

Supporting Information

A. Model Assumptions

The following is a full list of model assumptions used.

- Assume household electricity consumption per capita increases proportionally with GDP per capita
- Assume crude birth rate of 8.6 in 2021 continues after 2021 (*Births And Fertility Rates, 2022*)
- Assume crude death rate of 5.8 in 2021 continues after 2021 (*Death And Death Rates, 2022*)
- Assume crude net migration rate of 4 from 2021 onwards (*Crude Rate of Net Migration, 2022*)
- Assume vehicle population stays constant from 2021 onwards at 988755, due to registration of new vehicles largely being determined by deregistration of existing vehicles (*Changes Will Be Made to COE, 2022*)
- Assume EVs are manufactured in other countries and have zero local emissions
- Assume normal growth rate of EV adoption at 117% per year, estimated using Land Transport Authority data from 2010 to 2020 (*Annual Vehicle Statistics 2021 | Motor Vehicle Population by Type of Fuel Used, n.d.; Land Transport Datamall | Annual Motor Vehicle Population by Type of Fuel Used, n.d.*)
- Assume adoption of EVs increases proportionally with GDP
- Normal growth rate of transport-related electricity consumption: Accounts for growth in transport-related electricity consumption that is not related to EV adoption, e.g. electricity used for operation of Mass Rapid Transit lines and facilities; assume average growth rate calculated using Energy Market Authority data from 2010 to 2020 prevails (*EMA: Singapore Energy Statistics | Energy Consumption, 2022*)
- Normal growth rate of other electricity consumption: Is the sum of industrial-related, commerce and services-related and other miscellaneous consumption; assume average growth rate calculated using Energy Market Authority data from 2010 to 2020 prevails (*EMA: Singapore Energy Statistics | Energy Consumption, 2022*)
- Assume solar investment increases proportionally with GDP
- Assume a solar PV cost reduction factor of 2% per year, based on future levelised cost of energy (LCOE) estimates (Paton et al., 2019, p. 89)
- Assume specific yield of solar PV at 1282 GWh/GWp (Paton et al., 2019, p. 66)
- Assume typical degradation rate for solar PV in Singapore at 0.8% per year (Reindl et al., 2020, p. 36)
- Assume solar PV components are manufactured in other countries and have zero local emissions
- Assume natural gas continues to be the dominant fuel for electricity generation in Singapore (*EMA / The Future of Singapore's Energy Story, n.d.*)
- Assume base efficiency of natural gas electricity generation at 49.5% (Loi, 2019), which is equivalent to heat rate of 0.1375 GWh/TJ

- Normal other electricity generation: Calculated using breakdown of energy flows for electricity generators (*EMA: Singapore Energy Statistics / Energy Transformation, 2022*), subtracting the amount of energy produced by natural gas (inputs*50% assumed efficiency) from the total energy generated to get electricity generated by sources other than natural gas; assume that normal other electricity generation stays constant at 2020 level at 3079.72GWh/Year
- Assume CO₂ emissions target of 47.6 million tonnes, based on the greenhouse gas (GHG) emissions target of 65 million tonnes of CO₂ equivalent (*Singapore and International Efforts, n.d.*), and the average ratio of CO₂/GHG emissions, calculated using GHG and CO₂ emissions data from 2010 to 2019 (*Historical Emissions, n.d.*)
- Assume desired electricity generation to be 1.059*Total electricity consumption, with 1.059 calculated from the average ratio of generation to consumption from 2010 to 2020 (*EMA / Singapore Energy Statistics (SES), 2022*)

B. Quantification of Stock and Flow Diagram

The following is a full list of parameters and equations used in the SFD.

Parameter	Units	Equation
Births lookup	1/Year	[(0,0)-(10,10)],(2010,35129),(2011,36178),(2012,38641),(2013,35681),(2014,37967),(2015,37861),(2016,36875),(2017,35444),(2018,35040),(2019,35330),(2020,34233)
Crude birth rate	1/Year	8.6
Births (inflow)	1/Year	IF THEN ELSE(Time<=2020 , Births lookup(Time) , Population/1000*Crude birth rate)
Deaths lookup	1/Year	[(0,0)-(10,10)],(2010,16476),(2011,16887),(2012,17273),(2013,17810),(2014,18237),(2015,18640),(2016,18856),(2017,19763),(2018,20095),(2019,20288),(2020,20985)
Crude death rate	1/Year	5.8
Deaths (outflow)	1/Year	IF THEN ELSE(Time<=2020 , Deaths lookup(Time) , Population/1000*Crude death rate)
Net migration lookup	1/Year	[(0,0)-(10,10)],(2010,106611),(2011,72571.6),(2012,69061.7),(2013,64789.9),(2014,60167),(2015,38745),(2016,33643.7),(2017,33673.5),(2018,33832.1),(2019,39925),(2020,22743.2)
Crude net migration rate	1/Year	4
Net migration (inflow)	1/Year	IF THEN ELSE(Time<=2020 , Net migration lookup(Time) , Population/1000*Crude net migration rate)
Population (stock)	1	Births+Net migration-Deaths Initial value: 5.07673e+06
GDP per capita	Dollars	GDP/Population
Previous GDP per capita	Dollars	DELAY FIXED(GDP per capita, 1 , 56619.8)
GDP per capita growth rate	1/Year	GDP per capita/Previous GDP per capita - 1

Effect of GDP per capita on household electricity consumption per capita	GWh/Dollars	3.092e-09
Household electricity consumption per capita	GWh	Effect of GDP per capita on household electricity consumption per capita*GDP per capita + (0.001048)
Growth in household electricity consumption lookup	GWh/Year	[(0,0)-(10,10)],(2010,-153.3),(2011,146.8),(2012,125.4),(2013,169.5),(2014,296.5),(2015,364.9),(2016,-295.9),(2017,-58.4),(2018,449.8),(2019,563.2),(2020,-304.7)
Growth in household electricity consumption (inflow)	GWh/Year	IF THEN ELSE(Time<=2020, Growth in household electricity consumption lookup(Time), (GDP per capita growth rate)*"Household electricity consumption (annual)" + (Births+Net migration-Deaths)*Household electricity consumption per capita)
Household efficiency improvement	1/Year	0.033
Household electricity savings	GWh/Year	IF THEN ELSE(Time<=2020, 0 , "Household electricity consumption (annual)"*Household efficiency improvement)
Decrease in household electricity consumption (outflow)	GWh/Year	Household electricity savings
Household electricity consumption (annual) (stock)	GWh	Growth in household electricity consumption-Decrease in household electricity consumption Initial value: 6636
Base adoption of Evs	1/Year	2316
Normal growth rate of EV adoption	1	1.1701

Adoption of EVs lookup	1/Year	[(0,0)-(10,10)],(2010,1),(2011,1),(2012,-5),(2013,-1),(2014,-2),(2015,29),(2016,316),(2017,358),(2018,629),(2019,61),(2020,2316)
Adoption of EVs (inflow)	1/Year	IF THEN ELSE(Time<=2020, Adoption of EVs lookup(Time), Percentage of conventional ICE vehicles in vehicle population*(GDP/"Base GDP (2020)")*Base adoption of EVs*(1+Normal growth rate of EV adoption)^(Time-2020))
Number of EVs (stock)	1	IF THEN ELSE(Number of EVs+Adoption of EVs <= 988755, Adoption of EVs , 988755-Number of EVs) Initial value: 10
Vehicle population lookup	1	[(0,0)-(10,10)],(2010,945829),(2011,956704),(2012,969910),(2013,974170),(2014,972037),(2015,957246),(2016,956430),(2017,961842),(2018,957006),(2019,973101),(2020,973990)
Vehicle population	1	IF THEN ELSE(Time<=2020 , Vehicle population lookup(Time), 988755)
Percentage of EVs in vehicle population	1	IF THEN ELSE(Number of EVs <= Vehicle population , Number of EVs/Vehicle population, 1)
Percentage of conventional ICE vehicles in vehicle population	1	1-Percentage of EVs in vehicle population
Average CO ₂ emissions per conventional ICE vehicle (annual)	Tonnes	4.7
CO ₂ emissions saved by adoption of EVs	Tonnes/Year	Adoption of EVs*"Average CO ₂ emissions per conventional ICE vehicle (annual)"
Normal growth rate of transport-related electricity consumption	GWh/Year	71.15

Growth in transport-related electricity consumption lookup	GWh/Year	[(0,0)-(10,10)],(2010,125.5),(2011,104.4),(2012,40.5),(2013,71.9),(2014,3.8),(2015,194.6),(2016,128.5),(2017,181.6),(2018,71.4),(2019,-210.7),(2020,71.15)
Average annual charging demand per EV	GWh	0.006
Growth in transport-related electricity consumption (inflow)	GWh/Year	IF THEN ELSE(Time<=2020, "Growth in transport-related electricity consumption lookup"(Time), "Normal growth rate of transport-related electricity consumption" + Adoption of EVs*Average annual charging demand per EV)
Transport-related electricity consumption (annual) (stock)	GWh	Growth in transport-related electricity consumption Initial value: 2098.7
Other electricity consumption (annual) lookup	GWh	[(0,0)-(10,10)],(2010,33517.1),(2011,34300.3),(2012,35242.6),(2013,35824.8),(2014,37037.5),(2015,37848.1),(2016,38397.8),(2017,39579.9),(2018,40257.2),(2019,41011.2),(2020,39705.8)
Normal growth rate of other electricity consumption	GWh/Year	618.87
Other electricity consumption (annual)	GWh	IF THEN ELSE(Time<=2020, "Other electricity consumption (annual) lookup"(Time), 39705.8+(Normal growth rate of other electricity consumption)*(Time-2020))
Total electricity consumption	GWh	Household electricity consumption (annual)+"Transport-related electricity consumption (annual)+"Other electricity consumption (annual)"
Effect of total electricity consumption on amount of goods produced	1/GWh	0.002507

Amount of goods produced (Industrial production index)	1	Effect of total electricity consumption on amount of goods produced*Total electricity consumption - 28.48
Previous amount of goods produced (Industrial production index)	1	DELAY FIXED("Amount of goods produced (Industrial production index)", 1 , 59.614)
GDP growth rate	1/Year	Amount of goods produced (Industrial production index)"/"Previous amount of goods produced (Industrial production index)" -1
GDP growth (inflow)	Dollars/Year	GDP*GDP growth rate
GDP (stock)	Dollars	GDP growth Initial value: 3.2698e+11
Base GDP (2020)	Dollars	5.54888e+11
Investment per GWh of solar electricity	Dollars/GWh	1.20125e+06
Base investment rate	Dollars/Year	1.15038e+08
Investment in solar PV	Dollars/Year	Base investment rate*(GDP/"Base GDP (2020)") + 0.1*Revenue from carbon tax
Installation lookup	GWh/Year	[(0,0)-(10,10)],(2010,2.6922),(2011,5.3844),(2012,6.6664),(2013,22.5632),(2014,33.8448),(2015,84.8684),(2016,32.1782),(2017,72.433),(2018,186.916),(2019,95.7654),(2020,371.011)
Solar PV cost reduction factor	1	0.02
Effect of cost reduction on installation of solar PV	1	(1+Solar PV cost reduction factor)^(Time-2020)
Installation of solar PV (inflow)	GWh/Year	IF THEN ELSE(Time <= 2020, Installation lookup(Time), (Investment in solar PV/Investment per GWh of solar electricity + RAMP(0.5*Investment in solar PV/Investment per GWh of solar electricity, 2021 , 2050)) * Effect of gap to solar target on installation of solar PV * Effect of cost reduction on installation of solar PV)

Degradation rate of solar PV	1/Year	0.008
Degradation (outflow for "Electricity generated by solar PV (annual)", inflow for "Losses from degradation")	GWh/Year	Degradation rate of solar PV*"Electricity generated by solar PV (annual)"
Electricity generated by solar PV (annual) (stock)	GWh	Installation of solar PV-Degradation Initial value: 4.8716
Losses from degradation (stock)	GWh	Degradation Initial value: 0.019486
Specific yield	GWh/GWp	1282
Solar capacity	GWp	Electricity generated by solar PV (annual)/Specific yield
Solar target	GWp	2
Gap to solar target	GWp	IF THEN ELSE(("Electricity generated by solar PV (annual)"/Specific yield <= Solar target, Solar target - ("Electricity generated by solar PV (annual)"/Specific yield, 0)
Effect of gap to solar target on installation of solar PV	1	(Gap to solar target/Solar target)
Amount of natural gas saved	TJ/Year	(Installation of solar PV-Degradation)/Base efficiency of natural gas electricity generation
CO ₂ emissions saved by installation of solar PV	Tonnes/Year	Amount of natural gas saved*Tonnes of CO ₂ emissions per TJ from combustion of natural gas
Desired electricity generation	GWh	Total electricity consumption*1.05885
Other electricity generation (annual) lookup	GWh	[(0,0)-(10,10)],(2010,10676.9),(2011,10279.2),(2012,7762.31),(2013,3804.84),(2014,2392.64),(2015,2830.69),(2016,2948.62),(2017,3308.94),(2018,3502.1),(2019,3559.06),(2020,3079.72)

Other electricity generation (annual)	GWh	IF THEN ELSE(Time<=2020, "Other electricity generation (annual) lookup"(Time) , 3079.72)
Gap to desired electricity generation	GWh	Desired electricity generation-"Electricity generated by solar PV (annual)"-"Other electricity generation (annual)"-"Electricity generated by natural gas (annual)"
Growth in electricity generated by natural gas lookup	GWh/Year	[(0,0)-(10,10)],(2010,1020.8),(2011,3418.94),(2012,4934.88),(2013,2731.02),(2014,518.513),(2015,1185.25),(2016,275.55),(2017,481.25),(2018,1168.61),(2019,-576.813),(2020,1515.8)
Growth in electricity generated by natural gas (inflow)	GWh/Year	IF THEN ELSE(Time<=2020, Growth in electricity generated by natural gas lookup(Time), Gap to desired electricity generation)
Electricity generated by natural gas (annual) (stock)	GWh	Growth in electricity generated by natural gas Initial value: 34342.3
Growth in amount of natural gas burnt lookup	TJ/Year	[(0,0)-(10,10)],(2010,7424),(2011,24865),(2012,35890),(2013,19862),(2014,3771),(2015,8620),(2016,2004),(2017,3500),(2018,8499),(2019,-4195),(2020,11024)
Base efficiency of natural gas electricity generation	GWh/TJ	0.1375
Growth in amount of natural gas burnt (inflow)	TJ/Year	IF THEN ELSE(Time<=2020, Growth in amount of natural gas burnt lookup(Time), Growth in electricity generated by natural gas/Base efficiency of natural gas electricity generation)
Natural gas efficiency improvement	1/Year	0.01
Efficiency of natural gas electricity generation	GWh/TJ	IF THEN ELSE(Time<=2020, Base efficiency of natural gas electricity generation, ((Base efficiency of natural gas electricity generation)*(1+Natural gas efficiency improvement)^(Time-2020))*Effect of gap to CO ₂ emissions target on natural gas efficiency)

Previous efficiency of natural gas electricity generation	GWh/TJ	DELAY FIXED(Efficiency of natural gas electricity generation, 1 , (1/3.6)*0.495)
Natural gas savings with efficiency improvement	TJ/Year	Amount of natural gas burnt (annual)*(1-1/(Efficiency of natural gas electricity generation/Previous efficiency of natural gas electricity generation))
Decrease in amount of natural gas burnt (outflow)	TJ/Year	Natural gas savings with efficiency improvement
Amount of natural gas burnt (annual) (stock)	TJ	Growth in amount of natural gas burnt-Decrease in amount of natural gas burnt Initial value: 249762
Tonnes of CO ₂ emissions per TJ from combustion of natural gas	Tonnes/TJ	56.1
CO ₂ emissions saved by natural gas efficiency improvement	Tonnes/Year	Decrease in amount of natural gas burnt*Tonnes of CO ₂ emissions per TJ from combustion of natural gas
CO ₂ emissions from combustion of natural gas	Tonnes	Tonnes of CO ₂ emissions per TJ from combustion of natural gas*"Amount of natural gas burnt (annual)"
CO ₂ emissions per GWh of electricity generated	Tonnes/GWh	CO ₂ emissions from combustion of natural gas/Desired electricity generation
Growth in CO ₂ emissions (inflow)	Tonnes/Year	Growth in amount of natural gas burnt*Tonnes of CO ₂ emissions per TJ from combustion of natural gas
Decrease in CO ₂ emissions (outflow)	Tonnes/Year	CO ₂ emissions saved by adoption of EVs+CO ₂ emissions saved by installation of solar PV+CO ₂ emissions saved by natural gas efficiency improvement
CO ₂ emissions (annual) (stock)	Tonnes	Growth in CO ₂ emissions-Decrease in CO ₂ emissions Initial value: 4.241e+07

CO ₂ emissions savings (from 2020)	Tonnes	IF THEN ELSE(Time<=2020, 0, 4.83703e+07 - "CO ₂ emissions (annual)")
CO ₂ emissions target	Tonnes	4.76306e+07
Gap to CO ₂ emissions target	Tonnes	CO ₂ emissions (annual)-CO ₂ emissions target
Effect of gap to CO ₂ emissions target on natural gas efficiency	1	IF THEN ELSE(Gap to CO ₂ emissions target<=0, 1, 1+(Gap to CO ₂ emissions target/CO ₂ emissions target))
Carbon tax level	Dollars	IF THEN ELSE(Time>=2026, 45 , IF THEN ELSE(Time>=2024, 25 , IF THEN ELSE(Time>=2019, 5 , 0)))
Revenue from carbon tax	Dollars	Carbon tax level*"CO ₂ emissions (annual)"

C. Other BOTGs from Simulations

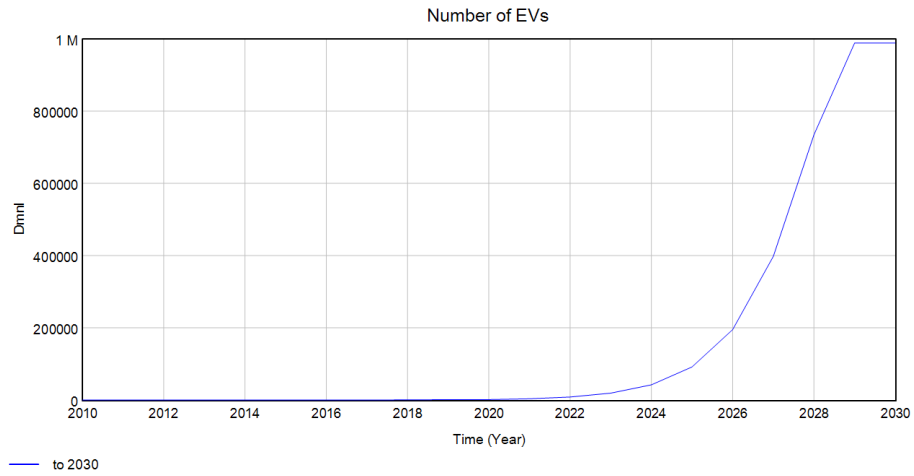


Figure C1: Simulated Result for Number of EVs

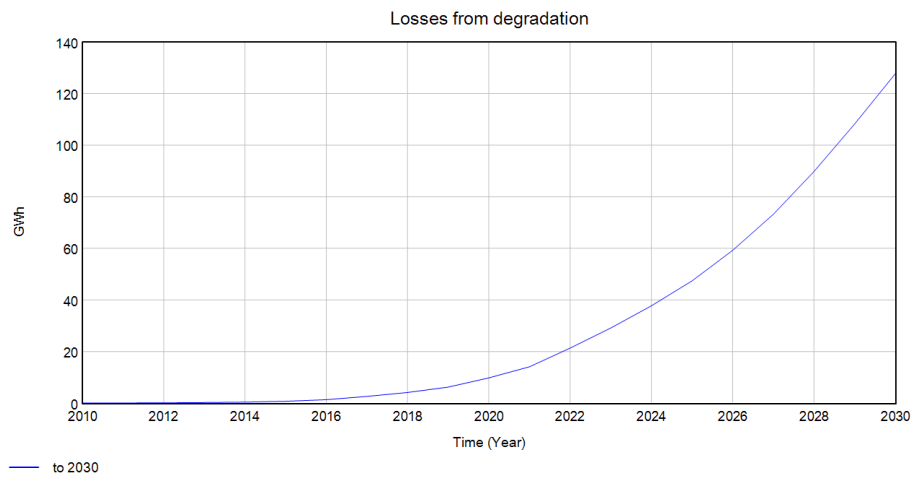


Figure C2: Simulated Result for Losses from Degradation (of Solar PV Systems)

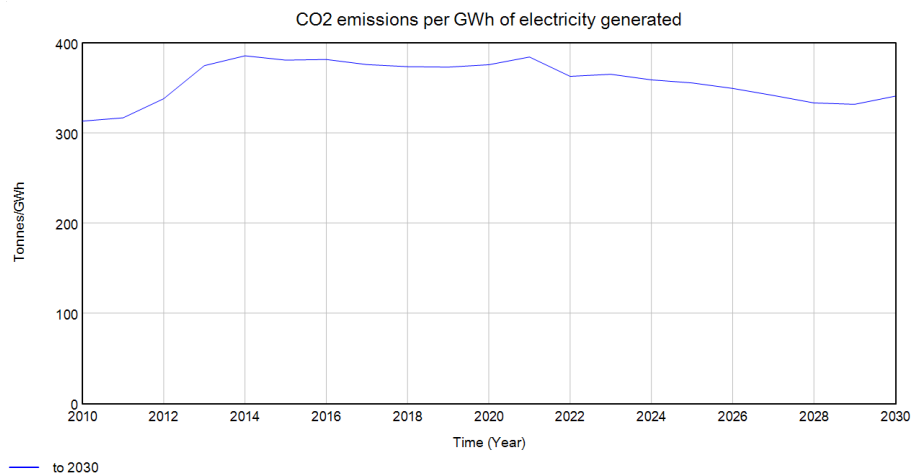


Figure C3: Simulated Result for CO₂ emissions per GWh of Electricity Generated