Final Report

Singapore Power Adequacy Forecast (up to 2050)

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Table of Contents

1. Introduction

Electricity, a man-made resource, while does not directly sustain life like how food does, is essential to keeping people well and alive by powering the various appliances and machineries that help to make life easier and safer. Without a reliable supply of electricity, the daily routine and quality of life of the population and the nation's economy would be greatly affected.

Given the impact of electricity as a resource, there are motivations to investigate how the consumption of electricity, within a population, changes over time. Together with economic data, this may be utilized to predict the future electricity consumption of a country with the goal of investigating whether the current energy generation capacity plans are adequate for the population's future demand.

Particularly, with the idea that Singapore's population will continue to grow, and that energy consumption is heavily influenced by the population and GDP of the region, it is of our interest to find out whether existing infrastructure and current expansion plans will be able to sustain the potential rise in energy demand.

It is also interesting to consider the impact brought by COVID19 that would have affected the energy consumption pattern too. This also paves way for further simulation of investigating how the future energy consumption will vary, if there any, depending on how long the COVID19 pandemic situation will persist.

2. Objective

In this project, we aim to conduct a detailed analysis on the energy consumption pattern in Singapore based on the historical energy consumption data and understand how the consumption pattern has changed over time and ultimately test the hypothesis of whether Singapore has sufficient power generation capacity to support the population till 2050.

To do this, electricity consumption of the country will be calculated in three parts. These are household consumption, goods sector consumption, and services & transport sector consumption. For household consumption, it is assumed that the total consumption is directly related to population. As such, population, birth rate, death rate, and net migration data of Singapore will be used to forecast the future population of the country and predict the future electricity consumption for households.

For goods sector and service & transport sector, the GDP growth will be forecasted based on past GDP data. A relationship between the GDP and electricity consumption will allow us to predict the corresponding power consumption. On top of these, further trade-off analysis and sensitive analysis will also be conducted to investigate and analyze how the model performs based on variations in the parameters and the decision variables on the model, including considerations of the influence of the model and its predictions vary based on certain COVID19 pandemic.

Through all these**,** it is hoped that not only will one be able to see whether the generation capacity of Singapore will continue to be sufficient in the following years until 2050, but also will it be possible to investigate how variations in the model impact the predicted values throughout the model.

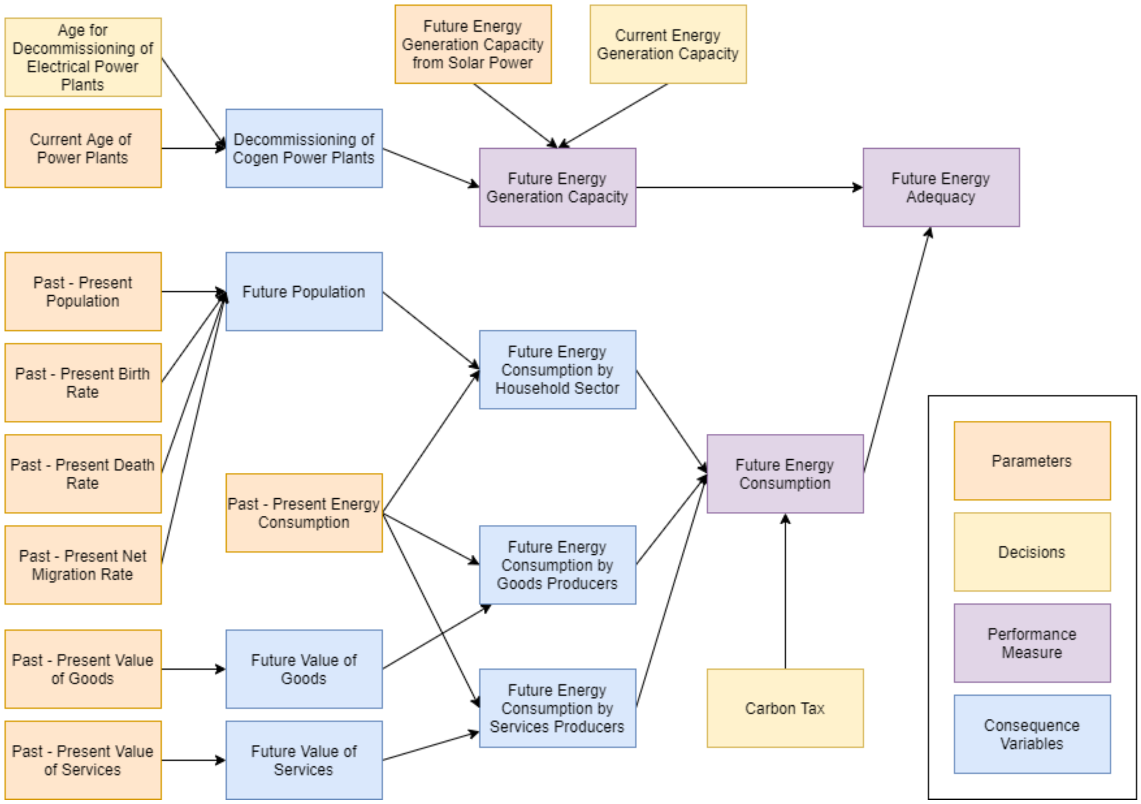
3. Data Sources

The following datasets (available in attached zip folder as well) for our Analysis:

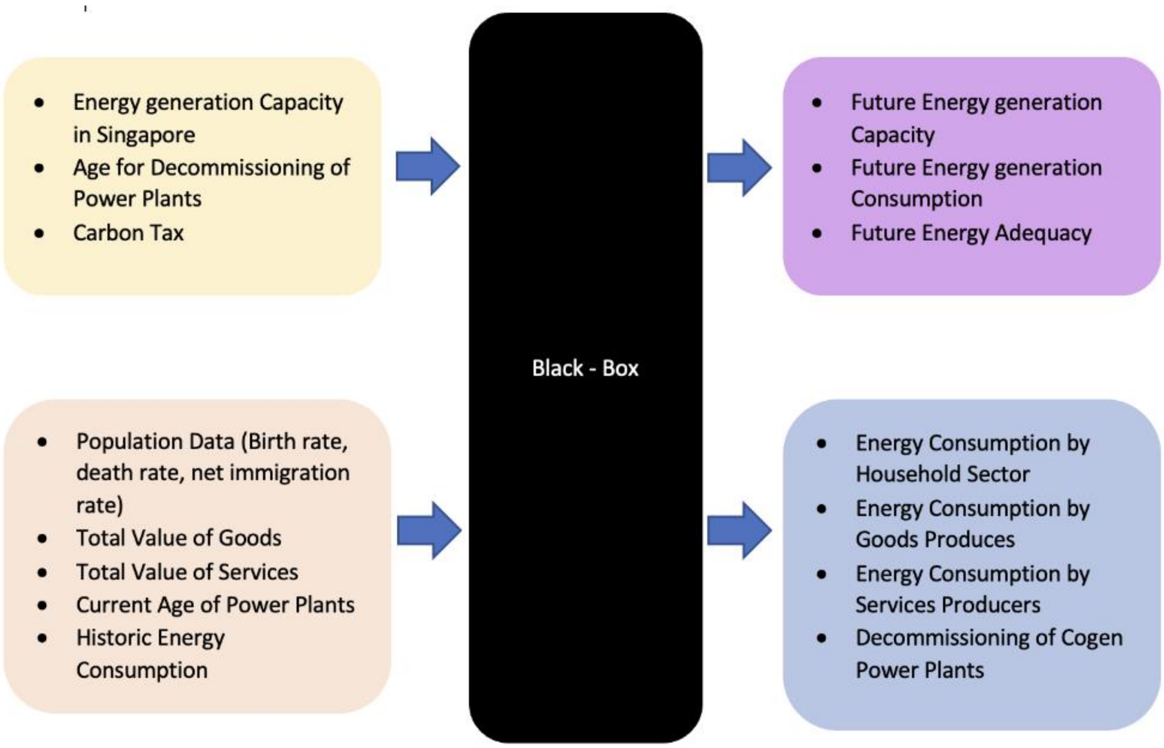
- Data of Singapore's historic energy consumption by sub-sectors (household/ manufacturing/ commercial/ transport/ others etc.) (Energy Market Authority, 2020)
- Singapore's energy sources their generation rate and available capacity (Energy Market Authority, 2021)
- Distribution of large/main power plant capacities (Energy Market Authority, 2021)
- Tariff rates applied by the government to analyze the effect of changes in tariff rate on the overall energy generation and availability (SPgroup, 2021), (Muller, 2021)
- Finland's electrical tariffs and carbon tax rates (Statista, 2021)
- Singapore population data source (MacroTrends, 2021)
- Singapore GDP data source (Worldbank, 2021)

4. Influence Diagram and Black-Box Model

4.1. Influence Diagram



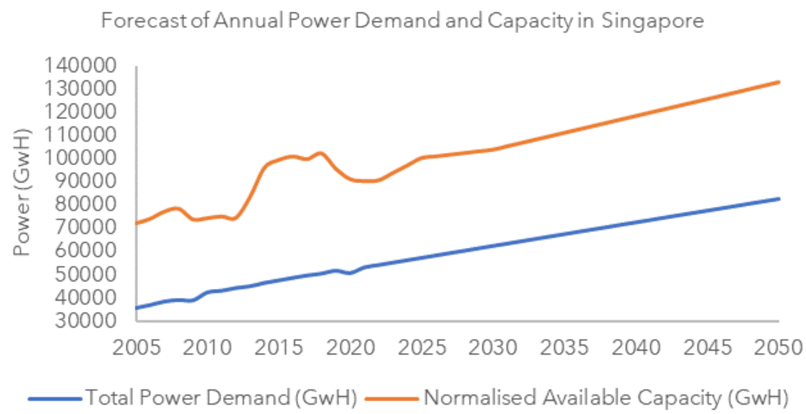
4.2. Black-Box Model



5. Model Computation

Our spreadsheet model forecasts the annual power demand and available capacity in Singapore up to the year 2050.

Total Power Demand = Power Demand (Households + Services + Goods Producers)
Available Capacity = (Current Capacity + Future expansion plans) * Availability Factor

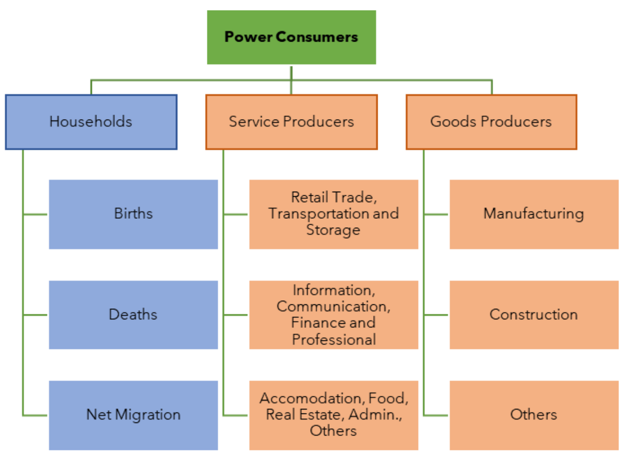


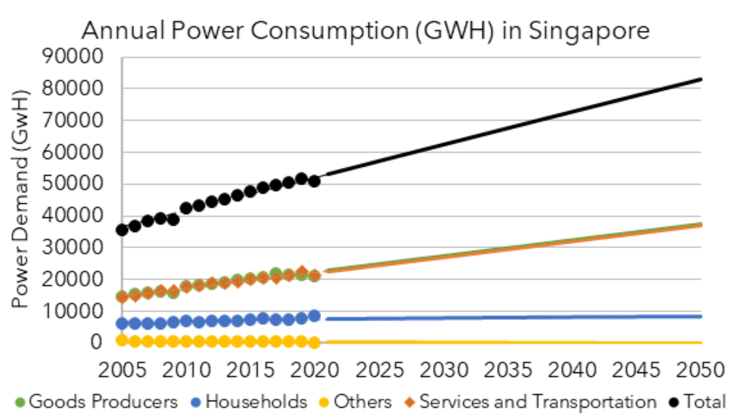
With the above formula, our model estimates:

- The demand and capacity of power for each year
- When the power plant capacities will run out

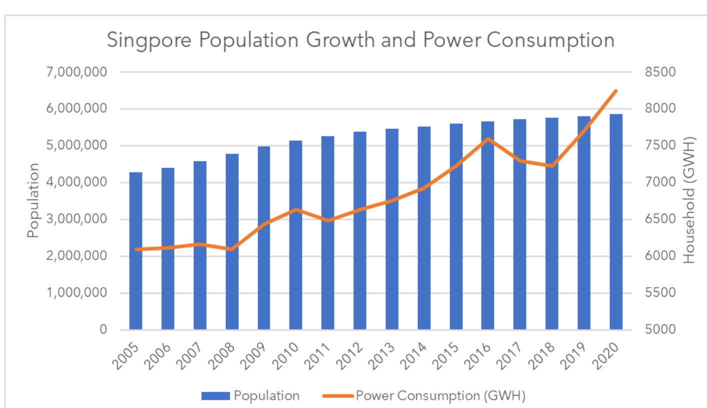
5.1. Forecast Power Demand from Consumers

The total power demand is forecasted from 3 main users – households, service providers and goods providers.





5.1.1. Households



From the graph above, with higher population growth, higher power consumption is expected. Hence, household demand was forecasted using the population growth rate in Singapore, whereby:
Net Growth = Births + Deaths + Net Migration

Birth, Death and Net rates were obtained from 2005 to 2020, and correlation was drawn based on the years as shown:

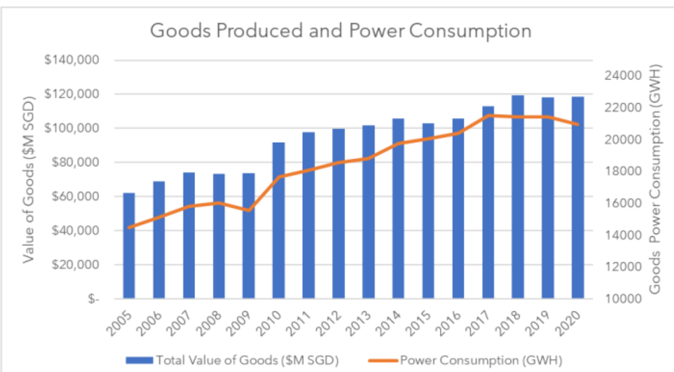
a. Forecast formula was used to predict annual birth, death and net migration rates till 2050.
   - Historic Data: Birth rate (Linear) R^2: 0.98; Death Rate (Linear) R^2: 0.70; Net migration rate (Exponential, post 2008) R^2: 0.99)

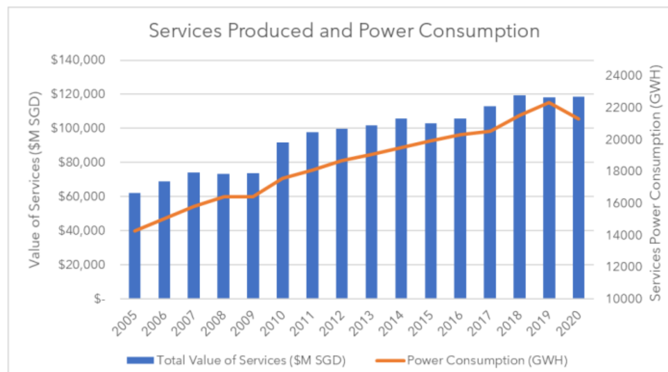
b. The annual net growth rate was computed to achieve the expected annual population

c. We were provided with data on annual household power consumption from 2005 to 2019 and used the Forecast formula to predict total power consumption in GWh from 2022 to 2050
   - 2020 data was not used in forecast due to COVID19, which will be explored as part of sensitivity analysis.

Hence, the household consumption model has allowed us to forecast the power consumption using population as the predictor variable.

5.1.2. Goods and Services Producers





From the graph above, with value of goods and services provided, higher power consumption is expected. The value of goods and services were forecasted individually via the following formula:

Value of Services = (Retail, Transportation, Storage) + (Info-comm, Finance, Professional)
+ (Accommodation, Food, Real Estate, Administrative, Others)
Value of Goods = Manufacturing + Construction + Others (Utilities, Agriculture etc.)

Individual components of the goods and services values were extracted from GDP data obtained from 2005 to 2020, to predict the future value of goods and services, and hence forecast the power consumption as shown:

<u>Goods Model</u>

a. Forecast formula was used to predict the values of the manufacturing and construction sector till 2050.
   - Historic Data: Manufacturing (Linear) R^2: 0.92; Construction (Linear) R^2: 0.87; Others (Linear) R^2: 0.92

b. The values from the sectors were summed up to achieve the predicted value of Goods produced.

c. Using data of annual power consumption of Goods producers from 2005 to 2019, forecast formula was used to predict total power consumption in GWh from 2022 to 2050.
   - 2020 data was not used in forecast due to COVID19, which will be explored as part of sensitivity analysis.

d. Hence, the Goods consumption model has allowed us to forecast the power consumption using Value of Goods as the predictor variable.

<u>Services Model</u>

a. Forecast formula was used to predict the values of the several Services sector till 2050.
   - Historic Data: Retail, Transport, Storage (Linear) R^2: 0.88; Info-comm, Finance, Professional (Linear) R^2: 0.99; Accommodation, Food, Real Estate, Administrative, Others (Linear) R^2: 0.88

b. The values from the sectors were summed up to achieve the predicted value of Services produced.

c. Using data of annual power consumption of Service producers from 2005 to 2019, forecast formula was used to predict total power consumption in GWh from 2022 to 2050.

- 2020 data was not used in forecast due to COVID19, which will be explored as part of sensitivity analysis.

d. Hence, the Services consumption model has allowed us to forecast the power consumption using Value of Services as the predictor variable.

5.2. Forecast Available Capacity of Power Sources

Power generation in Singapore consists of several technologies – Co-generation, Steam/Gas turbines, Waste-to-energy incineration, and Solar Photovoltaic Systems. Majority of power is produced by co-gen power plants, with the main source of fuel as natural gas.

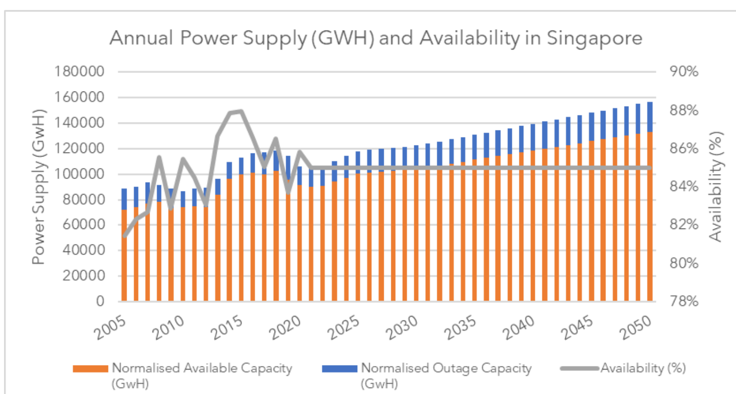
Future plans for energy transition mainly involve Solar, which seems to be the most promising renewable energy source for Singapore. Based on the Singapore Green Plan, Singapore Solar target is 1.5GWp by 2025 and 2.0GWp by 2030 (SG Press Centre, 2021). In the recent Singapore International Energy Week, future plans include importing of 4.0GWp of energy from Solar farms in 2035 (Tan, 2021). For simplicity, a gradual implementation of Solar plants was assumed, and implementation targets were computed as follows:

From	To	Incremental Target (MW)	Average Rate (GW/yr)
2018	2021	182	0.046
2022	2025	1318	0.439
2025	2030	500	0.100
2030	2050	4000	0.200

The lifespan and decommissioning of old power plants reducing total capacity will be explored in the sensitivity analysis due to deviations between guidelines and actual data.

The availability capacity model was then computed as follows:

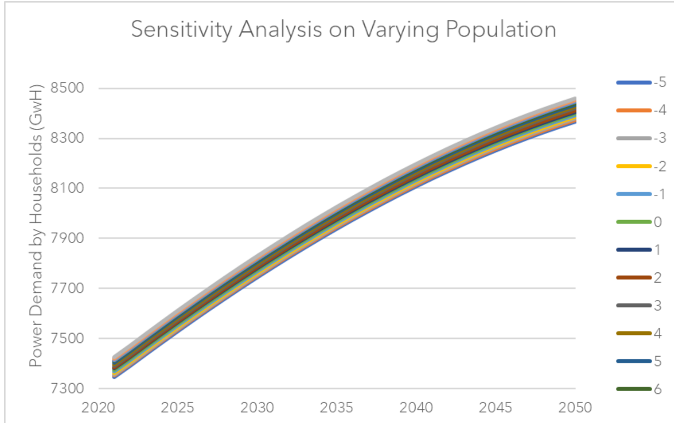
a. Monthly available capacity (MW) and outage capacity (MW) from 2005 to 2020 were extracted
b. Monthly values were multiplied by hours per month to compute the monthly capacity/outage in MWh
c. MWh data was summarized and summed up via pivot table to get the annual capacity and outage
d. The annual total capacity was computed whereby Total = Available + Outage capacities
e. The annual availability was computed whereby Availability = Available/Total capacities
f. Annual incremental Solar targets were added to predict the Total capacity after 2020
g. Average availability of 85% was applied to predict the Available capacity post 2020
h. Normalization factor was applied to ensure consistency across various analysis, as data extracted from different sources have varying total capacities (<1.0% difference)



6. Sensitivity Analysis

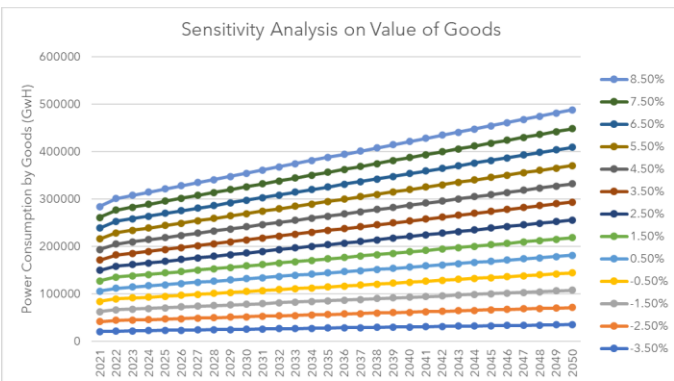
6.1. Incorrect population prediction

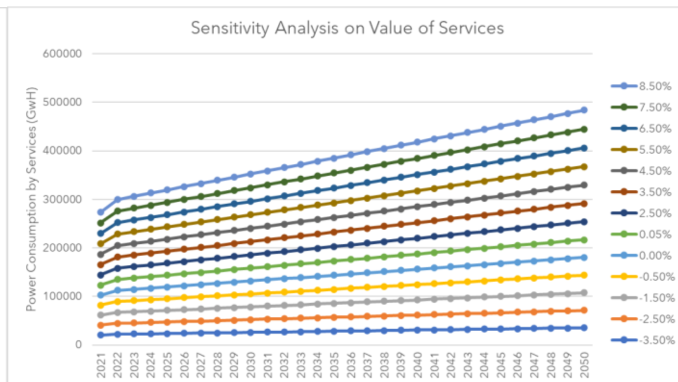
As part of investigating how the model is impacted by changes in the population prediction (based on incorrect prediction of growth rate), a sensitivity analysis is done across varying growth rates.



From the chart above, initial observation may seem like higher growth rate only results to higher consumption, regardless of what the year is or the expected population. However, closer look into it reveals that the range of values for the forecast in 2021 is narrower than those in 2050. As such, it may be inferred how the model seems more robust for closer predictions (2021-2030) than future ones. In the same way, for lower population values, the model also tends to vary less. This can be related to how the varying growth rate will result into population change directly influenced by the population number. In other words, total household electrical consumption becomes more sensitive to population growth rate in later years when population size increases.

6.2. Incorrect estimation of goods and services





A sensitivity analysis is performed to analyze the impact of changing value growth rate on the Electricity consumption for our model. The analysis is performed separately for the Goods model and the Services model. The Goods Model consists of value contributions by manufacturing, construction, and goods from agricultural industries. As the growth rate varies from -3.5% to 8.5% in with a step size of one, we observe that the influence becomes more pronounced as we proceed towards 2050. In the initial years the observed impact is less. Also, as the growth rate increases the slope for the electricity consumption increases.

The Services Model consists of contributions by Trade and Transportation, Information & Communications and Financial Services, and Accommodation & Food Services and Real Estate. With a varying growth rate from -3.5% to 8.5%, we observe that the effect of GDP becomes more pronounced as we proceed towards 2050. In the initial years the observed impact is less. The consumption for the year 2050 with -3.5% rate would be ~35000 GWh as opposed to ~39000 GWh for a higher 8.5% rate for the same year.

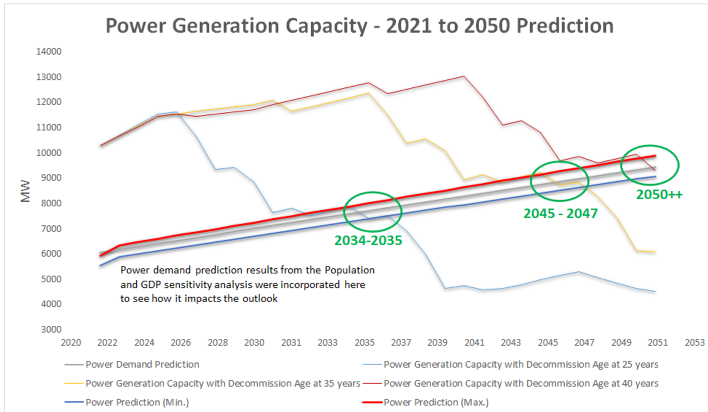
6.3. Decommissioning of power plants

With ~50% of our power plants built more than 15 years ago, we should be expecting a loss of power generation capacity over the next decade (typical lifespan is ~25 years).

Having said that, there is no definitive rule to the working age of a power plant as there are factors influencing how much longer the power plant will be run, be it economic or safety reasons which are to be determined by the power plants' business stakeholders. With proper maintenance and operations, or even upgrades, the plant can run well beyond 25 years. On the flip side, if the operating cost and/or capital cost exceeds the returns, the plant could be shut down for good. Regardless, the case of the loss of power generation capacity is realistic.

For the analysis, some assumptions were made:

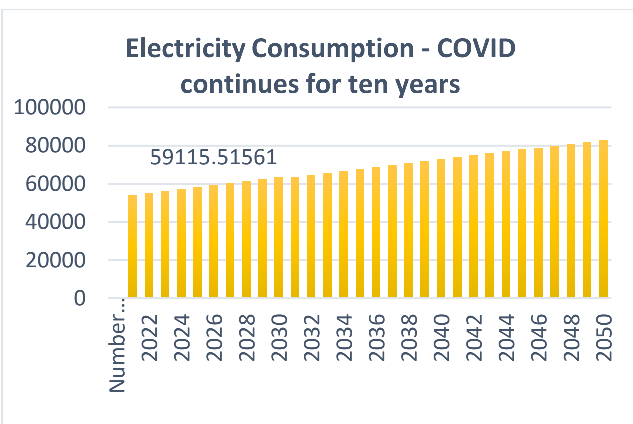
- Incineration type power plant were excluded from decommissioning
- Their purpose is for waste incineration, with heat recovery for power generation as secondary purpose
- Power plants will be decommissioned upon a set targets of operating years (age)

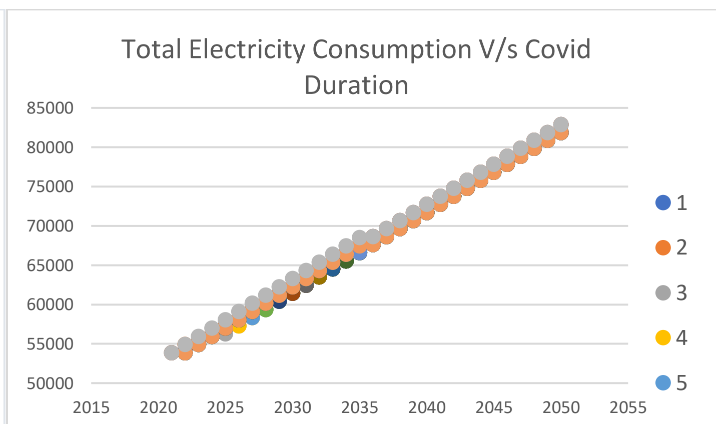


From the analysis, it appears that Singapore may meet a crunch in power supply in Year 2045 onwards (assuming decommissioning age of 35 years). If nothing were to be done, there is a strong likelihood that the price of electricity will go up significantly and thus will affect the population's quality of life. Potentially it would also hurt Singapore's GDP growth as businesses would not be able to operate efficiently due to rising operating cost.

With that, the potential consequences do reflect the current Government plans and actions to establish alternate power sources, from importing power from other countries, like Malaysia, Indonesia, Laos and Australia, to even exploring feasibility of building a nuclear power plant.

6.4. COVID19 Lasts for Certain Number of Years





Here we analyze the impact of the duration of covid on the yearly consumption. (Marking value for both for the year 2026) The electricity consumption for the Year 2026 is forecasted to be ~58000 GWh if the effects of COVID19 were to continue for five years while the forecasted consumption for that same year would be ~59000 GWh if COVID19 were to continue for ten years.

From the individual COVID19 electricity consumption prediction, we can infer that the electricity consumption the Household Model as well as well as the Services Model increases during COVID19 as more people work from home and as the services continue to operate. A decrease in electricity consumption is observed for the Goods Model as the manufacturing and construction services decreased their manpower and operational units during COVID19.

As the duration of pandemic increases from 1 year to 5 years, the total electricity consumption increases much more as the increase in value for household and services dominates the decrease in consumption in the Goods Model, during the years significantly impacted by COVID19. The table below shows the total electricity consumption based on the number of years COVID19 continues. Calculation in model has been done up to 15 years.

7. Trade-off Analysis

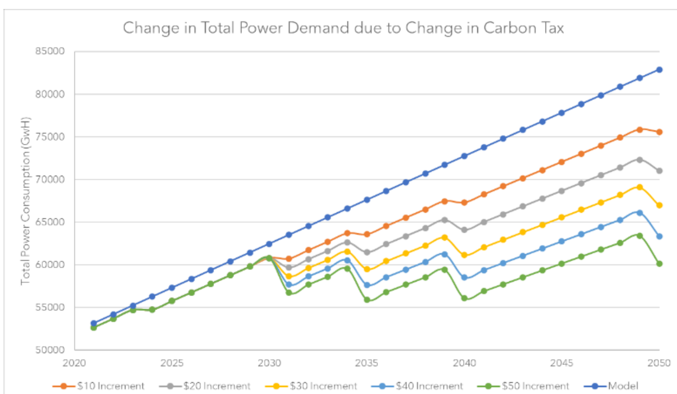
7.1. Impact of Carbon Tax

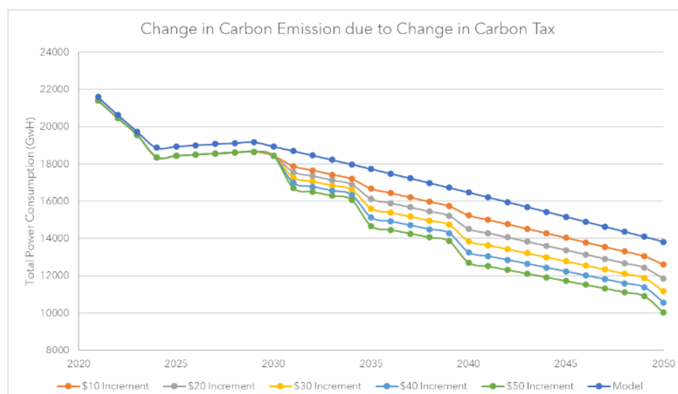
Current carbon tax is set at S$5 per ton CO2 equivalent (tCO2e), and only taxable to facilities emitting more than 25000 tCO2 annually. The trajectory of Singapore's carbon tax is set to be reviewed in 2022, with plans to increase it between S$10 – S$15/tCO2e by 2030. This cost is likely to be passed to consumers, resulting in higher electricity cost. At the same time, Singapore's plan for energy transition mainly involves Solar, which will reduce the CO2 emission rate per kWh energy produced.

The following assumptions into consideration while analyzing the impact of carbon taxes on the electricity consumption pattern:

- Solar energy implementation as per base model
- Carbon tax from 2024 - 2030 to be assumed as $15/tCO$_2$e, maximum rate based on news articles ($10-$15/tCO$_2$e), with gradual adjustment every 5-yearly.
- Average tariff rates used for households and industries, across different providers.
- For simplicity, the electricity tariff rates assume a small increment of 0.02% per year instead of LNG market rates due to the complexity LNG price prediction.
- Referencing from Finland's power tariffs post carbon tax implementation, assume 5% of tax cost to be transferred to consumers.
- 80% of power producers emit more than 25000T GHG annually
- Consumers' consumption pattern changes with respect to hikes in carbon tax:

Total Electrical Cost (without carbon tax) = Revised Cost + Carbon Tax





Our analysis depicts different scenarios with different increments in carbon taxes in future as shown above. The analysis shows that power consumption lowers over the years as carbon tax pricing rises, though this analysis is largely influenced by the assumption that consumers do reduce their consumption accordingly. Consequently, so are the carbon emissions across the years.

Based on outcomes from other countries which have implemented Carbon Tax with similar pricing to Singapore (eg. Japan), the overall consumption did not reduce, likely due to the small incremental cost to users by ~1 to 2% for a S$5 to $15/tCO2e carbon tax, which is akin to a slap on the wrist. For a better analysis, more data needs to be collected post implementation of higher levels of carbon tax.

8. Results

Based on the various models established, Singapore should not be facing inadequate power supply within the next 10 years even with the expected growth in population and GDP.

However, the reality of decommissioning power generation plants could send Singapore into an energy crisis if left unattended. This is in line with Government's effort to encourage local industries to generate/consume electricity more efficiently thru project funding and highlights the current urgency in Government's plan and actions to seek out alternate sources of electricity (e.g. solar farms, power import from like Malaysia, Indonesia, Laos and Australia, tender for new power plants and even feasibility study on nuclear power plant).

Although the model does not infer an immediate concern, various uncontrollable factors could change the outcome significantly. The power consumption pattern due to COVID-19 may also change depending on how the pandemic plays out. While it is currently deemed to be more stable, there is still a potential of an immediate escalation if a more dangerous virus variant were to be unleashed. With Singapore's pipeline natural contract expiring, future fuel price (natural gas) would be largely influenced by market demands and knowing it is on the rise, this could potentially skyrocket the electricity tariff.

Electricity supply to consumers is contractual in nature, hence if the fuel price skyrocketed (leading to a rise in operation costs for power generation plants), there is a potential risk that these companies will have to bear the cost and may shutdown to cut losses (as they are unable to pass the additional cost to consumers until next contractual terms), unless they have a healthy cashflow or if government intervenes with monetary aid.

9. Improvements and Recommendations

Although the resulting model is sufficient for the main objective, there are different ways further analyses and research can be done to improve said model. The first of which is to consider other variables that may impact energy consumption. An example may be further consideration of the electrical tariffs in Singapore that may influence the consumption of the population. Another possible area for improvement would be the COVID-19 assumptions and analyses the model considered. Since COVID-19 has only been around for less than 2 years, there isn't much data now with regards to how the pandemic has impacted the electrical consumption in Singapore. Considering additional COVID-19 electrical consumption data once available may more clearly depict the influence of the pandemic as well as whether this seems to last in the long term.

Aside from these, other factors can be considered in the model as well. For example, with the rise in popularity of solar power, solar power energy can be better incorporated in the model if more data can be gathered regarding the implementation plans and its growth. Finally, in general, it was made evident through the various analyses conducted that it seems inevitable how incorrect values or errors tend to propagate throughout the years the model is predicting for. Even though this may be inherent for most forecasting models, further research can be done to formulate ways of limiting the propagation of these errors and in turn, make the model more robust overall.

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