IEPPEC International Energy Policy & Programme Evaluation Conference

Energy Efficiency and its Contributions to Mitigating Singapore's GHG Emissions

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ABSTRACT

In its nationally determined contribution (NDC) Singapore pledged to reduce its GHG emissions intensity (per unit GDP at 2010 prices) by approximately 36 per cent as compared to 2005 levels by 2030, and to stabilize its emissions with the aim of peaking around 2030. Singapore has also pledged in 2009, following the Copenhagen Climate Summit, to reduce it GHG emissions by 16 per cent below 2020 BAU levels.

While it is on track to achieve its 2009 Copenhagen target, the NDC pledges are challenging targets due to national circumstances. As a small, densely populated island state having a total land area of 719 km2, Singapore has limited alternative energy sources. Large scale solar power installation is constrained by land size and solar intermittency, and nuclear power is not suitable for deployment based on current technology. Improving energy efficiency in all sectors of the economy is the key strategy in mitigating GHG emissions.

In this paper, we present the key features of Singapore's economy, total historical GDP growth and the contributions from its economy sectors, total energy consumption, total GHG emissions, GHG emissions by fuels and emissions by industry sectors. Singapore GHG emissions mitigation options and strategies are presented, addressing specifically Singapore's 2016 Climate Action Plan. We outline the policies and legislation in place to promote energy efficiency in each sector of the economy, including quantified emission reductions that have been identified. Finally, we consider the challenges in achieving the current and future NDC targets.

Introduction

Singapore is a small, densely populated city state comprised of one large diamond-shaped island and over 60 smaller islets. Located between latitudes 1°09'N and 1°29N, and longitudes 103°36'E and 104°25'E and approximately 137km north of the equator. The main island of Singapore is about 49km east to west and 25km from north to south with a coastline of 195km. The total land area (including that of smaller islands) is about 719 sq. km. (1). Among the islands, the larger ones are Pulau Tekong (25.5 sq. km), Pulau Ubin (10.2 sq. km) and Sentosa (5 sq. km). It is separated from Peninsular Malaysia by the Straits of Johor and from Indonesia's northerly islands by the Straits of Singapore. Most of the country is no more than 15 meters above sea level. The highest point is Bukit Timah Hill at a height of 164 meters.

An equatorial country with a tropical climate, Singapore experiences relatively uniform temperatures throughout the year – abundant rainfall and high humidity. The average daily temperature is 26.9°C, with an average daily maximum and minimum of 31°C and 25°C, respectively. There are high rainfall levels, the long-term mean annual rainfall total is 2328.7mm. The transitions between monsoon seasons occur gradually over a period of two months. Due to its geographical location within the tropical

and equatorial belt, Singapore experiences high levels of solar radiation. However, our location in the doldrums also means that we have a high daily average cloud cover. On an average day, cumulus clouds start to develop in the mid-morning itself, resulting in highly diffused solar radiation. Daily sunshine hours are mainly influenced by the presence or absence of cloud cover and average from four to five hours during the wettest months to eight to nine hours during the drier periods. The average annual solar irradiance is 1,580 kWh/m2/year. Winds throughout the year show a diurnal variation, with lighter winds during the night and stronger winds during the day. The strongest winds occur during the Northeast Monsoon in January and February. Winds in Singapore are generally light, with the mean surface wind speed normally less than 2.5 m/s (MSS 2017).

As of 2015, Singapore's total population, including foreigners working in Singapore, is estimated at 5.5 million. Singapore's small land area also means that the population density of 7,700 people per km2 is one of the highest in the world (DSS 2017a, 3).

Singapore economy

Singapore experienced rapid economic development in the past few decades. In 2015, Singapore's GDP was S$402 billion, of which 69% or S$265 are from the services producing industries, 26% or S$100.0 billion are from the goods producing industries and about 4% or S$16.4 billion are from ownership of dwellings. Under the goods producing industries sector, the share of contribution from the manufacturing industry to the GDP was 19.5% (DSS 2017a, 10). This share has been decreasing from more than 32% in the 1990s, nonetheless, the share in absolute terms was most significant at more than S$78 billion. The main contributors in the services producing industries are from Wholesale & Retail Trade, Transport & Storage, Finance & Insurance and Business Services whose contributions to the GDP were 14.7%, 6.9%, 11.9% and 14.8%, respectively.

As a small, open and export-oriented economy, Singapore is highly dependent on international trade. In 2015, Singapore's total external trade was S$884.1 billion, about 2.2 times its GDP, with S$476.3 billion from exports and S$407.8 billion from imports (MTI 2016). The main import commodities were Petroleum & petroleum products, chemical and chemical products, and electronics, accounting for 22%, 8% and 29 % of the total imports. The contributions of these three commodities accounted for 17%, 14% and 35%, respectively, of the total exports. In the petroleum & petroleum products and chemical and chemical production commodity sections, domestic exports were much higher than re-exports. In the case of the electronics section, the re-export component was much higher.

Singapore's greenhouse gas emissions grew at a Cumulative Averaged Growth Rate (CAGR) of 2.0% from 2000 to 2012. The total GHG emissions in 2012 was 49 Mt CO2e (about 0.2 % of the world total) of which 42.5% came from the energy and energy transformation industries, 38.8% came from industry and 15.9 % came from transport sector. The per capita emission was 9.25 t CO2e (NEA 2016). The emissions levels reflect Singapore's high economic activity and small land area and small population size.

National energy consumption and GHG emissions

Total final energy consumption

As a densely populated small island state, Singapore has no significant indigenous energy resources and is totally dependent on fossil fuel imports in the form of oil and natural gas for its energy needs. In 2012, Singapore's total final energy consumption was 13,026.0 ktoe (14,549 ktoe in 2014), with the industry-related and transport-related sectors accounting for the major shares of 63.3% and 19.3%, respectively (EMA 2016, 78). The data in Table 1, also shows that the contribution by different energy forms to the final energy consumption is dominated by petroleum products, which account for about

61.0% while that from electricity is about 29.2%. Natural gas final consumption is relatively small and is mainly confined to the industry-related sector.

Table 1 Singapore Final Energy Consumption in 2012 (in ktoe). *Source:* EMA 2016.

Year 2010	Coal and Peat	Petroleum Products	Natural Gas	Electricity	Others	Total
Total Final Energy Consumption	23.1	7,946.8	1,255.5	3,800.6	_	13,026.0
Industry-related Energy Consumption	23.1	5,562.0	1,092.2	1,596.6	_	8,247.2
Transport-related Energy Consumption	_	2,292.7	22.2	200.2	_	2,515.1
Commerce and Service Energy Consumption	_	68.3	83.5	1,407.2	_	1,599.0
Household Energy Consumption	_	23.7	56.9	570.0	_	650.6
Others	_	_	0.8	26.1	_	26.9

Power generation

Natural gas, however, is the main fuel source for power generation in Singapore. Its share in overall fuel mix has grown from 60% in 2003 to almost 95% of electricity generated in 2014 (EMA 2017). Singapore's substantial imports of piped natural gas from Indonesia's gas fields in Sumatera and the Natuna Sea started in 2003 through gas contracts signed with Indonesia in 2001. The share of natural gas a fuel source was further increased in the recent years as a result of national strategy to diversify and increase energy security in 2006 when the government announced plans to build a LNG terminal (MTI 2012).

In 2012 the total energy input for electricity generation from petroleum products and natural gas was 9747.7 ktoe with about 92.4% going to five main power generation companies and remaining 7.6% to the "Autoproducers". The gross generation efficiency in 2012 was approximately 44.8%, achieved through a mix of new and repowered combined cycle power plants, oil-fired steam plants and gas turbines (EMA 2016, 29).

Industry sector Energy Use and Emissions

In 2012, the primary energy consumption (mainly petroleum products and natural gas) of the manufacturing sector which contributed about 19% to the GDP, totaled 6,659 ktoe (NEA 2016, 66). This represented approximately 51% of Singapore's total final energy consumption and about 18.6 million tonnes CO_2 emissions. The Industry Energy Efficiency Technology Roadmap (NCCS 2016a, 2) provides a breakdown of the primary energy use and CO2 emissions by subsector for 2010, as shown in table 2 below.

Table 2 Primary Energy and CO2 Emissions by Industry Subsector. *Source:* NCCS 2016a.

Industry subsector	Primary Energy (%)	Emissions (%)
Chemicals	42	33
Petroleum Refining	34	29
Semiconductor	6	16

Pharmaceuticals	1	2
Food and Beverage	3	3
Printing	1	1
Precision Engineering	4	5
Marine and Offshore	2	2
Medical	<0.5	<0.5
Other	7	9

Three industries namely, the Chemicals, Petroleum Refining and Semiconductor subsectors can be seen to be the major energy consumers and emitters, accounting for approximately 82% of primary energy use and 78% of CO2 emissions from this sector.

Challenges to GHG Emission Reductions

In its Intended Nationally Determined Contribution (INDC), Singapore has committed to reduce its GHG emissions intensity (per unit GDP at 2010 prices) by approximately 36 per cent as compared to 2005 levels by 2030, and to stabilize its emissions with the aim of peaking around 2030 (NCCS 2015). Assuming Singapore achieves its planned reduction of emission intensity (EI) of 1.5% per annum from 2005 by 2020 under its Copenhagen pledge, the 36% emission intensity reduction would imply a peaking at about 65 million tons CO2e by 2030 if an average GDP growth rate of 2.75% per annum is assumed.

However, both the 36% EI reduction and stabilization of emissions are challenging targets under Singapore's national circumstances. There is no potential for alternative energy resources such as wind, hydropower or geothermal energy and nuclear power is currently not an option due to Singapore's small land area and high population density.

Solar Power as a Renewable Energy Source

Located near the equator, Singapore has a tropical climate and solar energy remains the most viable source of renewable energy. However, the deployment of solar power in Singapore faces two main challenges namely, limited land space, and intermittency arising from small land area and cloud cover. The Solar Photovoltaic Roadmap for Singapore (SERIS 2014, 32) estimates that there is potential to install solar PV in an area of 45 sq. km. in Singapore, out of which 34 sq. km. is rooftop space and remaining is space on neighboring islets, facades, and floating panels in reservoirs. Given this space, the study estimates that as much as 5 GWp of PV capacity can be installed in the baseline scenario.

However, despite having average annual irradiation of more than 1,580 kWh/m2/year, there is large variability in solar irradiation due to intermittent cloud cover. As such, the additional balancing power required that would be required to maintain grid stability is a major challenge.

As of now, the total installed solar PV installed capacity is about 125.7 MWp, a small fraction of the 6,733 – 7140 MW monthly peak system demand. In 2014, Singapore's Energy Market Authority released a determination paper which raised the then prevalent threshold on installed PV capacity from 350 MWac to 600 MWac (EMA 2014, 18).

Early Action on Power Generation Emissions

In early 1990s, Singapore's electricity generation industry began to move away from oil-fired steam turbines to natural gas combined cycle (CCGT) power plants. In 2015, the share of natural gas as a fuel source in power generation was approximately 95%. As a result, the overall generation efficiency

reached 48% and the average operating margin grid emission factor reduced to 0.4313 kg CO2 per kWh. Early action taken to use natural gas as a fuel source for power generation has led to high generation efficiencies, and further reduction in the emissions from this sector of the economy is a challenge. Currently, the total generation capacity in Singapore's electricity market is approximately 13,400 MW (EMA 2016, 24) which is almost 90% higher than the average peak monthly demand. A significant portion of this generation capacity consists of F-class CCGT that were installed after 2005, and thus have a large operating lifetime left. As such, further investment in more efficient H-class and J-class CCGTs would seem unlikely turbines in the near term.

National Mitigation Strategies

The constraints resulting from restrictions on renewable energy options and from the early action taken to switch to natural gas powered generation, suggest that GHG mitigation action would have to come from the industry, buildings (commerce & service) and transport sectors. Improving energy efficiencies has been identified as the key strategy to reduce emissions from these sectors. In this section, we outline policies for energy efficiency governance, implementation, and research & development for each of the sectors –industry, buildings, and transport.

Industrial Energy Efficiency

The Energy Conservation Act (ECA) 2012 is the primary legislation in Singapore that mandates businesses to measure and report their energy consumption. Under the act, which came into effect on 22 April 2013, businesses that use 54 or more Terajoules (TJ) of energy per year are required to appoint an energy manager; monitor and report energy use and GHG emissions; and submit energy efficiency improvement plans annually.

However, the act does not mandate achieving the energy efficiency measures listed in the improvement plans. To enable businesses to undertake energy efficiency improvement projects, Singapore has set up a number of incentives and grant schemes. These include the Productivity Grant (Energy Efficiency) formally known as Grant for Energy Efficient Technologies (GREET) which provides funding up to 20% of qualifying costs capped at $4 million per project for existing or proposed industrial facilities to invest in energy efficient equipment and technologies (E^2PO 2017a). Similarly, under the Design for Efficiency Scheme (DfE), funding is provided up to 50% of the qualifying costs or $600,000 with the objective of encouraging new facilities or expansion projects to integrate energy efficiency improvements in the design stage (E^2PO 2017b).

Specifically for SMEs, the National Small and Medium-Sized Enterprise Energy Efficiency (SMEEE) Initiative has a budget of S$17 million to help approximately 300 such enterprises achieve at least 10 per cent savings in energy costs. It does this by covering costs for energy audits, setting up of an Energy Monitoring System, implementation of efficiency projects, and leadership training (SEAS 2014).

To understand the overall potential for energy efficiency improvement in the industrial sector, a study was commissioned by Singapore's National Climate Change Secretariat in 2014. The study identified various processes and equipment in each major manufacturing sector where energy efficiency could be improved. The study found potential for energy savings of about 20 per cent by 2030.

However, analysis conducted in 2016 found that companies in Singapore achieved an energy efficiency improvement rate of only 0.4 per cent in 2014 and 0.6 per cent in 2015. To further improve these numbers, a number of enhancements have been made to the ECA, which will come into effect in 2018 (NEA 2017a).

Besides implementing a verifiable GHG emissions monitoring plan and submission of an enhanced emissions report, companies must review the design of any proposed new industrial facility or major expansions to ensure that they do not invest in oversized, energy inefficient equipment as is the current

practice. Furthermore, all such facilities will also have to install instruments and meters at system level, and report their energy performance based on metered data. On the other hand, existing facilities will be required to implement a structured energy management system and periodically conduct "Energy Efficiency Opportunities Assessments" (EEOA) covering energy systems that account for at least 80 per cent of total consumption. Facilities with energy consumption greater than 500 TJ per year must carry out an EEOA once every six years, whereas smaller facilities must assess the need for an EEOA every three years.

To support industry in adoption of energy efficient equipment, there are also plans to introduce Minimum Energy Performance Standards for common industrial equipment and systems, beginning with single speed 3-phase induction motors in 2018.

Furthermore, to simplify the various financial incentives and grants offered to incentivize energy efficiency, a new single Energy Efficiency Fund (E2F) has been developed. The fund, thus supports energy efficient design in planned new facilities and expansions, energy assessment and performance monitoring, and up to 30 per cent of investment cost of energy efficient equipment.

Building Energy Efficiency

The Commerce & Services related sector accounts for the third largest share of final energy consumption in Singapore. Broadly speaking, this sector includes wholesale & retail trade, accommodation & food service, real estate, financial & insurance activities, public administration, health, social services, and education amongst others. Consequently, its energy use is dominated by the consumption of electricity in non-residential buildings and therefore, improving building energy efficiency is one of Singapore's major mitigation strategies. As a result, Singapore has set a target of achieving 80 percent green buildings by 2030 (BCA 2017, 5).

To achieve this target, Singapore introduced the Building Control (Environmental Sustainability) Regulations in 2008. Under this law, a minimum environmental sustainability standard (equivalent to a "Green Mark Certified" level) is required for new buildings and existing buildings undergoing retrofits or expansions, with a Gross Floor Area of more than 2000 sq. m. (BCA 2008). Compliance with this regulation requires buildings to achieve 28 percent energy efficiency improvement as compared to the 2005 building codes.

The Green Mark is an assessment scheme which evaluates the overall environmental performance of buildings on multiple criteria and was launched by Singapore's Building and Construction Authority (BCA) in 2005. Under the scheme, buildings are awarded four types of ratings based on their assessment score: Certified rating for a score between 50 and 74, Gold for 75 to 84, GoldPlus for 85 to 89, and Platinum for a score of 90 and above. The maximum points that could be awarded to a building were 190, out of which 116 points were for energy efficiency related criteria such as air conditioning system performance (BCA 2013). However, the latest edition of the scheme, applicable since November 2016, has changed the points system and the assessment criteria. Out of a maximum total of 140 points, building energy performance now accounts for a maximum of 30 points with categories such as climate responsive design, resource stewardship, and smart & healthy buildings accounting for 30 points each. For existing non – residential buildings, the assessment criteria has remained unchanged since 2012, with energy efficiency accounting for maximum of 89 points and all other criteria accounting for a total of 91 points (BCA 2016).

To encourage building developers and owners to incorporate energy efficient design and equipment in buildings and achieve higher Green Mark ratings, the BCA offers a number of incentive schemes. These include the Green Mark Gross Floor Area (GM GFA) scheme which grants permission to develop an additional floor area of 2 percent to developments that attain Platinum rating and 1 percent to those that attain the GoldPlus rating. The Green Mark Incentive Scheme - Design Prototype (GMIS-DP)

is a 5 million dollar fund that provides funding at the design stage of the building to hire expert design consultants, conduct workshops and simulation studies, and come up with optimal green building designs.

For existing buildings, the Green Mark Incentive Scheme for Existing Buildings and Premises (GMIS-EBP) provides cash incentives to offset up to 50 percent of the costs to retrofit buildings to improve their energy efficiency. The scheme is mostly targeted towards commercial buildings whose owners or tenants are Small and Medium Enterprises (SMEs) such as shopping malls, offices, and other buildings such as premises of NGOs, welfare organizations and religious organizations etc. The Building Retrofit Energy Efficiency Financing (BREEF) is another scheme that facilitates financing of green building development at lower interest rates by making the BCA a party that will share the risk of loan defaults with financial institutions that provide loans for carrying out green retrofits.

As a result of the legislation and incentive schemes, there are more than 2800 Green Mark building projects as of 2015. These represent more than 31 percent of Singapore's entire building stock. Studies have found that Green Mark commercial buildings demonstrate 9 – 13 percent lower energy use intensity (EUI) as compared to non-Green Mark commercial buildings. As a result, the EUI of the commercial building stock has shown a 7 percent improvement from 2008 to 2015 (BCA 2017, 5).

Transport Energy Efficiency

Singapore is considered to be one of the most expensive places in the world to own a car. This is primarily because vehicles are taxed more than 100 per cent of their open market value. Furthermore, a prospective vehicle owner must own a Certificate of Entitlement (COE) before purchasing a vehicle. A limited number of COEs are auctioned by the Singapore government every month and the average price for a certificate for a car upto 1600 cc has hovered around S$ 50,000 in 2017 (LTA 2017a). The limited number of certificates available for auction also ensures that the total number of private vehicles is restricted.

In addition to these policies, Singapore also introduced an additional tax on vehicles based on their carbon emissions in 2013. The Carbon Emissions-Based Vehicle Scheme (CEVS) applies a surcharge on vehicles that emit more than 185 gCO2/km, whilst providing a rebate to vehicles that emit less than 135 gCO2/km. As a result, the scheme incentivizes investment into energy efficient cars, particularly petrol-electric hybrids whose numbers have gone up steadily in recent years (LTA 2017b). Government studies estimate that the average CO2 emissions of new cars and taxis have reduced by about 15 percent since the CEVS was introduced (NEA 2017b).

The Fuel Economy Labelling Scheme (FELS), introduced in 2012, mandates a Fuel Economy Label on cars and light goods on display for sale. The label provides information on car's fuel consumption (litres/100km), CO2 emissions (gCO2/km), and the CO2 emission and fuel consumption comparison with respect to other vehicles in Singapore (LTA 2012).

Furthermore, Singapore has targeted to increase the modal share of public transport from 59 percent in morning peak hours in 2008, to 75 percent modal share in morning and evening peak hours by 2030. To achieve this target, the length of the rail network system is planned to be increased from 178 km in 2012 to about 360 km by 2030, accompanied by a rapid growth in the bus fleet (NCCS 2016b, 18).

Market Mechanisms

Besides energy efficiency measures, the Singapore government is also considering using market mechanisms as a means to push through its energy efficiency objectives. In February 2017, the Minister for Finance announced plans to introduce a carbon tax on large direct emitters of GHGs such as power stations and the refining and petrochemical industry. The carbon tax will be implemented in 2019 and the tax level will be between $10 - $20 per tonne of direct emissions and covered installations with direct emissions greater than 25,000 tonnes of CO2e.

While there are no indications of the tax revenue being hypothecated for financing energy efficiency initiatives, initial analysis using Computable general equilibrium (CGE) models have found that recycling the tax revenue back to the industry will result in higher overall benefits as compared to recycling the revenue to households or no revenue recycling at all.

Achieving 2020 and 2030 Emissions Targets

2020 Mitigation Target

Assuming a Business as Usual (BAU) scenario from 2005, it was estimated that Singapore's emissions would reach 77.2 million tonnes (MT) CO2e by 2020 (NCCS 2012, 43). The 2009 Copenhagen pledge of reducing emissions by 16% below 2020 levels implied a mitigation reduction of approximately 12.35 million tonnes. Strategies and polices for reducing emissions including fuel switching, deployment of solar PV, and energy efficiency improvements for each major sector namely industry, buildings, and transport, have been discussed in the preceding section.

Various government agencies are responsible for implementation, monitoring and documentation of mitigation actions under their purview. The information collected by the lead agencies is then consolidated by the Long Term Emissions and Mitigation Working Group (LWG), a working group under the Inter-Ministerial Committee on Climate Change. The LWG assesses the collective impact of various mitigation measures and tracks Singapore's progress towards meeting the overall objectives.

The projected quantified mitigation goals for each sector to meet the 2020 pledge are given in the Second Biennial Update Report (BUR2) submitted to the UNFCCC in December 2016 (NEA 2016) and are summarized as given in Table 3.

Table 3: Singapore's Sectoral Mitigation Goals Results Achieved. *Source:* NEA 2016.

Mitigation Action	2020 Mitigation Goal (MtCO2e)	Results Achieved 2014 (MtCO2e)
Fuel mix switch in power generation	4	4
Solar PV	0.179	0.015
Cogeneration plants	0.73	0.488
Manufacturing energy efficiency	0.4	0.472
Fuel mix switch in industry	0.07	0.07
Data center energy efficiency	0.04	0.00028
Green mark in new buildings	0.47	0.364
Green mark in existing buildings	1.08	0.131
Increasing public transport modal share	0.78	0.38
Off peak vehicles and non-motorised transport	0.2	0.05
Car/Taxi fuel efficiency CEVS*	0.67	0.05
Green Technology Programme**	0.1	0.01
MEPS*** for households	0.79	0.44
Promotion of energy efficiency in households	0.28	0
Wastewater sludge disposal by incineration	0.1	0.08
Increase overall recycling rate	0.05	NIL
Total	**9.939**	**6.550**

It can be seen from the table that the total mitigation goal falls short of the pledged reduction of 12.35 MT. The goal set for the industry sector in terms of manufacturing energy efficiency and fuel mix switch of 0.47 MT seems modest in terms of the industry sector's total primary emissions of 6.654 MT in 2014 and which also accounts for 1596.6 ktoe or 42% of the total national electricity consumption. It is

also observed that are significant emission reductions to be achieved under green mark for existing buildings and fuel efficiency in cars and taxis. However, as per the statement by the Minister for the Environment and Water Resources at UNFCCC COP-22, Singapore is on track to meet its Copenhagen pledge (UNFCCC 2016). The total mitigation goal and emission reductions achieved can be expected to be revised upwards in the next few years in view of the announced implementation of the carbon tax in 2019.

2030 INDC target

Singapore's INDC target aims to reduce it emission intensity by 36% in 2030 from 2005 levels and to peak its absolute emissions around 2030 at about 65 million tonnes CO2e. Achieving this target will be challenging in the context of Singapore's national circumstances and early action taken in power generation sector.

As improving energy efficiency is a key strategy to achieve its 2030 target, Singapore has developed the industry energy efficiency technology roadmap (the Roadmap) to identify the technological potential and opportunities to reduce energy use from business-as-usual levels up to 2030. Focusing on the five main subsectors of the industry, the Roadmap estimated that the technical potential energy savings from the best available technologies that are currently not in use and next generation technologies to be 18.8% of the projected 2030 levels. The corresponding technical potential reduction in emissions from 2030 levels is 20.4% (NCCS 2016a).

There is no published data on the total or industry-related BAU emissions levels. A projection of emission levels based on Singapore's 2020 target of 65 MT CO2e and on CAGR of 2.0 % over a 10-year period estimates the emission in 2030 of 79.3 MT CO2e. A further assumption of constant share of the industry-level contribution of 42.2 % (2012 share) gives a projected industry-related emission level of 43.9 MT CO2e. The Roadmap's estimated reduction potential indicates a reduction level of about 9 MT in 2030 for the industry sector. It is envisaged that the Energy Efficiency Fund established to provide assistance to industry, the proposed enhancements of the Energy Conservation Act, and the carbon tax to be implemented from 2019 would provide the needed incentives for the industry-related sector to achieve this target.

For the buildings sector, the major improvement in energy efficiency will be achieved by ensuring that all new buildings confirm to the requirements of the Green Mark standard and that the existing building stock is also retrofitted to be energy efficient in an organized manner. In a short time since the Green Mark was introduced, already 31% of Singapore's entire building stock has confirmed to the standard.

The main strategy in reducing emissions in the transport sector is expected to be through achieving a 75% modal share of public transport by 2030. Current policy to curb the growth of vehicle population and discourage use of private transport through heavy taxation and limited availability of car ownership certificates have worked well and would be supplemented by high vehicle taxes and fuel duties.

The power generation sector contributes about 43% of the total emissions, however, reducing emissions in this major sector is most challenging in the near term. With peak electricity demand in 2030 expected to reach anywhere between 8 – 9 GW by 2030, integration of 1 GW of solar PV would contribute only a small portion of the overall system demand. Import of zero carbon renewable electricity from Singapore's ASEAN neighbors is another option. A study by Ahmed et al. (2017) estimates that the ASEAN region has a total renewable energy potential of 344 GW. The Mekong basin countries, namely Cambodia, Lao PDR and Myanmar have hydropower sources that could exceed their respective country demand.

The ASEAN interconnection master plan working group estimates that 19,596 MW of cross-border power trade and 3000 MW of cross border power exchanges will be established by 2025. The Laos-Thailand-Malaysia-Singapore (LTMS) Power Integration Project (PIP) working group has been established to study the viability of 100MW of cross-border power trade from Lao PDR to Singapore (MTI 2014). This project and other envisaged projects such as the Sumatra-Singapore cross-border project under the

ASEAN power grid suggest potential for power purchase and emission reductions in Singapore's power generation sector in the longer term.

Conclusion

Due to its small land size, dense population, lack of alternative energy resources and being totally dependent on fossil fuel imports, energy efficiency is the key strategy for Singapore to reduce its GHG emissions. Early action taken to switch to natural gas makes GHG mitigation even more challenging. Policies and measure to increase energy efficiency are in place in all sectors of the economy. A national climate action plan outlining strategies to improve energy and carbon efficiency and achieve its 2030 pledged has been published. Current efforts are on track to meet Singapore's 2009 Copenhagen pledge target.

While reducing emissions in the power generation sector remains a challenge in the near term, emission reductions in other sectors of the economy, including the industry-related sector have been identified. In the words of Foreign Minister Vivian Balakrishnan, Singapore's 2030 pledge is unconditional and *"… is one that we believe is not only achievable, but also good for us"* (The Straits Times 2015).

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