industrial sector in Minato for base year 2018 is presented in the following table.

<table>
<thead>
<tr>
<th>Industrial Sector - 2018</th>
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<tbody>
<tr>
<td>Final Energy Consumption - Tokyo (GWh)</td>
<td>14720</td>
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<tr>
<td>Final Energy Consumption - Minato (GWh)</td>
<td>155</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Electricity</td>
<td>34.0%</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>33.3%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>31.8%</td>
</tr>
<tr>
<td>Others</td>
<td>0.9%</td>
</tr>
</tbody>
</table>

For the industrial load curve, it is assumed that there is no variation between seasons, and that energy consumption during weekends is 70% of that consumed during weekdays (Figure 26).
2.5 Waste

Waste Management in Tokyo is performed collaboratively. The 23 special wards independently manage their own waste collection and transfer, the management of intermediate processing of waste (incineration, pulverization, etc) is then done by the Clean Authority of Tokyo, due to the fact that some wards do not have their own incineration plant, and the final disposal into landfills is handled by the Tokyo Metropolitan Government. [67]

In Minato, the total amount of generated waste in 2015 was of 75 984 tons, from which 65% was combustible waste [56] (Figure 27).

Once the waste is collected and sorted, recycling materials are taken to private recycling plants. Minato currently recycles about 30% of its recyclable materials and the goal is to recycle 42% by 2021 [23]. Combustible waste is burned at Minato Incineration Plant; thermal energy from combustion is then used to generate electricity. [67]
Table 2: *Minato Incineration Plant data* [68]

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Heat Capacity</td>
<td>13 400</td>
<td>KJ/kg</td>
</tr>
<tr>
<td>Incineration Capacity</td>
<td>900</td>
<td>tons/day</td>
</tr>
<tr>
<td>Power Generation Capacity</td>
<td>22</td>
<td>MW</td>
</tr>
<tr>
<td>Price FY2015</td>
<td>556,2</td>
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</tr>
</thead>
<tbody>
<tr>
<td>Combustible Waste</td>
<td>574,6</td>
<td>tons/day</td>
</tr>
<tr>
<td>Electricity</td>
<td>2,5</td>
<td>MWh/day</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>393,8</td>
<td>m3/day</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outputs</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>272,3</td>
<td>MWh/day</td>
</tr>
<tr>
<td>Sold Electricity</td>
<td>169,6</td>
<td>MWh/day</td>
</tr>
<tr>
<td>CO₂ Emissions</td>
<td>253,0</td>
<td>tons/day</td>
</tr>
</tbody>
</table>

The main challenges in Minato regarding waste management is to increase the recycling rate, and use organic waste not only for heat and power generation, but also for biofuel production.

3. Key Performance Indicators

The goal of this project is to propose methods to guide the development of Minato towards becoming a sustainable city by 2040. In order to measure how well the objective is being reached, four different Key Performance Indicators (KPIs) were used. The KPIs are listed below; the first three are required by the project description and the last one is proposed by the project team. It is important to note that the KPIs are interrelated, and that the actions taken to achieve one of them is going to have an effect on the others. A detailed qualitative model per KPI is found in Appendix 11.1.

**KPI 1:** Primary Renewable Energy Fraction of 80%

**KPI 2:** Net-Zero CO₂ Emissions

**KPI 3:** Total Primary Energy Supply of less than 17,5 MWh/year.person

**KPI 4:** Public Transportation within 100% of Designed Capacity

As the three given KPIs were focused mostly on energetic and environmental aspects, it was the group’s intention to select a fourth KPI that covered the social aspect, which is also an important pillar of sustainability. In order to understand Tokyo and Minato citizens’ everyday needs, questionnaires regarding the current situation and suggestions for improvement were sent to several residents in Tokyo. The most frequent complaint was about overcrowded transportation. This problem seemed relevant to Minato, as a central ward with lots of commuters and tourists. This was
confirmed by a survey carried out in 2008 by the municipality on transportation, where around 40% of respondents felt inconvenienced with the train system, and 26% complained specifically about getting in and out of the station premises [52]. Transportation affects many people and contributes to the social environment. A well structured transportation system would contribute to a more sustainable Minato, with the possibility to improve not only the social conditions, but also environmental and economical conditions.

A table showing where Minato was standing in the model base year of 2015 regarding the accomplishment of the goals set for 2040 can be seen below.

<table>
<thead>
<tr>
<th>KPI</th>
<th>2015</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary renewable energy fraction, PRF</td>
<td>9,6%</td>
<td>80%</td>
</tr>
<tr>
<td>Net CO₂ emissions (tCO₂eq/yr)</td>
<td>7 225 637</td>
<td>0</td>
</tr>
<tr>
<td>Total primary energy supply (MWh/yr.pers)</td>
<td>69,2</td>
<td>17,5</td>
</tr>
<tr>
<td>Public transportation crowdedness factor</td>
<td>173%</td>
<td>≤ 100%</td>
</tr>
</tbody>
</table>

Primary renewable energy fraction was calculated using the equation below and the assumptions from Table 4.

\[
PRF = \frac{\text{Total Primary Renewable Electricity} + \text{Total Primary Renewable Thermal Energy}}{\text{Total Primary Electricity} + \text{Total Primary Thermal Energy}}
\]

<table>
<thead>
<tr>
<th>Technology</th>
<th>Primary energy multiplier</th>
<th>Renewable fraction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid</td>
<td>2,25</td>
<td>0,27</td>
</tr>
<tr>
<td>PV</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Wind</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Incinerator</td>
<td>2,78</td>
<td>0,76</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>1</td>
<td>0,27</td>
</tr>
</tbody>
</table>

The CO₂ emissions were calculated using the inbuilt calculation tool in HOMER Pro® and Long-range Energy Alternatives Planning System (LEAP), accounting for the emissions from both direct and indirect fuel usage within the sector of transport, buildings, and industry. Total primary energy per person was calculated using the assumptions stated in Table 4 and the total energy was then divided by the assumed population for Minato by 2040. Public transport crowdedness factor were estimated based on a study carried out in 2015 on the most crowded train lines in Tokyo [69] where the actual number of people riding in rush hours are compared to the designed capacity of the
line. The current rating of crowdedness, 173%, were obtained by taking the weighted average of the lines passing through Minato - Hanzōmon, Tōkaidō and Ginza.

4. System Mapping and Modelling

Figure 28 depicts the model of Minato that was used to further develop and measure these indicators. Entities representing energy resources, waste products, transportation means, and buildings are linked by arrows illustrating the flows of goods and materials, people, and information. In the middle, the people and government of Minato are represented.

![System model, defining components, boundaries and their interactions](image)

Figure 28: System model, defining components, boundaries and their interactions

The red-dotted line defines the system boundary which is not strictly linked to the physical boundary of the ward. Everything inside of it is part of the system and can be controlled. Components outside are part of the environment and cannot be controlled but do affect the system. Technologies that will be added in order to reach the objectives are shown in grey.

Quantitative models were developed based on the described qualitative system model. Models were developed using both HOMER Pro® and LEAP. LEAP was used to model changing energy trends
over the time period of 2015 to 2040. The HOMER Pro® model simulated various configurations of energy technologies for the project period of 2040 to 2065. Significant economic and technical post-processing of results was done to analyze progress towards the KPIs. Within both models three scenarios were used, which will be described further in section 5. Scenarios.

As in the qualitative model, energy inputs were treated as either outside the system or within it. Electricity from the grid was treated as an external input to the system and was treated identically within each scenario, only varying the amount of external electricity required. Electricity generated within the system included both electricity generated within Minato’s geographical boundaries as well as from remote facilities dedicated to serve Minato’s local demand. A list of the most critical assumptions used in the scenarios can be found in Appendix 11.2. [46]

5. Scenarios

Three different scenarios were created to show various possible pathways for the future. Further information and input data for each of them are found below. Inspiration for the names was found in a Japanese manga series “The Amazing 3” written by Osamu Tezuka in 1965. He is sometimes referred to as the Japanese equivalent to Walt Disney; his series have been translated to different languages and spread across the world. In the story, Earth is considered a threat to the universe and three agents from space - Pukko the duck, Bokko the rabbit, and Nokko the horse (Figure 29) - are sent there to determine if the planet should be destroyed [70]. The personality of the agents, along with their heights, is analogous for the different scenarios and how far they will reach from today. A list of the critical assumptions of each scenario can be found in Appendix 11.2.

![Figure 29: Pukko, Bokko, and Nokko, respectively](image)

5.1 Pukko, the duck

Pukko, the duck, is the character who is most willing to destroy the earth and is often in conflict with the others. This scenario was created to show what the future in Minato would look like, if energy trends continue as today. Based on the current state, mentality, and priorities of today, values were extrapolated to 2040 using an annual growth of 0.89%, that corresponds to the
population growth. By 2030 Japan plans with reasonable certainty to reach a new energy mix in the electricity grid. Once achieved in 2030 this grid mix was kept constant for the remainder of the scenario as well as in all other scenarios. Pukko, the duck, served as a rough baseline with which the following scenarios were compared.

5.2 Bokko, the rabbit

Bokko, the rabbit, loves humans and sees no need to destroy the earth. This scenario shows what the future would look like if Minato achieves the existing policies and goals of Japan and Tokyo, amongst others found in the following documents: The Long-Term Vision for Tokyo, Tokyo Environmental Master Plan, Long-term Energy Supply and Demand Outlook, Tokyo Action Plan for 2020. Any policies that were deemed to be reasonably certain for implementation were included, however no further extrapolation on these goals were made. Major changes include improvements in lighting and building energy use, while introducing more energy efficient transportation methods, including hydrogen based transportation.

5.3 Nokko, the horse

Nokko, the horse, is a character who is speedy, tough and capable of creating inventions incredibly quickly; he wants to save the earth. This scenario was developed to show what improvements should be made to existing policies and goals in order to achieve a sustainable city in 2040. Table 5 illustrates the various changes in behavior, proposed measures, and their rough timeline for implementation along with what KPI they affect.
<table>
<thead>
<tr>
<th>Proposals</th>
<th>KPIs</th>
<th>Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV: rooftops + parking + on top of railway station &amp; the tracks</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Wind: onshore</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Hybridization of Hydrogen generation: Solar and Wind to produce H2</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Battery storage</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Carbon capture technologies</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen-based transportation</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Electric-based transportation</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>ICT, Self-driven &amp; optimized transportation</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Work from home</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Drones (transportation of goods and/or people)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Multi-use buildings (residential, commercial, entertainment)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Electrified lane for charging up vehicle while driving</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Less privately owned vehicles, focusing on sharing (“car-pool”, bicycles)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Larger bike lanes and sidewalks</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Built Environment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More green areas &amp; vertical gardens</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Rooftops with gardens &amp; beehives</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Increase LED lighting to 100% and tax incandescent bulbs</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>External shading to minimize incoming radiation/heat</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Better insulation</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Demand controlled ventilation in commercial buildings</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Heat pumps</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>ICT for buildings</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Thermal storage</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Efficiency of electrical appliances</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Free cooling in commercial buildings</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Ventilation energy recovery</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Lighting dimmers (daylight use)</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Specific policy and development recommendations for Nokko, the horse, include:

**Minato Government, Ministry of the Health, Labor, and Welfare**
- Companies must incorporate work from home programs, or remote/virtual office technologies to minimize commuter traffic and energy
- Promotion of office sharing

**Tokyo Metropolitan Government, Ministry of Land, Infrastructure, Transport, and Tourism**
- All new passenger cars sold after 2030 must be hydrogen or electric

**Tokyo Metropolitan Government, Urban Infrastructure**
- All new buildings should incorporate the prescribed systems and their lifetime should be extended to 60 years or more, with structural design that is more resilient, due to the use of higher quality materials and construction techniques
- All buildings, 20 years old or younger in 2018 should be retrofitted to reach energy performance equivalent to new buildings and their lifetime should be extended by at least 20 years
- Major roads in Minato should incorporate wider bicycle lanes and be narrowed for passenger car traffic while maintaining dedicated bus or tram lanes
- Bicycle and car sharing programs should be implemented, to reduce the number of vehicles
- Implementation of a tax on privately owned vehicles during rush hour

**Tokyo Metropolitan Government, Ministry of Foreign Affairs**
- Embassies located in Minato will be encouraged to embody the “Sustainable Minato” spirit by upgrading to the latest energy saving measures using ICT and incorporating PV on rooftops

Specific stakeholders impacted by these policies will be the Tokyo and Minato government, transportation related industries, building construction enterprises, private utility companies, building owners and users, and many of the citizens of Minato. Nearly everyone in Minato will experience the positive changes that these measures will bring, such as a more pleasant living and working environment, more efficient energy usage and higher energy security. Multinational companies will continue to be drawn to the area and the contributions of foreign embassies will demonstrate to the world that Minato is on the forefront of energy innovation.

Carbon capture and storage (CCS) technologies should be implemented within and outside of the ward, including planting vegetation with high carbon fixation throughout the Fukushima wind farm, and the use of microalgae, which can achieve efficiencies almost 10 times higher than terrestrial plants. Regarding the proposed energy generation system, the Minato/Tokyo government could open tenures so that private utility companies can build the necessary capacity. This system would be composed of:
- 3195 MW (426 x 7.5 MW turbines) of wind turbines installed in three phases (with turbines coming into operation in 2025, 2030, and 2035) along the coast of Fukushima prefecture (37°N, 141°E), revitalizing the area affected by the tsunami and the ensuing nuclear accident which made land unusable for agriculture.

- 456 MW of solar PV installed on the rooftops in Minato and a remote site in Okayama prefecture (35°N, 134°E), in three phases (in 2027, 2032, and 2037).

5.3.1 Proposed Energy System Greenfield Analysis for Nokko, the horse

As previously mentioned, the final energy system proposed for Nokko, the horse, encompasses both new installations of onshore wind and solar energy. The following wind and solar profiles demonstrate that in each of the chosen locations (Okayama, for solar, and Fukushima, for wind), the required natural resources are sufficient. The resources of these places were used in HOMER Pro®’s simulations.

![Global Horizontal Irradiation for Japan and onshore wind power potential in Japan](image)

Figure 30: Global Horizontal Irradiation for Japan [71] and onshore wind power potential in Japan [72]

The Fukushima prefecture was home of a nuclear plant of significant capacity, that because of its unfortunate accident is no longer in use. However, because of that nuclear plant, the region is connected to Tokyo by a 500 kV transmission line. Okayama is also already connected to Tokyo by a similar capacity transmission line. Although the energy transmission and distribution lines’ costs and losses were not considered in this modelling, the proximity to the transmission system is a determining factor in the feasibility of a project. Additionally, both areas are not home to any national parks or nature conservation areas. This means that the power plants in those regions would not disturb protected natural environments. For Fukushima specifically, because of the previous nuclear accident, relatively few people live there, which signalizes that people’s acceptance to the
installation of the wind park will likely not be an issue as well. In fact, another consequence of the accident is that the Japanese people’s openness to and acceptance of new energy generating technologies is very big, since they are not willing to suffer again from another similar accident.

Figure 31: Map of Japanese Electricity Grid [73] and Japan’s National Parks [74]

6. Results

6.1 Economic Portfolio Analysis

Nokko, the horse, was the scenario developed keeping in mind the achievability of the proposed KPIs. That being said, this was the scenario chosen as the most probable one to happen to make Minato sustainable by 2040. Various values were inputted in HOMER Pro® so that simulations of different energy systems could be run. That yielded over 7 000 points, which were organized in the three graphs below.

Figure 32: Pareto Frontier of NPV versus System \( CO_2 \) emissions
All these points resulted in Pareto frontiers (the lower ‘barrier’ of each graph). To choose the specific final system proposed by Nokko, the horse, the Pareto frontiers of Figures 32 and 33 were used. A point along the frontier on the lowest NPV and lowest CO₂ emissions side of Figure 32 was desired, as well as one along the frontier in the lower right section of Figure 33 representing high renewable fraction and low NPV. This same positioning in the graph was the desired one for Figure 34. A position in all figures was found, analysing the marginal benefit obtained against a reasonable increase on the possible investment. To choose the final system, some iterations among the three graphs were made, checking the values for economic feasibility. The final energy system for Nokko, the horse is shown in Table 6.
Table 6: Final System Proposition for Nokko, the horse

<table>
<thead>
<tr>
<th>System Characteristic</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV</td>
<td>¥ 2,64 Trillion</td>
</tr>
<tr>
<td>CO$_2$ Emissions</td>
<td>1,0 Million Tonnes</td>
</tr>
<tr>
<td>Renewable Energy Fraction</td>
<td>59,1 %</td>
</tr>
<tr>
<td>System Efficiency</td>
<td>70,5 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy Component</th>
<th>Capacity [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid</td>
<td>9 999</td>
</tr>
<tr>
<td>PV</td>
<td>456,7</td>
</tr>
<tr>
<td>Wind</td>
<td>3 195</td>
</tr>
<tr>
<td>Battery</td>
<td>1 805</td>
</tr>
<tr>
<td>MSW Incinerator</td>
<td>22</td>
</tr>
<tr>
<td>Reformer</td>
<td>6,5</td>
</tr>
<tr>
<td>Electrolyzer</td>
<td>880</td>
</tr>
</tbody>
</table>

6.2 KPIs

6.2.1 KPI 1: Primary Renewable Energy Fraction of 80%
With this KPI’s goal in mind, scenarios were evaluated on the basis of renewable energy fraction. Figure 35 compares each scenario’s progress towards reaching this goal. Renewable energy fractions shown are based on average annual energy consumed, acknowledging that the fraction would vary daily based on weather conditions and demand.
By 2040 the average annual primary renewable energy fraction reached in each scenario, presented by the LEAP model, was 17.6% for Pukko, the duck, while Bokko, the rabbit, reached 23.1% through the installation of local rooftop PV. The construction of additional PV and a remotely located wind farm enabled Nokko, the horse, to reach a renewable energy fraction of 53.0%. These results were confirmed by the HOMER Pro® model, showing similar values, where the primary renewable fraction for each scenario was 21.9% for Pukko, the duck, 22.0% for Bokko, the rabbit, and 59.1% for Nokko, the horse. These differences can be explained by the greater detail in load curves used in HOMER Pro® for 2040, while the LEAP model focused on large scale annual trends.

6.2.2 KPI 2: Net-Zero CO₂ Emissions

The measures taken in each scenario were also compared on their ability to minimize the emissions of CO₂. Carbon capture and storage (CCS) technologies were not included in either model, so measures in the scenarios were focused on reduction of CO₂ emissions. Specific CCS technologies are suggested in the policy recommendations to counteract the calculated annual emissions. Therefore, no scenario successfully met the objective of net-zero CO₂ emissions, but steps were taken to significantly decrease emissions. Emissions considered included both direct emissions from the final point of use of a fuel, as well as indirect emissions that occurred during the transformation of energy such as a natural gas power plant. The emissions that occurred during the production of fuels, such as coal mining, petroleum processing, or hydrogen production, were not considered.
Figure 36: Total CO$_2$ emissions of Minato, direct and indirect

Emissions in 2040 in Pukko, the duck, grew with the increasing population despite the mild increase in renewable energy, reaching 6.16 million tonnes of CO$_2$. Energy saving measures and an increase in local renewable electricity generation decreased emissions in Bokko, the rabbit, to 3.61 million tonnes by 2040. The considerable reductions in building energy requirements and high penetration of renewable electricity led emissions in Nokko, the horse, to reach a minimum of 1.03 million tonnes in 2040. These values were very similar in both models, numbers above are generated from LEAP while HOMER Pro® gave Pukko, Bokko, and Nokko 5.86, 3.19 and 1.0 million tonnes, respectively.

6.2.3 KPI 3: Total Primary Energy Supply of less than 17,5 MWh/year.person

Total primary energy consumed annually per capita was also evaluated in each scenario. A challenge for Minato with regard to a metric using per capita is the large difference between day-time and full-time populations of the ward. To avoid unfairly attributing all the day-time energy used by commuters to the significantly smaller resident population an “assumed population” was used. This value considered one third of the daily inbound commuters as residents due to the approximately eight hours a day spent working in Minato.
The total primary energy used in Minato, generated by LEAP, is depicted in Figure 37. Although the overall annual energy usage increased to 39,33 million MWh in Pukko, the duck, the population increased at a similar rate as energy, keeping the per capita energy use constant around 69 MWh/yr.pers. Total energy used per capita for Minato in Bokko, the rabbit, and Nokko, the horse, is 45,1 MWh/yr.pers and 24,24 MWh/yr.pers respectively. For this KPI, the results from HOMER Pro® slightly disagree with LEAP, so due to their greater level of detail those results are presented in the table below.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Pukko, the duck</th>
<th>Bokko, the rabbit</th>
<th>Nokko, the horse</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWh/yr.pers</td>
<td>62,25</td>
<td>44,34</td>
<td>23,54</td>
<td>17,5</td>
</tr>
</tbody>
</table>

6.2.4 KPI 4: Public Transportation within 100% of Designed Capacity

The final performance criteria that was measured reflected a concern voiced by several Tokyo residents on the crowded Tokyo public transportation system. The three most crowded subway or train lines were used to estimate the crowdedness while acknowledging that the remaining Minato lines would have lower crowdedness rates. While in both Pukko, the duck, and Bokko, the rabbit, the public transportation system was increased to handle to growing population this caused an increase in energy usage, detracting from progress in other KPIs. In order to counter this,
alternatives were developed in Nokko, the horse, that reduced the number of commuters or encouraged other means of travel, leading to less crowded public transportation. Multi-use buildings that combined living, working, and recreation spaces, work from home or virtual office technologies, and increased bicycle lanes areas all contributed to the reduction in Table 8.

Table 8: Crowdedness rates of Minato public transportation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Pukko, the duck</th>
<th>Bokko, the rabbit</th>
<th>Nokko, the horse</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest crowdedness</td>
<td>173</td>
<td>173,5</td>
<td>150</td>
<td>100</td>
</tr>
</tbody>
</table>

6.3 Sensitivity Analysis

Several values were used during the modelling of the system proposed for Nokko, the horse, such as the costs of implementing wind energy, solar energy, battery storage, etc. Since every future projection for 2040 has intrinsic uncertainties, there is a risk that the values used will not be the exact ones in 2040. Therefore, a range of plausible input values for the cost of wind energy, solar energy and battery storage were modelled and resulted in the following sensitivity analysis:

Figure 38: Sensitivity Analysis for how the cost of wind energy, solar energy and battery storage impacts the system NPV of Nokko, the horse

To develop the analysis, capital expenditures of the three technologies (wind, solar and batteries) was varied from -20% to 20%, with 5% steps; obtaining the the figure above, from where it is possible to see that the variation in price of wind energy is what impacts the system’s NPV the
most. In addition, the proposed installed capacity for wind is about six times greater than solar energy. Therefore, wind installation was chosen to be analysed on the next section for its implementation in Nokko, the horse.

### 6.4 Economic Cost-Benefit Analysis

For the scenario Nokko, the horse, a total amount of 3 195 MW of onshore wind is required, which is equivalent to 426 turbines of 7.5 MW generating 8 771 407 MWh/year. The values considered for the economic calculations are presented below, and the assumptions can be found in Appendix 11.2 Table of Assumptions. Since this project needs to be economically attractive for commercial actors, like utility companies, a discount rate of 7% was used. This rate was considered to already include the inflation rate of 2%. For the following calculation purposes, it is assumed that the full wind power capacity will be installed together.

#### Table 9: Parameters used in the Economic Cost-Benefit Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Amount</th>
<th>Present Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>i  Nominal discount rate</td>
<td>7%</td>
<td>-</td>
</tr>
<tr>
<td>n  Lifetime</td>
<td>25 years</td>
<td>-</td>
</tr>
<tr>
<td>B  Annual benefit</td>
<td>¥ 108 600 982 919 / year</td>
<td>¥ 1 265 590 587 684</td>
</tr>
<tr>
<td>C  Annual cost</td>
<td>¥ 23 734 856 250 / year</td>
<td>¥ 276 596 121 533</td>
</tr>
<tr>
<td>C0 Initial cost</td>
<td>¥ 917 747 775 000</td>
<td>-</td>
</tr>
<tr>
<td>S  Salvage cost</td>
<td>¥ 3 984 375 593</td>
<td>¥ 46 432 252 388</td>
</tr>
</tbody>
</table>

With the values of Table 9 and considering the time value of money, the calculations for Net Present Value (NPV), Benefit to Cost Ratio (BCR), Discounted Payback Period (DPP) and Internal Rate of Return (IRR) were made.

\[
NPV = (B - C)[(1 + i)^n - 1/(i \cdot (1 + i)^n)] - C0 + S/(1 + i)^n
\]

\[
NPV = (108 600 982 919 - 23 734 856 250)[((1 + 0.07)^{25} - 1)/(0.07 \cdot (1 + 0.07)^{25})] - 917 747 775 000 + 3 984 375 593/(1 + 0.07)^{25} = ¥ 71 980 809 076
\]

The NPV represents the difference between the present amount of cash inflows and the present amount of cash outflows over the lifetime of the technology [75]. If NPV is a positive number, it indicates that the investment is a good opportunity, since the cash inflows are greater than the outflows. In this case, the wind power’s NPV is ¥ 71 980 809 076, which means it is a good investment.
\[ BCR = \frac{\text{present value of } B}{\text{(present value of } C + C_0 - \text{present value of } S)} \]
\[ BCR = \frac{1 265 590 587 684/(276 596 121 533 + 917 747 775 000 - 46 432 252 388)}{1,10} \]

The BCR identifies the relationship between a project’s costs and benefits, and is calculated dividing the discounted amount of benefits by the total discounted value of costs [76]. Therefore, if the BCR is greater than one, it means that the NPV of benefits outweigh the NPV of costs, and the project is an attractive investment. The wind power capacity suggested for Nokko, the horse, has a BCR of 1,10.

\[ DPP = \frac{\ln (B - C) - \ln ((B - C) - i \times C_0)}{\ln (1 + i)} \]
\[ DPP = \frac{\ln(108 600 982 919 - 23 734 856 250) - \ln((108 600 982 919 - 23 734 856 250) - 0,07 \times 917 747 775 000)}{\ln(1 + 0,07)} = 20,9 \]

The DPP determines the profitability of a project and gives the number of years necessary to break even from investing the initial expenditure, by discounting future cash flows, with the appropriate time value of money [77]. Of course different investors may have different thresholds for acceptable DPP, but as a rule of thumb, if the DPP is smaller than the total lifetime of the project, the investment is good to be made. In this case, the DPP is 20,9 years and the lifetime is 25 years, which means again that the project is a good investment option.

Therefore, the proposed wind system has a positive NPV, a BCR greater than one and a DPP smaller than its lifetime. All these parameters indicate that the project is a good investment opportunity. Lastly, the Internal Rate of Return (IRR) is the discount rate that makes the NPV equal to zero, that is, that makes the present value of the project’s costs equal to the present worth of the project’s benefits [78]. So, for the IRR calculations, the value of \( i \) was changed in the NPV formula until NPV was zero, which happens when \( i \) is 7,85\%, which is the project’s IRR. This must be compared to the average value of Marginal Annual Rate of Return (MARR) of projects that the utility company that will install the wind park is used to having on its investments. If the IRR is greater than this company’s MARR, then the investment is attractive.

For the previous calculations, the simplification that the wind park will be built at once was made. However, as mentioned before, the renewable energy system of Nokko, the horse, is comprised of new installations of wind and solar energy of 3 195 and 457 MW, respectively. As thorough analysis and search for investments are required for such a significant construction, the proposed solution is to implement these new installations in 6 steps. In 2025, 2030 and 2035, 1 065 MW of wind energy should be finished (by those years), and in 2027, 2032 and 2037 152 MW of solar is advised to be constructed (by those years). Additionally, it was considered that as soon as construction of one wind/solar farm was done, this park could start selling energy to the grid at current electricity prices.

A basic cumulative discounted cash flow was made to illustrate this stepwise implementation. A discounted cash flow analysis uses future free cash flow projections and discounts them to arrive at
a present value [79]. The cash flow for this plan is described below, considering capital expenditures, operating expenditures and energy sales, all brought to present values.

![Cumulative Discounted Cash Flow](image)

**Figure 39:** Cumulative cash flow for Nokko, the horse, for wind and solar technologies, and the sum of both

It is worth mentioning that the energy generated by wind is much greater than from solar energy because their installed capacities differ significantly. Because of that, and because wind starts to be built before solar energy power plants, the incoming cash flow from wind is much greater than from solar. Since all amounts were brought to present value, they can be added. It’s possible to see that by 2040, the overall cash flow will be positive, which is again attractive for an investor. In addition, the accumulated earnings from solar will surpass its accumulated costs by the end of its lifetime, although it is not shown in the graph.

Sometimes, the benefits (parameter B) cannot be translated into qualitative terms. One example of this is the pollution that will not be emitted by the installation of wind and solar, since they are substituting electricity from the national grid, which is highly based on natural gas and coal power plants. Thus, the benefits of a more healthy population and possible decreased health investments from the government were not considered. Another example is that by installing those two renewable technologies, energy security increases and Minato is less exposed to fuel price variation risks. In the previous calculations, the two mentioned benefits were considered externalities, which are intrinsic to any economic analysis. Therefore, these two externalities’ qualitative values were not considered in the economic cost-benefit calculations.
6.5 Business Model Innovation

The largest energy consuming sector in Minato are the commercial buildings, such as offices and embassies. Therefore, a change in this sector is crucial to reduce the ward’s demand for energy. Below follows a proposal of a business model that is believed to make a significant change and help the ward to reach the KPIs and contribute in making Tokyo a sustainable city.

The proposed business is to have a smart, ICT-controlled system in buildings to control and optimize their energy consumption. This will be done by installing motion, temperature, CO₂, and light sensors coupled with a cutting-edge software which regulates the buildings heating, cooling, ventilation and lightning systems according to temperature, available daylight, thermal resources and occupants. The system will amongst other have automatic shading system of windows, demand controlled ventilation and lightning. It will also have a controlled thermal storage along with connection and communication with surrounding buildings to exchange excess thermal and electrical energy to optimize the usage of available energy. This system will optimize the building’s energy consumption, take advantage of the free available energy, and reduce the energy demand, thus contributing towards reaching KPIs 2 and 3.

![Business Model Canvas](https://www.businessmodelgeneration.com)

**Figure 40:** Business Model Canvas for an ICT-controlled system in buildings
The product is suitable for a large but niche market consisting of the owners of commercial buildings, both public and private. The customer could also be a private owner of a residential building, but that is not the prioritized customer for this product.

The offer is a complete service, including delivery, installation, updates, maintenance, and taylormade solutions for the costumer. The foremost value proposition is energy and cost savings along with a simple and convenient solution. The product also provides the customers a CO₂ reduction system that will help them get below the Cap and Trade limit and also give their users an improved indoor climate.

The dominating channel type that will be used is direct sales force. An ideal channel to create awareness would be a large conference or fair about sustainable energy usage. This can be complemented by online collaboration and idea-sharing sites regarding buildings. The aim is to provide a long-term relationship with the customers based on a dedicated and personal assistance. An important channel type is therefore the company's own web page where customers can evaluate the product, talk to each other and contact the support for help. The primary revenue stream is the monthly subscription fee that the customers are paying for the service. A monthly bill is considered to be the most suitable for the customers, since they are currently paying bills for the building operating costs on a monthly basis. The pricing mechanism is based on a fixed menu pricing with a combination of list- and volume dependent prices.

The most important key resource is intellectual, since the product is based on a complex software that needs continuous updates. Human resources are crucial for doing those updates and developing the product, as well as installing and maintaining it. Physical resources are also playing a part since equipment such as sensors and controllers are needed along with servers. The major key activity is problem solving due to the customer relationship and the fact that each building and its needs are unique, resulting in individual customer problems. The business is relying on a buyer-supplier relationship as well as acquisition of particular resources for the supply of required equipment, such as sensors.

The cost structure is value-driven and focuses on providing a taylormade smart solution for each customer that will reduce the buildings’ energy demand. There is no single characteristic that fits the cost structure, but rather a mix of them all, with salaries as fixed cost and physical equipment and servers as economies of scale.

The product can also be used as a marketing tool for a sustainable image - perfect for the central ward in the heart of Tokyo, with lots of tourists, embassies, and companies. It is thus believed that these customers are willing to pay for this service and make an effort in reducing their energy demand. They have a strong incentive of taking the lead towards sustainable energy use and are therefore willing to invest in a new product to contribute and promote themselves as a “green-building”.

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7. Discussions

The four KPIs have been a clear and consistent way of measuring the different scenarios outputs, thus allowing for a fair comparison. Despite their positive aspects, there are some uncertainties regarding the calculations behind each KPI. KPI 1, aiming towards 80% renewable energy, is based on a constant grid mix of 27% renewables. This automatically forces the ward, or a private investor to make its own investments, which might not be the most realistic and economically beneficial solution. A proposal could be to make national investments and further increase the renewable energy fraction of the grid. The models used in this project were not able to account for carbon capture technologies, or even account for natural absorption by vegetation, making the KPI 2, aiming towards net-zero CO₂ emissions, larger than it could have been. KPI 3, primary energy per capita, is strongly affected by the assumption regarding future population. This is also the case for KPI 4, crowedness factor. For the last KPI it is also important to remember that it focuses on the most busy hours of the day, thus showing the worst possible case. Even though the numbers are not below the desired limit of 100% in any of the scenarios, there are many hours of the day, where the crowdedness will be below the designed value.

In Pukko, the duck, business and measures continue as it has been historically done. This scenario is heavily dependent on the assumption of population growth, and most numbers are linked to the annual growth of 0,89%. When its results are compared to the KPIs goals, it’s clear that they are far from being reached. Bokko, the rabbit, indicates that Tokyo’s and Japan’s current policies are indeed in the right track, since all KPIs are closer to being reached than in Pukko, the duck. But, these policies alone are not enough and the KPIs achievement is still far from the desired values. That is why the system of Nokko, the horse, is this project’s proposal and conclusion for a sustainable Minato. For this scenario, even though the KPIs goals are not yet met, a large part of the road is covered towards a sustainable city. The renewable energy fraction increases from 9,5% to 59,1%, the total primary energy supply (per year per person) and the CO₂ emissions are reduced by 66% and 86% respectively, and the crowdedness factor is brought down from 173% to 150%, all with regards to base year 2015. If compared to the goals set by the Japanese Government for 2030, (22-24% renewables, 26% emissions reduction and 24% self-sufficiency ratio) [80] it can be seen that the values obtained for Nokko, the horse would largely exceed them.

No matter how well the model is defined, the future can never be predicted with absolute certainty and the results can only act as a guideline. The modelling is based on assumptions, thus not being a perfect description of the reality, however many sources were examined which supports the credibility of assumptions. Not all of the costs that would be associated with these changes were included. The model also did not account for the losses and costs of the transmission and distribution lines from the power plants to the final user. Threats that could make a great impact on the results, but were hard to model, are the fact that constructions can be delayed or that there can be a lack of funding. Another bad situation for this project’s development could be an unfortunate earthquake or tsunami, which may require attention and investments to be made in emergency
services. Technical feasibility of the improvements in the building sector has been based on available data, however lacking some key figures, therefore there are uncertainties of the actual efficiency improvements that can be reached.

Despite this, there are some clear strengths in the final proposed system. First, the local resources were examined to understand the potential limits, and later available sources outside the ward were examined. Most of the new energy system is made out of onshore wind, which was proven to pay back and is already an established technology in the market, which reduces its implementation risks. Although Minato’s population will increase, its energy demand is met by this proposed system. Lastly, both the HOMER Pro® and LEAP models in general agree or show similar results, like for CO₂ emissions and renewable energy fraction.

Sustainability, which relies on environmental, economical, and social pillars, is much more than reaching the KPIs. Although this project’s KPIs aimed to encompass all of these pillars, improvements can be made to Minato that can neither be modelled with the available softwares or easily quantified. Examples of this can be the circular usage of resources and vegetation/algae for carbon capture. However, these factors were still taken into account (Table 5) and are key to making Minato a truly sustainable ward.

8. Future Work

Throughout this project ideas have arisen that would widen the extent of the project and generate a more accurate and realistic model as well as results. Due to the time and modelling software limitations they haven’t been enacted in this project, however suggestions for future work are presented below.

- Include the energy losses in transmission and distribution from the PV and wind farms outside of the wards geographical boundary.
- Include other type of emissions, except CO₂, that also contributes to climate change.
- Include the energy and emissions for producing the energy carriers (petroleum products, natural gas, hydrogen) that are being used in the system.
- Consider the cost of generating, transportation and distribution infrastructure for the energy carriers.
- Examine the water resource availability and usage.
- Include economic analysis of implemented building energy efficiency measures.

9. About the Authors

The team of students working on this project comes from a wide variety of backgrounds, and its members are natives of South America, North America, and Northern Europe. This diversity has balanced cultural paradigms and led to the creation of better solutions. All group members were valuable in giving suggestions and feedback. They were also all active in gathering data, discussing
the results, and writing and reviewing the entire report and presentation. An overall group manager was not assigned, but in the beginning of every weekly meeting the goals to be achieved in that meeting and during the week were set. Responsible people were then assigned to that week’s tasks, making accountability better and the achievability of the week’s tasks more likely. The students had more focus on the following areas:

Francisco Beltran focused on analysing the industry sector and waste management, developing future projections for all scenarios. He worked a lot on gathering the necessary data, whatever support with specific numbers was asked by the colleagues.

Frida Jalkenäs’s responsibilities in this project widely extended from examination of the transport sector to searching for current policy measures in Japan and Tokyo. Frida oversaw development of the business model, and she worked heavily with result post-processing.

Juris Pomerancevs was in charge for the building sector, compiling and organizing the available information, and developing scenarios based on it. He also assisted with HOMER Pro® modelling.

Lesley Fisher developed most of the modelling on LEAP, which helped analyse the project trends and development over time, using it as a base for economic analysis. Work on result post-processing was also in her arena.

Maria Cecilia Oliveira was largely responsible for the economics analysis, conducting numerous iterations and guiding the team on economic sense of the proposal. She is also the artistic designer, with an acute attention to detail.

Weimar Mantilla’s role was broad, involving several fields of study including research on transport sector data and hydrogen potential in Japan. His primary responsibility was overseeing countless iterations of HOMER Pro® models.
10. References


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11. Appendix

11.1 KPIs System Model

**Figure 41:** Net Zero CO$_2$ Emissions

**Figure 42:** 80% Primary Renewable Energy

**Figure 43:** 17.5 MWh/(yr.pers)

**Figure 44:** Public Transport within 100% Designed Capacity
11.2 Tables of Assumptions

Table 10: Critical assumptions for Pukko, the duck

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Assumption</th>
<th>Based on Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population Growth</td>
<td>0.89% Annually</td>
<td>[56]</td>
</tr>
<tr>
<td>Assumed Population</td>
<td>Resident + 0.33* Inbound Commuters</td>
<td></td>
</tr>
<tr>
<td>Assumed Population Pukko, Bokko</td>
<td>561 522</td>
<td></td>
</tr>
<tr>
<td>Assumed Population Nokko</td>
<td>523 040</td>
<td></td>
</tr>
<tr>
<td>Annual working days</td>
<td>232</td>
<td>[81]</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growth in number of private cars</td>
<td>0.89% Annually</td>
<td></td>
</tr>
<tr>
<td>Average distance driven with a private vehicle by Minato citizen</td>
<td>Annual distance driven by a car / # of cars (Japan totals)</td>
<td></td>
</tr>
<tr>
<td>Daily train passengers</td>
<td>75% of all commuters</td>
<td>[56]</td>
</tr>
<tr>
<td>Daily tram passengers</td>
<td>8% of all commuters</td>
<td>[56]</td>
</tr>
<tr>
<td>Daily bus passengers</td>
<td>17% of all commuters</td>
<td>[56]</td>
</tr>
<tr>
<td>Peak crowdedness in Minato public trans</td>
<td>173%</td>
<td>[69]</td>
</tr>
<tr>
<td>Fossil fuel vehicles</td>
<td>98.9%</td>
<td>[56]</td>
</tr>
<tr>
<td>Electricity and hydrogen vehicles</td>
<td>1.1%</td>
<td>[82] [83]</td>
</tr>
<tr>
<td><strong>Buildings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial &amp; Residential Building Floor Area</td>
<td>Growth rate matches that of population (0.89%)</td>
<td></td>
</tr>
<tr>
<td>Refurbished buildings in 2040</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Final energy use</td>
<td>Depends on building type and function</td>
<td>[59]</td>
</tr>
<tr>
<td>Shares of energy source</td>
<td>Depends on building type and function</td>
<td>[60]</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------------------------------</td>
<td>-----</td>
</tr>
<tr>
<td>Lighting technologies</td>
<td>LED’s in 58% of buildings, rest incandescent</td>
<td>[26]</td>
</tr>
</tbody>
</table>

### Energy

<table>
<thead>
<tr>
<th>Primary renewable energy in the grid</th>
<th>27%</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&amp;D losses</td>
<td>0%</td>
</tr>
<tr>
<td>RE fraction in waste</td>
<td>76%</td>
</tr>
</tbody>
</table>

### Table y: Critical assumptions for Bokko, the rabbit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Assumption</th>
<th>Based on Source</th>
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</thead>
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<tr>
<td><strong>Transport</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen vehicles</td>
<td>8.4 %</td>
<td>[85]</td>
</tr>
<tr>
<td>Hydrogen Road Fuel Efficiency</td>
<td>0.8 Kg/100 Km</td>
<td>[86]</td>
</tr>
<tr>
<td>Fossil fuel vehicles</td>
<td>90.6 %</td>
<td></td>
</tr>
<tr>
<td>Electric vehicles</td>
<td>1.0 %</td>
<td>[87]</td>
</tr>
<tr>
<td>Transport energy efficiency</td>
<td>5% increase</td>
<td>[88]</td>
</tr>
<tr>
<td><strong>Buildings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero energy buildings</td>
<td>50% reduction in final energy use for new buildings</td>
<td>[89]</td>
</tr>
<tr>
<td>Zero energy houses</td>
<td>20% reduction in final energy use for new buildings</td>
<td>[90]</td>
</tr>
<tr>
<td>New building share in 2040</td>
<td>Residential 60% Commercial 50%</td>
<td>[56]</td>
</tr>
<tr>
<td>Lighting technologies</td>
<td>100% LED</td>
<td>[26]</td>
</tr>
<tr>
<td>Hydrogen fuel cells in homes</td>
<td>Covers 25% of heating demand Covers 30% of electricity demand</td>
<td>[85]</td>
</tr>
</tbody>
</table>
Space and water heating source in commercial sector
50% heat pumps
50% gas boilers

Cooling energy source
50% electric chillers
50% gas absorption chillers

Energy

Hydrogen production
Reformer

Reformer Efficiency
55%

Table 11: Critical assumptions for Nokko, the horse

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Assumption</th>
<th>Based on Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction of cars</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Reduction in km/car</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>More people choose public transport and ICT improves route efficiency</td>
<td>10% reduction in distance driven by citizen</td>
<td></td>
</tr>
<tr>
<td>New cars and busses from 2030</td>
<td>50% electrical, 50% hydrogen</td>
<td></td>
</tr>
<tr>
<td>Hydrogen vehicles</td>
<td>41.3%</td>
<td></td>
</tr>
<tr>
<td>Hydrogen Road Fuel Efficiency</td>
<td>0.6 Kg/100 Km</td>
<td>[86]</td>
</tr>
<tr>
<td>Electric vehicles</td>
<td>41.3%</td>
<td></td>
</tr>
<tr>
<td>Fossil fuel vehicles</td>
<td>17.5%</td>
<td></td>
</tr>
<tr>
<td>Work from home incentives, office sharing</td>
<td>15% commuter reduction</td>
<td></td>
</tr>
</tbody>
</table>

Buildings

New buildings
50%

Refurbished buildings
50%

Overall heat loss coefficient
20 - 30% heating energy reduction

[86] [91]
<table>
<thead>
<tr>
<th>Energy recovery ventilation</th>
<th>5 - 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar shadings</td>
<td>20 - 35% cooling energy reduction [92]</td>
</tr>
<tr>
<td>Demand controlled ventilation in commercial buildings</td>
<td>30% reduction energy use reduction for ventilation [93]</td>
</tr>
<tr>
<td>More efficient fans and pumps</td>
<td>15% more efficient [58]</td>
</tr>
<tr>
<td>Lighting technologies</td>
<td>100% LED</td>
</tr>
<tr>
<td>Lighting dimmers (daylight use)</td>
<td>10% lighting energy reduction [94]</td>
</tr>
<tr>
<td>Thermal storage</td>
<td>10% energy reduction</td>
</tr>
<tr>
<td>Electrical appliances</td>
<td>15% more efficient [58]</td>
</tr>
<tr>
<td>ICT´s</td>
<td>Reductions: 10% electrical appliances; 10 - 20% water heating; 10% cooling</td>
</tr>
<tr>
<td>Free cooling in commercial buildings</td>
<td>5% cooling energy reduction [95]</td>
</tr>
</tbody>
</table>
| Heating sources           | 80% heat pumps  
20% gas boilers |
| Cooling sources           | 100% electric chillers/air conditioners |

**Energy**

All hydrogen production From electrolyser, driven by electricity from the grid.

Electrolyzer Efficiency 87% [86]

**Economics**

Discount rate in HOMER Pro® 4%

Inflation rate in HOMER Pro® 2%

Discount rate for private company/utility 7%

Conversion Rate of US Dollars to Average from March 2008 to [96]
<table>
<thead>
<tr>
<th><strong>Yens</strong></th>
<th><strong>March 2018: ¥ 99,05</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wind CAPEX &amp; OPEX</strong></td>
<td>¥ 287,245/kW; ¥ 7,429/kW [97]</td>
</tr>
<tr>
<td><strong>Solar CAPEX &amp; OPEX</strong></td>
<td>¥ 435,675/kW; ¥ 5,183/kW [97]</td>
</tr>
<tr>
<td><strong>Salvage Value of Wind Turbine</strong></td>
<td>$ 94,427/turbine [98]</td>
</tr>
<tr>
<td><strong>Ratio of Energy Prices in Japan/USA</strong></td>
<td>Average proportionality of solar, wind, and CCGT prices between both countries: 2.38 [99]</td>
</tr>
<tr>
<td><strong>Price to Generate Grid Electricity</strong></td>
<td>¥ 12,381/MWh</td>
</tr>
<tr>
<td><strong>Price Consumers currently pay for electricity</strong></td>
<td>Average of the three energy charges: ¥ 25,180/MWh [100]</td>
</tr>
</tbody>
</table>
11.3 HOMER Pro® Modelling - Scenarios

Figure 45: Pukko, the duck.

Figure 46: Bokko, the rabbit.

Figure 47: Nokko, the horse.
11.4 Hydrogen load curve in residential buildings for Bokko, the rabbit

![Image of Hydrogen Residential Load Curve for 2040 (Bokko)](image)

**Figure 48:** Load curve for residential hydrogen use

11.5 Space heating and cooling demand measure implication

![Image of Heating and Cooling Demand Graph](image)

**Figure 49:** Representation of how the heating and cooling demand was reduced