Modelling and Analysis of Singapore Electricity Market towards Future Scenarios with Higher Solar Penetration and Fluctuated Natural Gas Price

Group 12

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1. Introduction

In this chapter, the electricity market of Singapore will be presented in a brief overview. Section 1.1 will discuss the market itself, section 1.2 will detail the future plans for the market and finally, in section 1.3, the research question will be formulated.

1.1 Market Overview

The island nation of Singapore has been managing its electricity and gas since 1963, and subsequently liberalized its markets 30 years later. In 2001 the national government set up the Energy Market Authority (EMA) to oversee the further liberalisation of the market as the regulating authority. [1]

From the establishment of the EMA onward, the Singapore energy market was restructured to include a 30-minute spot bidding based wholesale market where commercial parties can buy and sell energy. The further competition was introduced in 2019 on the retail level, allowing consumers to select and switch between retailers according to their current needs. [1]

Electricity for mass consumption in Singapore is generated primarily by seven power companies. Natural gas provides 95 per cent of the energy required for the nation's electricity generation needs. The rest comes from coal, petroleum and other sources such as solar energy. In 2017, about 72 percent of Singapore's natural gas was piped in from Indonesia and Malaysia, while the other 28 per cent was imported from other parts of the world in the form of liquefied natural gas (LNG). [2]

1.2 Four switches to power Singapore's future

The minister of trade and industry, Chan Chun Sing, introduced the "Four Switches" strategy in 2019 to power the energy future, namely natural gas, solar, regional power grids and emerging low-carbon alternatives. The "4 switches" will transform the energy supply and will support the efforts in energy efficiency to reduce energy demand. [3]

According to EMA, the gas reserve will last another 200 years so there is no pressure to look for other alternatives. Therefore, Singapore will use natural gas in the near future while they can develop the other 3 switches. Solar power is regarded as the most promising renewable energy in Singapore. In 2020, 350 MWp capacity will be installed, 2GWp by 2030, and a storage of 200 MW will be deployed. The third switch promotes the cost-competitive regional power grids through bilateral cooperation or regional initiatives. The last one, emerging low-carbon alternatives include carbon capture and utilisation or storage technologies to reduce carbon footprint.

1.3 Research question

Given the outlined strategy for the future of the Singaporian energy system, it is interesting to observe whether these proposed changes will have the desired effects. To that end, we will look into how the energy price develops with increasing renewable energy, fluctuating natural gas price and other potential policies in the energy industry. Therefore, the research question is as following:

How does the electricity price in Singapore develop in the context of four switches towards the future power market, with a focus on solar penetration and natural gas price fluctuation?

2. Methodology

In this chapter we will define the scope of the research in section 2.1, followed by a description of the main data sources in section 2.2. The chapter will conclude with a description of the model design in section 2.3.

2.1 Scope definition

The scope determines what will be analysed in the research and what is left out. In this research, the spatial scale is Singapore itself and the temporal scale is 2016 (as a base year to model) and 2030 (for scenario considerations). Since natural gas takes up over 95% of the fuel mix for generation, the considered power plants include Combined Cycle Gas Turbines (CCGT), Gas Steam Turbines (ST), Open Cycle Gas Turbines (OCGT) as well as Solar generators. Choosing from the inventory of generation companies, 13 major natural gas plants from 7 companies are selected with a total capacity of 13091.6 MW. The research focus is the modelling and prediction of electricity price under different price scenarios, energy mix and policies.

2.2 Data sources

Table 2.1 shows an overview of data sources used in the model. Half-hour System Demand data was obtained from the Singapore Market Authority, and Python programming was utilized for data pre-processing, namely extracting and merging 52 weekly data files into a one-year file with the same format. The Uniform Singapore Energy Price (USEP) is the half-hourly wholesale price, which is used for validation of the model results.

Capacity mix in 2016 and projection in 2030 data was obtained from the annual energy statistics report [2]. The monthly natural gas price pattern is considered to increase the model accuracy, where the price of Indonesian LNG is used. Besides the basic plant efficiency, a correction factor is introduced to represent the operation efficiency of each company, equal to the ratio of individual market share and capacity share (both obtained from the same annual energy statistics report [2]). Then the generation efficiency is equal to the product of basic plant efficiency and company correction factor.

Item	Source
Half-hourly system demand	EMA: Half-hourly system Demand Data, 2016
Half-hourly actual price (USEP)	EMCSG: Price Information, 2016
Generation capacity mix	EMA: Singapore Energy Statistics, 2018
Monthly natural gas price	Indexmundi: Natural Gas, Indonesian LNG, 2016
Hourly solar availability	EU: Photovoltaic Geographical Information System

For the solar generation, hourly solar availability data is referred from the Photovoltaic Geographical Information System by EU Science Hub. Figure 2.1 shows a relatively stable ten-year solar availability, ranging from 724 to 765 kWh per capacity. The average value of 746 is used for the 2030 projection and the inverter efficiency is set as 77%. Figure 2.2 demonstrates a dramatic increase of solar capacity in Singapore.

To meet the 2030 target, 2 GW nominal capacity, as set by the national authority, Singapore requires an annual growth rate of 19% on average from 2020 to 2030. If the 2030 target is met, the solar generation will serve a maximum 25% of total demand at full capacity.

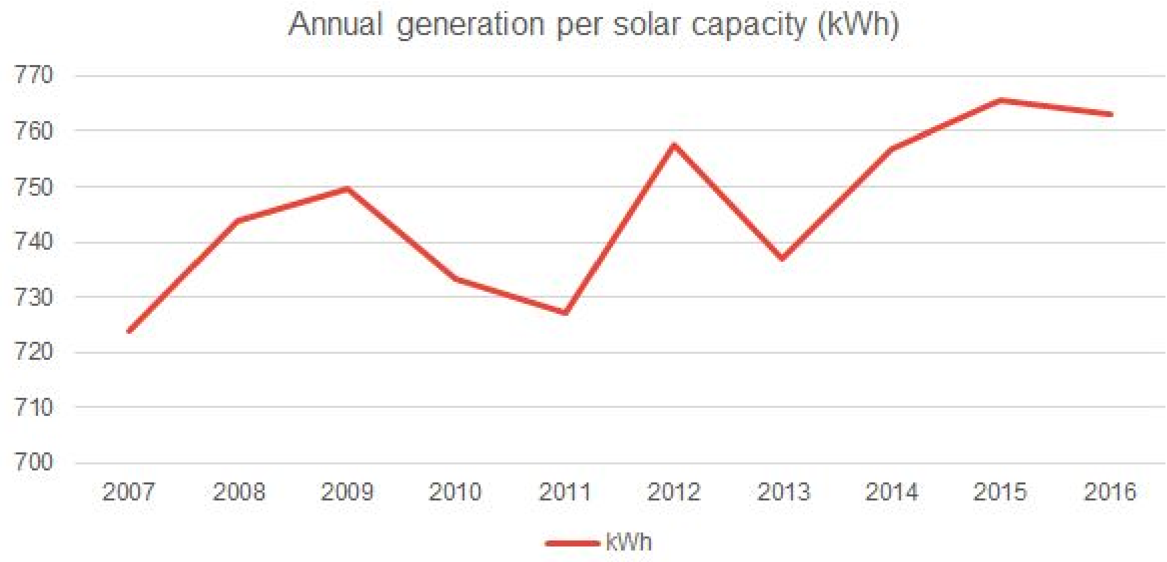

Figure 2.1 Solar availability in Singapore from 2007 to 2016

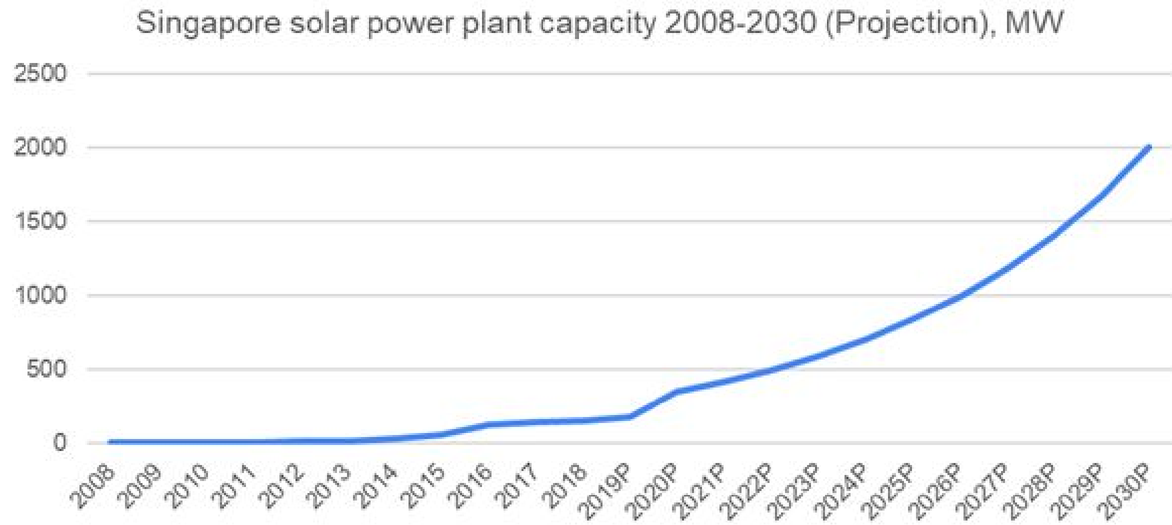

Figure 2.2 Solar power plant capacity from 2008 to 2030

2.3 Model design

2.3.1 Model assumptions

Two versions of models are established based on different assumptions. The first version meets the basic requirements with no demand price elasticity, no storage, no ramping limit, no maintenance rate, and fixed dispatch order (from lowest to highest marginal cost). The clearing price is equal to the marginal cost of the last operation unit.

The second version model is developed to improve accuracy and reliability. The capacity factor of 80% is introduced to each gas plant, which means a randomly distributed maintenance with 20% probability on average. The price elasticity of demand-side is set at -0.1 €/MWh per MW with a price cap of 1000 €/MWh. Other assumptions are the same as the first version.

2.3.2 Model structure

An Excel-based model is developed to answer the research question. The spreadsheet is classified into Database, Calculation, Output sheets as well as Scenario parameters for adjusting. The database sheets include all the collected data for calculation and analysis as mentioned in section 2.2. The hourly generation dispatch is conducted to obtain the demand and price duration curves, and relevant indicators such as fuel mix. The scenario analysis complying with the four switches focuses on a higher penetration of Solar PV and the changing natural gas price. Investment analysis, as was originally planned (see figure 2.3), has been excluded in the current version of the model and could be explored in further research on the topic.

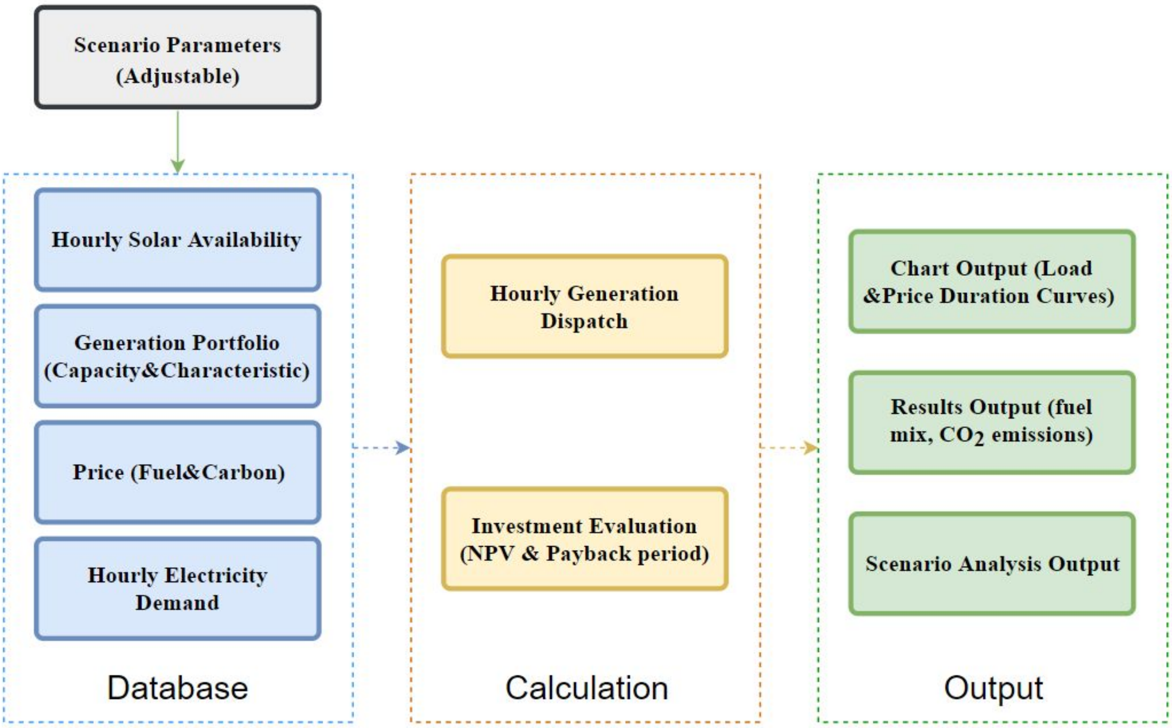

Figure 2.3 Model structure diagram

3. Result & Discussion

In this chapter the results of the model will be presented in two separate sections. Firstly, section 3.1 will present and discuss the model results for the year 2016, as well as the validation of these results by using the price data as discussed in section 2.2. Then, in section 3.2, a small scenario analysis is performed and discussed.

3.1 Generation analysis

As can clearly be seen in figure 3.1 and 3.2, the main difference in the generation mix between the two models is the inclusion of the probabilistic capacity factor, which leads to the occurrence of shortages in the newer model.

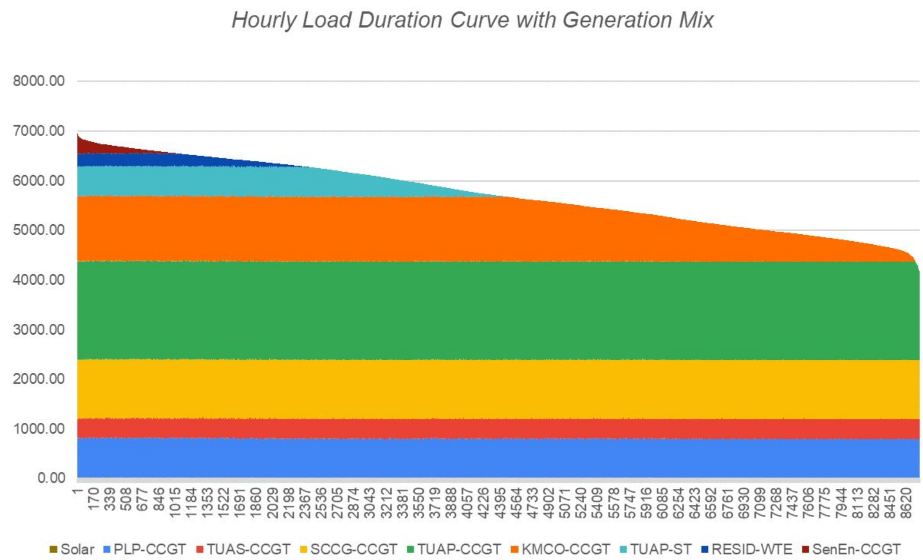

Figure 3.1 Hourly load duration with generation mix (1st version model)

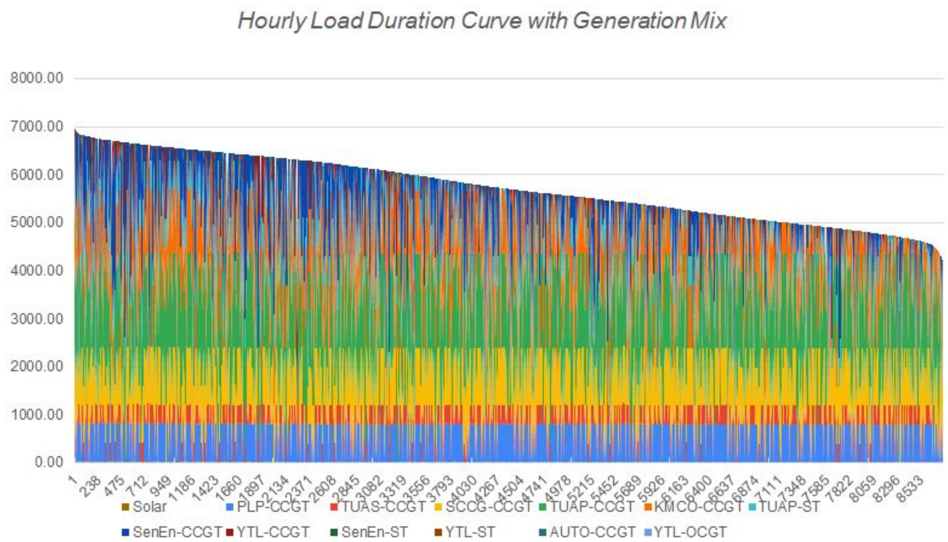

Figure 3.2 Hourly load duration with generation mix (2nd version model)

Whilst shortages have a positive impact on the model accuracy in terms of prices, the manner of modeling could be improved by creating a more coherent maintenance model. That way, outages would occur for longer, less random periods of time, which is a more accurate representation of reality.

As can be seen in figure 3.3 and 3.4, the accuracy in terms of price has increased due to the shortages introduced in the 2nd version, leading to a nice fit with the red validation line. It has to be noted though that model prices are heavily dependent on the gas price, and thus any assumption with respect to this price has a severe impact on the results. Nevertheless, the fit presented in figure 3.4 gives us enough confidence to say that the model can be used for qualitative assessments.

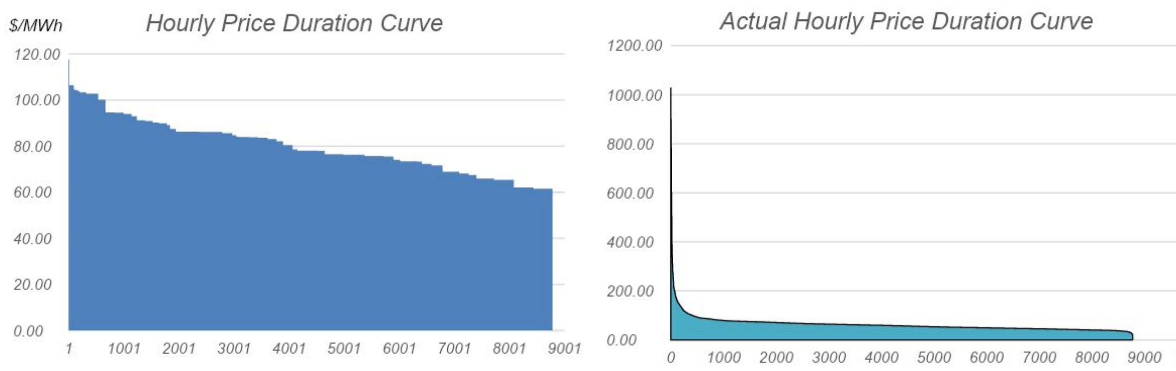

Figure 3.3 Price duration comparison (Left: model, Right: actual; 1st version model)

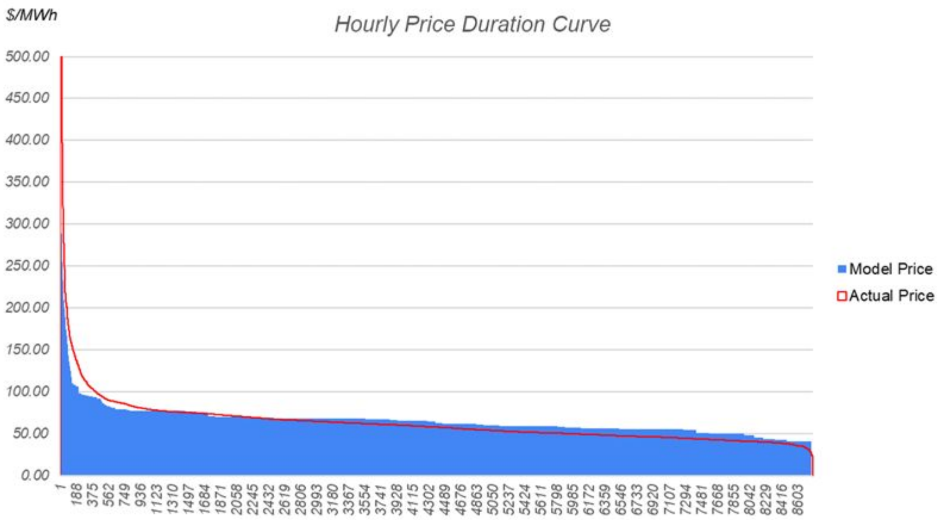

Figure 3.4 Model & Actual price duration comparison (2nd version model)

In figure 3.5, a comparison of the monthly prices can be seen for January and July, with the red line representing the actual prices and the blue line representing the model prices. Clearly, the prices are in the correct order of magnitude, although shortages occur at different times due to the way the model deals with the capacity factor.

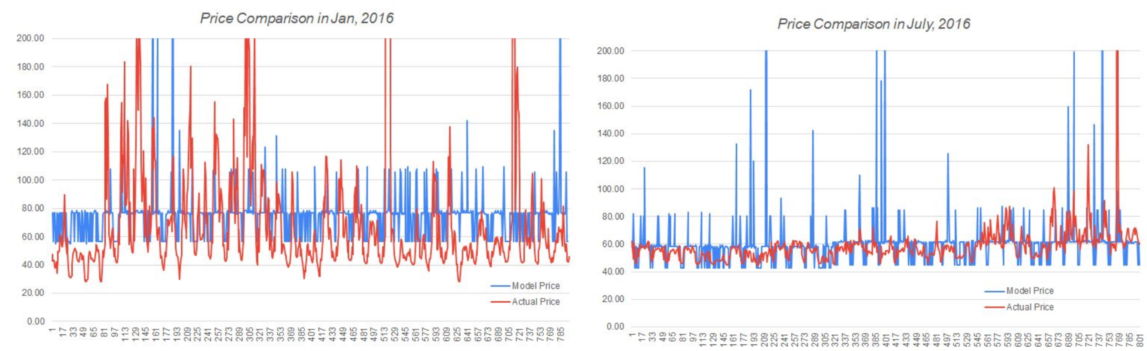

Figure 3.5 Price fluctuation comparison (Left: January, Right: July; 2nd version model)

Lastly, table 3.1 and 3.2 provide some validation data in terms of model accuracy. Given the similar price and generation mix ratio, we are confident to say that the model can be used as a tool in making qualititative assessments.

Table 3.1 Model and actual price statistical comparison

	Model price	Actual price
Mean	65.79	63.27
Standard deviation	22.60	41.18
Average difference over time series	19.41	
Average difference over sorting price series	7.44	

Table 3.2 Model and actual technology mix comparison

	Sum (MWh)	Model ratio	Actual ratio
Solar	73716	0.15%	0.20%
CCGT	46219209	92.41%	97.30%
OCGT	20317	0.04%	
ST	3701616	7.40%	0.10%
Total	50014858	100.00%	

3.2 Scenario analysis

For the scenario analysis, two scenario parameters have been built into the model to explore the effect of the "four switches" described in section 1.2. Firstly, the amount of solar generation can be adjusted up to the expected 2030 level of 2 GWp. Secondly, adjustment of gas prices for every month can be made to explore the effect of energy crises, tariffs and other price changing factors.

Solar generation:
In terms of price changes that occur due to the availability of more solar generation, the effect is negligibly small. Changing the solar capacity to 2000 GWp leads to a new mean price of 64.64 SGD, which is only 1.13 SGD lower than the price in the original set-up. Of course, this change does not take into account demand growth (a limitation of the current model which could be expanded upon in more extensive research). Given that 2000 GWp of solar capacity only covers 2.35% of 2016's level of yearly demand, the fact that price changes are minimal is not surprising. In order for renewable generation to really start influencing the price in Singapore, the amount of installed capacity needs to be at least an order of magnitude larger.

Gas price fluctuations:
As expected from the generation mix in Singapore, changing the gas price heavily influences the mean price in Singapore. An increase of only 10 SGD per BTU for every month leads to an almost doubling of the energy prices. This is not unexpected as only the solar generation is not dependent on the gas prices.

Therefore, any type of policy that affects the gas price is sure to have an immediate effect on future energy prices. An example could be the Singapore government introducing some kind of import tariff, or the introduction of a CO2 tax.

4. Conclusion

In this assignment we have developed a simple dispatch model for the Singapore energy market, and have tried to assess the impact of further development of solar generation on the Singapore energy price. Additionally, we have explored the generation mix of the current energy market and tried to analyze the effect of future gas price fluctuations on the market.

In the dispatch model, the dependance of the Singapore Energy system on natural gas can be clearly seen, as only the solar generation is not dependent on this fuel type. Therefore, the scenario analysis shows that small changes in the gas price lead to almost identical price changes. Increasing the amount of solar generation capacity has only a limited effect, as solar generation needs to grow by an order of magnitude more to start really affecting the prices.

The model itself is still rather limited, given that it does not take into account demand growth for the future scenarios. Furthermore, the manner in which the capacity factor has been modeled (by introducing a probability of maintenance hours that are disjoint) is not very realistic. A better version would create maintenance blocks of several hours or even days, reducing the hourly variability in availability of the generators. Also, gas price assumptions heavily influence the results, showing that the model is rather susceptible to bias. Therefore, the results presented in this assignment can only be applied in a limited scope. A qualitative assessment of the effect of solar generation and gas price fluctuations can be made with reasonable certainty, but a quantitative assessment should still be subject to serious considerations. Further validation will be needed in this case.

Reference

[1] EMA Singapore, Overview of Singapore Electricity Market, https://www.ema.gov.sg/electricity_market_overview.aspx, Accessed on Feb. 1, 2019
[2] EMA Singapore, 2017 Singapore Energy Statistics, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Publications/SES17/Publication_Singapore_Energy_Statistics_2017.pdf, Accessed on Feb. 1, 2019
[3] EMA Singapore, The Future of Singapore's Energy Story, https://www.ema.gov.sg/media_release.aspx?news_sid=20191029Yk3uENU5Z4bL, Accessed on Feb. 1, 2019
[4]

Appendix:

Model: Singapore Model_final version_Feb 9.xlsx