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PURSUING GROWTH AND MANAGING THE ENVIRONMENT: THE SINGAPORE MODEL*

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Since its independence, Singapore has faced a tradeoff between increasing economic growth and maintaining environmental quality. We qualitatively assess Singapore's success in managing these tradeoffs. We present, illustrate and discuss seven strategies that have contributed to this, namely (I) Spearheading of Green Industrialization Efforts by the State; (II) Environmental Regulations; (III) Quantification of Economic Benefits from Going Green; (IV) Active Engagement of Stakeholders; (V) Use of Market Instruments; (VI) Use of Behavioral Interventions; (VII) Investment in Renewable and Clean Technologies. We also highlight some areas for improvement, as well as provide some insights on the thought processes behind certain policies and suggestions as to how these strategies can be refined where applicable.

Keywords: Tradeoffs; environmental sustainability; economic growth; Singapore.

1. Introduction

In more than 50 years since its independence in 1965, Singapore has achieved much economic progress from a low GDP per capita of $1,581 at current SGD ($516.535 at current USD) to about $97,798 ($72,599 at current USD) in 2021. Singapore was second in the world by GDP per capita at purchasing power parity (PPP) in 2020 and was placed first

* This journal article is originally based on Quah (2020).

in Asia and 12th globally, in the Human Development Index in that same year.[1] In addition, Singapore also topped Asia and ranked 8th globally in the Schroders Global Cities Index in 2021, which identifies and ranks cities based on their economic, environmental, innovation and transport performance (Kerk, 2022). More recently, Singapore was once again touted as the "the most liveable location in the world for expatriates from East Asia in 2022" based on ECA International's Location Ratings.[2]

Much of Singapore's landscape was also significantly transformed to become today's thriving modern metropolis surrounded and infused with much greenery. By the 1990s, Singapore was transformed into an attractive global city, and the clean and green environment became Singapore's fame. This came not by chance but by meticulously planned efforts to ensure growth with sustainable development.

Economic growth has historically taken center stage and has always been the backbone of the country's material progress. There were good reasons for this. In the early years of independence, Singapore faced existential challenges. Real income per capita was only approximately one-twelfth of what it is today. The unemployment rate was between 10% and 12%. The emphasis on economic growth can be easily observed from the policies adopted then. Doors were opened, and red carpets were rolled out to attract foreign direct investment (FDI). The Economic Development Board (EDB) was set up and specifically linked to FDI inflows, a crucial mandate that has remained largely unchanged till now. Foreign trade agreements were also actively pursued to expand Singapore's export market.

However, economic growth per se was not pursued without acknowledging some major environmental concerns. It was recognized that Singapore's small geographical area would mean that the living environment and industrial activities needed to find a space for coexistence. As such, the paradigm was that while economic growth was extremely important and had to be pursued, serious consideration would still be paid out to the living and natural environment. These considerations and their outcomes can be categorized as such:

First and most importantly is the notion that economic growth is not the be-all and the end-all for a good quality of life. Conserving the living and natural environment is a very important factor. In such a case, Singapore was and is still prepared to accept some degree of tradeoffs between further economic growth and negative environmental impacts. Since independence to the present, Singapore has carefully weighed the consequences of further growth with that of diminished greenery and mitigated significant harms from development and growth. Browning the economy through intensive industrialization was followed closely by greening the economy so that the pursuit of growth would not come at the expense of environmental degradation. The Singapore government being at the forefront of both industrialization and environmental policies has allowed for this tradeoff to be carefully and prudently managed.

Secondly, taking the lead in economic development and resource management has enabled the Singapore government to enforce law and order to ensure that economic and

[1] See https://www.theglobaleconomy.com/rankings/human_development/
[2] See https://www.eca-international.com/news/march-2022/singapore-is-once-again-the-most-liveable-location

environmental outcomes are achieved as intended. Since the early days post-independence, land zoning was carried out, and efficient land use planning was also outlined in both the long-term concept plan and the midterm masterplan by the Singapore government. Much consideration was also given to the need to increase land supply through reclamation, and improve land use through vertical urbanization, and improve land use through vertical urbanization, and in more recent decades, more eco-friendly buildings and eco-smart lifestyles. Pollutive industries were located as far away as possible from residential areas. Standards on waste and pollutant discharge — policies that were not commonly observed in developing countries — were enforced from the start.

Third is the engagement of experts, intellectuals and scientists, within and outside of Singapore, from the private sector, academia and the wider civic society. Crucial to this is the gathering and analysis of critical data first to establish environmental baselines, and the estimation of the environmental cost from infrastructure and commercial projects. Singapore recognizes the importance of a multi-stakeholder approach in evaluating environmental policies accurately, providing opportunities for collaboration and ensuring that the views of all members of society are encompassed.

The fourth, fifth and sixth strategies are about the use of both active and passive incentives/disincentives to encourage businesses and consumers to go green. Showing that it pays to go green and assisting in that regard, having the willingness to explore the use of market instruments as well as promoting green consumerism and practices have contributed to the embracement of integrating sustainability in the livelihoods of Singaporeans.

Last but not least, the surge in momentum toward moving to a truly carbon-free nation has brought investment in renewable and clean energies into the limelight during the past and present decades. Such alternative energies, while still expensive to implement on a wide scale, have been gaining traction in terms of cost savings with recent advancements in technology and the provision of more governmental support. Therefore, they stand to become more commercially viable in the near future.

In managing these tradeoffs however, possible areas for improvement include but not limited to (i) biodiversity protection and conservation; (ii) pricing of ecosystem services, climate change damages, as well as environmental impacts of car-pooling services and renewable technologies; (iii) attenuation of socio-cultural barriers in the promotion of energy efficiency and effective waste management; (iv) more transparent and structured methodologies in carbon pricing and abatement targets; (v) reducing reliance on imported fuels; (vi) market instruments with stronger social safety nets. We posit that the above seven key strategies can be refined to address these challenges.

The remainder of this paper is as follows. Section 2 explains some factors that contribute to the tradeoffs and studies that have attempted to quantify these tradeoffs. Section 3 describes and examines the seven key strategies in greater detail. The last section concludes the paper.

2. Choices and Tradeoffs

The tension between the economy and the environment often results in governments having to prioritize one over another when allocating resources. While all countries face

this challenge, Singapore's size and unique circumstances make the tradeoffs especially stark.

Economic growth entails greater production and consumption of goods and services. This inevitably involves higher levels of energy consumption. How best to meet this increased energy demand forms a major challenge that Singapore faces.

Based on data from 1995 to 2014 in major Asia-Pacific Economic Cooperation (APEC) economies, which include Singapore, it was found that the electricity price for industry had a significant negative impact on the competitiveness of energy-intensive industries, as proxied by relative trade balance (APERC, 2016). Therefore, to maintain competitiveness, Singapore needs to keep energy cost low. If cost were the only consideration, coal would definitely be the fuel of choice. However, coal emits the most carbon dioxide when burnt and is the most pollutive of fossil fuel. Again, the pressure to maintain competitive and environmental considerations pulls Singapore in two different directions. The problem is compounded by the fact that Singapore is deficient in renewable energy.

Waste generation, on the other hand, presents another challenge as it is a by-product of growth. With growth, there is greater output and consumption that both contribute to waste. Treatment and decomposition of waste contribute to greenhouse gas (GHG) emissions. The restricted land space would mean that the conventional landfill would not be a good option. Since 1986, there are six waste-to-energy (WTE) incineration plants to treat combustible mixed waste: Tuas Incineration Plant (recently decommissioned), Senoko WTE Plant, Tuas South Incineration Plant, Keppel Seghers Tuas WTE Plant, TuasOne WTE Plant and the upcoming Tuas-Nexus Integrated Waste Management Facility, with the resulting incinerated ash and other non-incinerable waste being sent to the Tuas Marine Transfer Station for disposal at the offshore Semakau Landfill. There is a need to increase incineration capacity and utilize green technologies to shrink the volume of mixed municipal solid waste significantly, extract useful materials and recover energy. The Semakau Landfill is expected to reach peak capacity by 2035 given the current rate of waste growth, and that constructing new WTEs as well as offshore landfills over the next few decades is not a viable option given land scarcity, the issue of which is compounded by Singapore's aggressive land reclamation projects.

Singapore's ageing population and very low fertility rate will also present serious challenges as labor is also necessary for economic growth. Both energy and population constraints mean that economic growth will slow down and may even be negative. Increasing emphasis on environmental protection and conservation campaigns may put more pressure on urban land utilization planning and the green premium may exacerbate the rising cost of living in Singapore. All these pose significant challenges in maintaining a delicate balance between Singapore's environmental sustainability and economic growth.

The restrictions imposed on economic activities due to the long-withstanding COVID-19 pandemic have caused global economies to slow down and inadvertently provided an opportunity for government and society to re-evaluate and appreciate the sustainable use of resources more urgently and critically. Improving air quality in buildings with architectural redesigns is also said to have a significant role to play in stemming the spread of COVID-19 (BCA, 2020). In view of the job losses caused by the pandemic, much consideration

was also given to creating new job opportunities in the sustainability sector (Sambhi, 2020). The fact that the Singapore government pushed ahead with the Singapore Green Plan (SGP) 2030 despite the economic uncertainties caused by the pandemic reflects the urgency and importance of post-COVID-19 green recovery.

2.1. *Possible ways of quantifying these tradeoffs*

The tradeoff between economic growth and environmental quality traditionally stems from the concept of the Environmental Kuznets Curve (EKC) which hypothesizes an inverted U-shaped relationship between indicators of environmental quality and economic growth. The EKC shows that environmental degradation is unavoidable for a country during its early stages of economic development due to the high opportunity cost, knowledge and resolution to regulate polluters, especially given a richer initial endowment of environmental resources to work with. Nevertheless, as the country reaches an affluence threshold, the degradation in environmental quality becomes more apparent with increased industrialization activities and consumption. The marginal benefit of protecting the environment starts to outweigh the marginal cost in doing so which causes more national emphasis to be placed on environmental protection measures without compromising on subsequent economic growth (Vogel, 1999; Tan *et al.*, 2014).

Two studies found empirical evidence suggestive of an inverted U-shaped EKC in Singapore. The first study by Chen and Taylor (2019) used atmospheric emissions of a heavy metal (chromium, Cr)[3] as a proxy of environmental quality due to the significance of its immediate environmental impact during the period of heavy industrialization in Singapore and GDP per capita as a proxy for economic growth. They also controlled for foreign direct investments (FDI) and trade openness (IE) as proxies for pollution haven effects, as well as the existence of atmospheric environmental regulations. Under these conditions, they estimated the long-run relationship and found that the turning point of a potential EKC happened in 1999–2000 and was estimated to be at 33,080 USD (in 2010 dollars). The second study by Tan *et al.* (2014) analyzed how GDP per capita as an indicator of economic growth and energy consumption per capita (proxied by electricity production and total energy consumption), led to an increase in carbon dioxide emissions per capita as an indicator of environmental degradation. They found that if electricity production was used as a proxy for energy consumption per capita, Singapore would still be on the left-hand side of the inverted EKC curve in 2011. If total energy consumption was used instead, then there is some evidence that the turning point of the EKC was achieved in 2010–2011.

However, it should be noted that the EKC offers a superficial analysis of this tradeoff due to its assumptions of near-optimal behavior. In reality, polluters and pollutees may not have aligned interests thus demand and supply of pollution abatement activities would not

[3] Originally, there were eight activities/industries associated with Cr emissions in Singapore, including that of steel manufacturing, bricks and cement works.

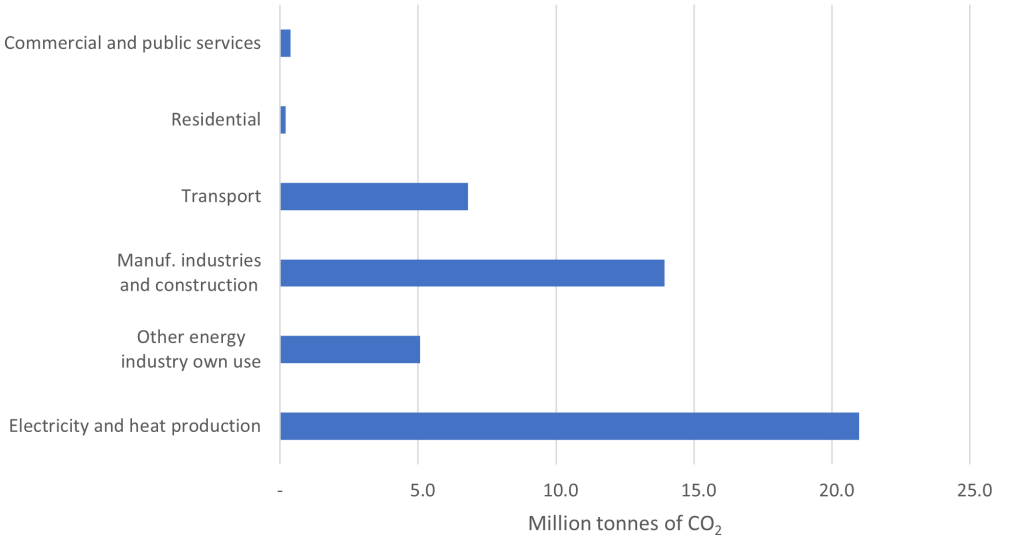
intersect. Even if they do, because of the non-market, public characteristics that are associated with environmental quality, it may not be rational from a business perspective for polluters to undertake private pollution abatement activities.

Another argument is that the EKC does not reflect the complexity of various agents either directly or indirectly involved in environmental outcomes (Vogel, 1999). For example, since the 1990s, after the succession of second-generation leaders, the sphere of environmental governance in Singapore began to be influenced by an increasing environmental awareness characterized by the emergence of environmental nongovernmental organisations (ENGOs) and lobbyists, accompanied by a more formulated and inclusive environmental policy (Han, 2017; Japan MSE, n.d.). Currently, there are about 55 such ENGOs and organisations closely linked to sustainability acknowledged by the government in the Singapore Green Landscape 2020.[4] The Nature Society Singapore (NSS) has made substantial contributions to flora and fauna conservation and restoration efforts both independently and by assisting environmental institutions created by the government such as the Nature Reserves Board (NRB), Parks and Recreation Department (PRD) and National Parks Board (NParks).

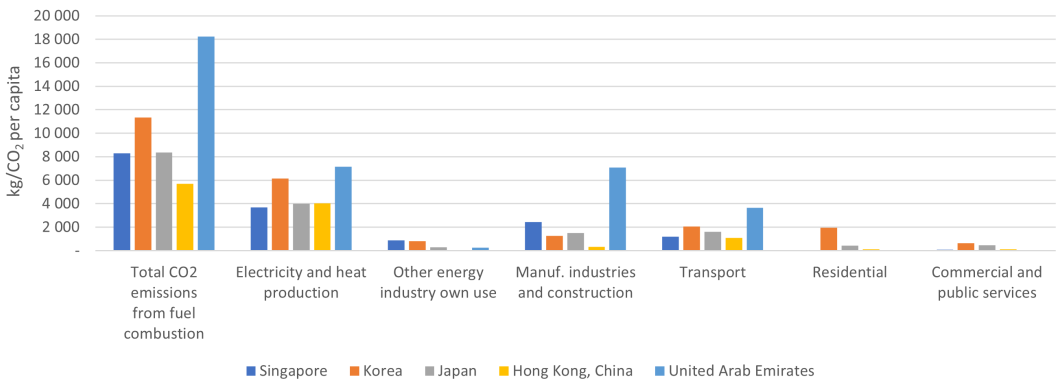
Other objections to the EKC include the fact that it only applies to certain attributes such as industrial pollution, air pollution or illegal dumping and does not account for irreversible environmental damages such as biodiversity. For example, due to warmer seas and early unsuccessful attempts at relocation to accommodate land reclamation works, mass coral bleaching beyond remediation had ensued, causing the intertidal coral reef habitat area to shrink thrice from its original area since 1953. Coral restoration efforts are resource-intensive not just from the perspective of income but also requires scientific knowledge and stakeholder engagement, which the EKC does not capture (Ng and Chou, 2017).

The implicit assumption that abatement technology or less-polluting alternative processes are sufficiently efficient or available may not hold true for all sectors of the economy, even with modern advances in environmental technologies (Vogel, 1999). For example, as seen in Fig. 1(a), energy or emission intensive sectors in Singapore such as power generation, manufacturing (e.g. in semiconductor and petrochemicals) and transport may take a longer time to reduce their resource usage and waste generated but is not captured in the EKC (Su *et al.*, 2017). A sectoral comparison with other economies that exhibit similar characteristics to Singapore shows that the intensities of Singapore's carbon emissions per capita from those sectors are relatively significant (see Fig. 1(b)). Wolf *et al.* (2022) ascertain this point by empirically showing that across countries, a sensible correlation only significantly applies to more material attributes such as sanitation and drinking water but not for less material ones such as biodiversity and habitat protection and provision of ecosystem services. Therefore, income alone is not a good predictor of the variation in environmental quality.

[4] See http://www.greenfuture.sg/singapore-green-landscape-2020/ngos-and-non-profits/#:~:text=Here%20is%20a%20list%20of,and%20related%20to%20the%20environment.



(a) Singapore's CO_2 emissions from fuel combustion by sector in 2019



(b) Comparison of per capita emissions by sector in 2019 between selected economies

Source: IEA (2021).

Fig. 1.

2.2. *Other tradeoff considerations*

In the case of climate change, while carbon taxes will help reduce the carbon emissions and slow down global warming, mitigations and adaptations will be made to accommodate the reality of an already warmer world. With the high urban density trapping heat in the atmosphere and about 30% of Singapore's land being less than 5 m above sea level, Singapore is especially vulnerable to the effects of climate change. By the end of the century, Singapore's temperature is expected to rise by about 1.4°C to 4.6°C, experience more intense and frequent heavy rainfall events, and see an increase of mean sea level rise

of up to 1 m.[5] Therefore, with time, the external costs of environmental pollution imposed on society and the benefits of mitigation and adaptation measures may be progressively given more weightage.

Mitigation measures are primarily policy interventions, as well as public and private initiatives that specifically aim to reduce and curb greenhouse gas emissions by addressing the sources of these emissions e.g. increasing the share of renewable energy in the overall mix and planting more trees to enhance natural sinks. On the contrary, adaptation measures are understood to be adjustments made to human systems and lifestyles to accommodate to, minimize or prevent various types of present and future damages associated with climate change e.g. infrastructure that is flood- and heat-resilient, as well as behavioral shifts to reduce waste and crop strain diversification. As shall be highlighted in Sec. 3, the Singapore government has implemented a mix of both mitigation and adaptation measures.

There are two kinds of tradeoffs to bear in mind when drafting climate policies: (I) Costs of implementation vs. costs of damages and (II) Resource allocation between mitigation and adaptation measures. The marginal costs of implementing climate protection measures should be lower than the marginal damage costs of climate change to the economy and society for climate protection measures to be worth undertaking. The lower the mitigation efforts, the more severe global warming will be, thus necessitating more adaptation measures. If successful mitigation efforts are higher, that would imply that fewer adaptation measures are required, as well as leaving less adaptation efforts feasible or desirable (Seah *et al.*, 2019; Tol, 2007). A baseline alternative scenario should also be established as a point of reference to evaluate if the overall socio-economic impacts have increased or decreased after the implementation of climate policies.

It is also important to consider the mode of payment vehicle for the overall national adaptation cost to ensure that socioeconomic stability is not compromised while hedging against climate change risks. The Ministry of Finance has drawn up three options: (I) By tax revenue and return on investments from ministerial budgets; (II) By borrowing i.e. issuance of government infrastructural bonds; (III) By drawing down on past reserves. These options can be used in combination with one another, and the extent of each would depend on how much weight is assigned to the various adaptation measures to be adopted. For example, option (I) would be sufficient to fund smaller-scale infrastructure such as localized flood barriers that protect public goods, while option (II) would be more suitable to fund larger-scale infrastructure with long life cycles such as sea walls as it will enable the distribution of costs across generations that have standing. Future generations tend to benefit more from climate change adaptation measures due to greater severity of climate-related incidents with time. Therefore, imposing a larger cost burden of loan repayment to present investors on future generations would allow for the addressment of intergenerational equity concerns. Option (III) would be most appropriate to fund land reclamation

[5] See https://www.nccs.gov.sg/faqs/impact-of-climate-change-and-adaptation-measures/#:~:text=The%20Centre%20for%20Climate%20Research,to%201%20metre%20by%202100.

Table 1. Singapore's environmental performance index performance.

Year	EPI Global Ranking[a]	EPI Regional Ranking[b]	EPI ASEAN Ranking[c]
2010	28	2	1
2012	52	9	5
2014	4	1	1
2016	14	1	1
2018	49	3	1
2020	39	3	1
2022	44	2	1

Source: Emerson *et al.* (2012); Hsu *et al.* (2014, 2016), Wendling *et al.* (2018, 2020); Wolf *et al.* (2022).

[a]Global ranking based on 163 countries in 2012, 132 countries in 2014, 178 countries in 2016 and 180 countries in 2018–2022.

[b]Regional ranking based on the following Asian countries (tentatively): Japan, Taiwan, Singapore, Brunei Darussalam, South Korea, Sri Lanka, Malaysia, Philippines, Mongolia, Maldives, China, Thailand, Micronesia, Timor-Leste, Bhutan, Vietnam, Indonesia, Myanmar, Cambodia, Laos, Papua New Guinea, Afghanistan, Pakistan, Nepal, India, Bangladesh.

[c]ASEAN countries include Singapore, Brunei Darussalam, Malaysia, Thailand, Vietnam, Philippines, Cambodia, Indonesia, Laos, Myanmar.

costs from building polders or reclaiming offshore islands as it is already in accordance with the Reserves Protection Framework, which is mutually agreed upon by the government and the President of Singapore. Fiscal sustainability concerns are allayed because when the reclaimed land is eventually sold, the proceeds would accrue fully to past reserves (Mahmud, 2019; Lim, 2019).

3. Elements of Success

While Singapore has been quite successful in transforming itself into the modern and prosperous metropolis as we know today, Singapore is also well known as a garden city and for its sustainable development. As Table 1 shows, in 2022, Singapore is ranked 44th globally, 2nd in Asia and 1st among ASEAN countries in the Environmental Performance Index (EPI), which currently ranks countries based on 40 performance indicators across 11 environmental issue categories under 3 policy objectives (Wolf *et al.*, 2022). Within these objectives, Singapore fared best in environmental health, followed by climate change mitigation and lastly ecosystem vitality.

What have been some of the strategies that have contributed to this? The Japanese government noted that the reasons for Singapore's effective concomitant strategy of pursuing both economic development and environmental protection essentially boiled down to three elements of good governance, namely environmental monitoring, law enforcement and pollution prevention (Japan MSE, n.d.). Tan and Kwek (2015) noted that the successful implementation of environmental management policy while maintaining the objectives of economic growth in Singapore is very much attributable to the strong political leadership in Singapore. Indeed, in 2022, Singapore ranked first in the Elite

Quality Index (EQx), which measures the quality of the political leadership across countries in the areas of value creation and economic growth, for the third year consecutively out of 151 countries.[6] This was complemented by an effective and efficient public sector, a competitive and socially responsible private sector, as well as public participation and ownership in environmental efforts (Tan and Kwek, 2015).

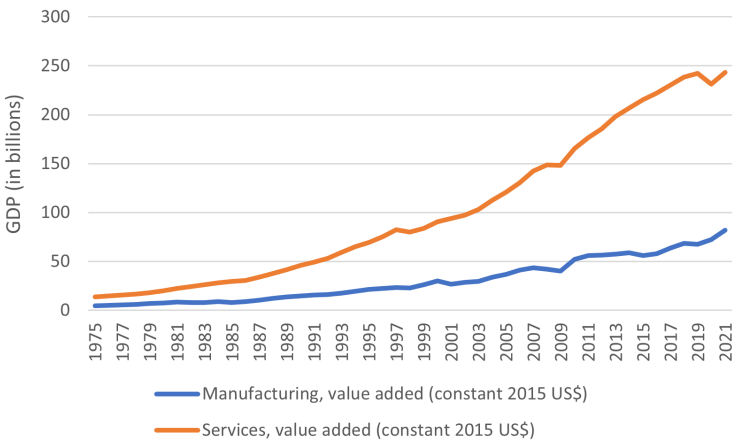
It should not be ignored, however, that Singapore saw a slight dip in its EPI global ranking from 2020 to 2022. This suggests that other countries are catching up swiftly in the quality of their environmental management policies and Singapore's current success trajectory may be culminating and restrained by its existing tradeoff challenges pertaining to energy efficiency, climate change mitigation, waste management and biodiversity.

In consideration of the existing literature, as well as past and present developments, we propose seven significant strategies, which are closely interrelated.

3.1. *Spearheading of green industrialization efforts by the state*

The Singapore government traditionally takes the lead in environmental policy making by adopting an authoritative, technocratic and managerial approach, which is similar to its approach to economic development. It was argued that Singapore traditionally maintains a "utilitarian and instrumental" perspective toward the environment, whereby green initiatives that generate present material value or those that were aligned with the objective of economic competitiveness are prioritized. Essentially, the state acts as a central planning bureau and appoints an executive agency to mobilize its environmental decisions (Han, 2017). This model of environmental governance allows for better coordination across the individual ministries thus facilitating a more efficient implementation of environmental programs. As early as 1963, the Founding Prime Minister of Singapore Lee Kuan Yew demonstrated the nation's commitment to environmental protection goals with his tree-planting campaign with an emphasis on providing shade and greenery. The Ministry of National Development (MND) and its statutory board NParks in charge of environmental matters, which comprises specialists in areas of architecture and landscape management, have managed the early greening efforts across the island. The initial tree-planting campaign was followed in 1967 by the "Garden City" campaign where the Public Works Department (PWD) set up a specialist Parks and Trees Unit. The Garden City Action Committee (GCAC) was formed in 1968 to oversee island greening policies and to coordinate the greening initiatives of the various government agencies. Tree Planting Day was initiated in 1971 to encourage public participation in greening the economy. Concomitantly, the Keep Singapore Clean campaign emphasized the importance of maintaining a clean-living environment. The heavily polluted Singapore River and the Kallang Basin were cleaned up within 10 years and reopened for use in 1987. As Wolf *et al.* (2022) showed empirically, high level of government effectiveness is strongly and positively associated with environmental quality outcomes.

[6] See https://news.smu.edu.sg/news/2022/04/29/singapore-takes-top-spot-third-year-elite-quality-index-2022



Source: World Bank (2022).

Fig. 2. Comparison of the value added to GDP between Singapore's goods and services producing industries.

One possible driver for Singapore's early emission control policies and nation greening was its exponential progression from a manufacturing economy to services-oriented economy starting in the 1970s (see Fig. 2). Faced with fierce competition with the other Asian Tigers at the time, apart from offering pro-business policies, maintenance of a stable macroeconomic environment as well as political and industrial relations, there was also a need to prioritize liveability aspects to attract tourists and the setting up of regional head offices in Singapore. For example, in the mid-1960s, upon some economic success from manufacturing-led industrialization, the Singapore government made a timely decision to repurpose Sentosa, an island on the fringe of the city center, into a recreational and tourism hotspot rather than the siting of an Esso oil refinery plant. This was done to avoid generating negative externalities to the living environment from oil processing activities and to create the ideal conditions for a potential key source of revenue from recreation and entertainment services in the near future as the nation became more affluent (Quah *et al.*, 2022).

As greenness became synonymous with liveability, the government started to explore ways to green the increasingly urban landscape such as promoting rooftop greenery. Creepers were planted on retaining walls, overhead bridges, flyovers and fences. Hardy trees were planted in areas plagued by poor soil conditions, for instance, the reclaimed land at Marina Centre and Marina South (now known as Marina Bay). Not only do these trees have the tangible benefit of reducing dust and establishing topsoil, but they also have the intangible, non-pecuniary benefit of providing a pleasant view for high-rise office workers at the Central Business District, which could reduce stress levels amidst a hectic working environment. The Parks and Recreation Department (PRD), set up in the 1970s, allocated about $71.8 million toward the implementation of 23 park projects in the 1990s (MND, 2015). The GCAC adopted the Park Connector Network proposal in 1991, which aimed to create an island-wide network of narrow linear open spaces around major residential areas, linking up parks and nature sites. In that same year, two Tree Conservation

Areas were selected at the southern and eastern parts of Singapore based on the extent of greenery and the number of mature trees within the areas that are worth conserving. One million trees are planned to be planted by 2030, along with the expansion of green spaces such as park connectors, nature reserves and skyrise greenery (Co, 2020).

Despite their greening efforts, the Singapore government has been somewhat criticized by environmentalists for overemphasis on flora over fauna in their environmental strategy, and that the nature of emphasis on flora itself was too interventionist and contrived and had more to do with aesthetic reasons rather than for genuine environmental protection (Han, 2017). Perhaps the hardest dilemma came from the implementation of land reclamation activities, which might have been seen as a "necessary evil"[7] for a country's population to have the fundamental assets to function socially and economically in the areas of industrial expansion (i.e. to establish the petrochemical industry at Jurong Island), tourism services (i.e. expansion of Sentosa Island), waste management (i.e. construction of a 7 km perimeter rock bund around the Semakau landfill to avoid waste leakage) and to hedge against climate change risks (construction of artificial sloping and vertical seawalls along the coastline as a buffer against strong tidal waves). Aquatic habitats, even those offshore, are still being increasingly threatened by anthropogenic activities, namely coastal protection infrastructure and the release of silt into water bodies from coastal land reclamation works. Such marine biodiversity and habitats are not easily identifiable, and the lack of specific attention paid to this area has resulted in certain animal species such as cones and lampshells becoming critically endangered (Tan *et al.*, 2016). Reef degradation due to land reclamation works ensues from increased sedimentation and turbidity levels which hinder sunlight penetration for photosynthesis and increased ocean acidification which diminishes calcium carbonate accretion rates needed for reef cementation (Ng and Chou, 2017). The intensity of land reclamation activities in Singapore thus led to the shrinkage, fragmentation and encroachment of many natural habitats over the years.

Lai *et al.* (2015) showed that a tradeoff clearly exists between various areas of ecological conservation and economic development following the Urban Redevelopment Authority (URA) 2008 Master Plan, a statutory land use plan "which guides Singapore's development in the medium term over the next 10 to 15 years". While there was an increase in mangrove forest area between 1993 and 2011 following greater emphasis on environmental protection and conservation, the authors deduced that land reclamation works as guided by the 2008 Master Plan would cause increasing fragmentation of mangrove patches, which might lead to a 94.36% loss of Singapore's original mangrove area by 2030. This is supported by Tay *et al.* (2018) who reconstructed the past habitats of fringing coral reefs and mangrove forests surrounding the Ayer Islands and found that they were almost completely lost following offshore land reclamation works between 1969 and 2002. Moreover, the difficulty in quantifying the degree and consequences of habitat degradation due to insufficient information on ecological species distributions could have

[7] Kok (2016) studied the issue of ethics with regards to the "wicked waste problem" of the Semakau Landfill. He contemplated the possibility that including an ethical analysis of the urban waste situation in Singapore in the past, subject to data availability on coastal land reclamation, may have reduced possible biased framing effects and induced greater reluctance to construct an offshore landfill.

led to greater understatement of the intangible benefits of marine biodiversity to society (Lai *et al.*, 2015; Ng and Chou, 2017).

However, as the nation developed, the Singapore government had more leeway to factor in less material environmental attributes in its planning decisions, such as biodiversity conservation. Reconciliation of environmental goals with economic goals became an easier task with more freedom of resource allocation. Since 2008, the URA Master Plan was also reviewed twice every subsequent 5 years, with the latest official review in 2019. The last time the minimum land reclamation level in Singapore was raised above sea level was in 2011, from 3–4 m above the Singapore Height Datum.[8] One of the earliest efforts to conserve Singapore's natural ecosystem efforts comes from the creation of a bird habitat at East Coast Park, before seeing more progression in the 2000s in terms of level and scope of efforts, both locally and internationally. In 2002, URA launched the Parks and Waterbodies Plan which designated 19 nature areas beyond nature reserves. In 2006, the National Biodiversity Centre (NBC) was established to function as a central coordinating agency in all biodiversity-related matters and in 2009, the guiding principles for Singapore's biodiversity master plan were laid out in the National Biodiversity Strategy and Action Plan (NBSAP). The NBSAP was then revised into the Nature Conservation Master Plan (NCMP) in 2015 which aims to build a comprehensive and systematic base of clearly streamlined and defined biodiversity conservation plans.

From 1993 to 2015, NParks carried out a total of 12 biodiversity surveys at various terrestrial, marine and mangrove sites, including that of nature reserves and offshore islands (MND, 2015). Since then, some degrees of success regarding conservation efforts have been observed such as the discovery of several nationally endangered species in the Southern Islands such as the oriental magpie-robin, spotted wood owl and textile cone snail (Yang, 2020), as well as releasing 119 critically endangered hawksbill turtle hatchlings in 2020 (Ng, 2020). However, biodiversity studies were not always smooth sailing when it comes to coordination of information between ministries (or their statutory boards) and the private sector. A recent example of this is the erroneous clearance of forested land in Kranji Woodlands by Jurong Town Corporation's (JTC)[9] private contractor to make way for the Agri-Food Innovation Park, which occurred even before the assessment results of the biodiversity baseline study conducted by JTC in collaboration with ENGOs were available.[10]

The 40 hectares Sisters' Islands Marine Park, Singapore's first marine park, opened in 2015 and is located around Sisters' Islands and along the western reefs of both St John's Island and Pulau Tekukor. Singapore's largest reef structure was also installed in that area in 2018 and was expected to contribute approximately 1,000 m^2 of additional reef substrate to the Sisters' Islands Marine Park by 2030 (Teh, 2018). However, as Singapore continues to extend its maritime economic activities, the conduciveness of offshore areas to the establishment of a proper marine conservation area is debatable. According to the Maritime

[8] The fixed datum surface set at 0.000 m of Singapore's 30 historical mean sea level. The Singapore Land Authority introduced the term in 2015 for standardization across the construction industry.
[9] A statutory board under the Ministry of Trade and Industry in charge of Singapore's sustainable industrial progress.
[10] See https://www.channelnewsasia.com/singapore/land-kranji-road-close-mistake-cleared-study-plan-jtc-huationg-354346

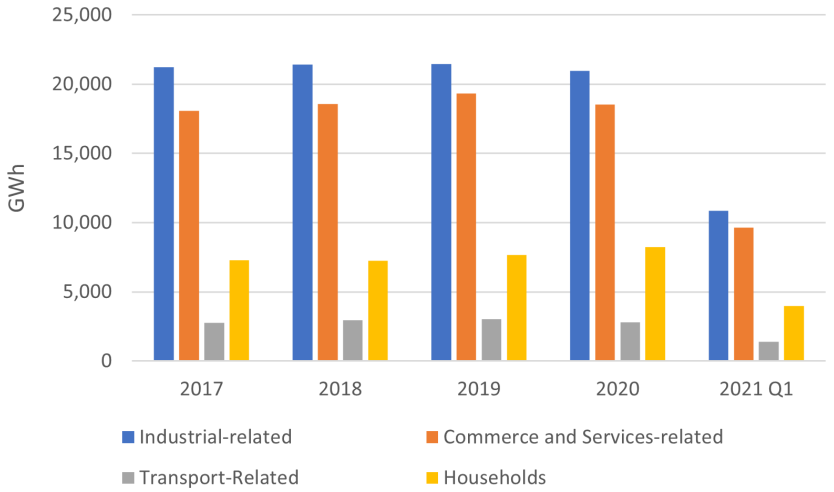
and Port Authority of Singapore (MPA), Singapore's port performance was characterized by a record high container volume of 37.5 million twenty-foot equivalent units (TEUs) in 2021 (Tay, 2022). For example, with greater industrial activity near or on water bodies, there is the discharge of concentrated brine and other pollutants back into the sea from potable water manufacturing processes, treated sewage effluent, chemicals used for seawater pipes for industrial cooling purposes, accumulation of nutrients and pollutants from estuary runoff, as well as the invasion of non-native oceanic species inadvertently carried by foreign container vessels[11] (Tan *et al.*, 2016). Increasing container volume at Singapore's port of call also increases the risk of oil spill pollution at beaches. The 2017 major oil spill that affected Singapore, caused by a collision of two container vessels in neighboring Malaysian's southern state of Johor, resulted in adverse impacts on the marine environment that was rich in biodiversity at the coastal districts of Changi, Pasir Ris and Punggol, as well as on mangrove areas at Pulau Ubin.[12]

Given the uncertain economic outlook in 2022 and the existential threat of climate change, deciding to further regulate and restrict Singapore's sources of container volume traffic, land space for high-value industries and new residential buildings, as well as adaptation measures against the risk of sea level rise, becomes a delicate task. More proper cost-benefit analyses should be conducted to identify, measure and weigh both the tangible and intangible benefits and costs of marine protection versus economic expansion on Singapore's maritime routes.

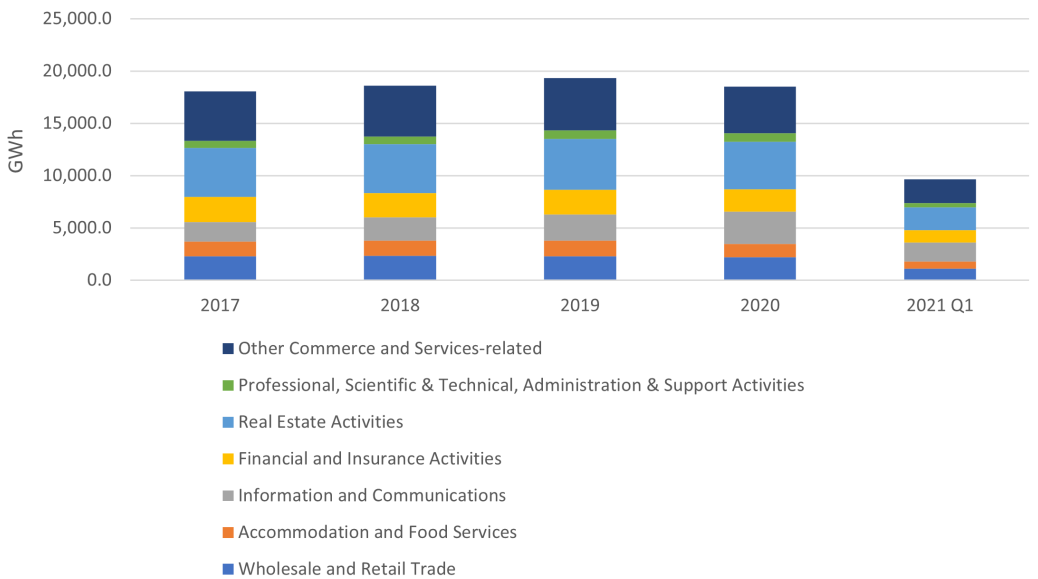
The government has also placed much emphasis on energy efficiency as it is an environmental aspect that can fulfill the dual objectives of environmental sustainability and economic competitiveness. In addition, the services sector only performs marginally better in energy consumption compared to the industrial sector in recent years as seen in Fig. 3(a), implying that inefficient use of energy may continue to be a concerning trend amidst a service-oriented economy. A breakdown of the services sector reveals that the bulk of energy consumption comes from real estate activities, financial and insurance activities and other undefined commerce and services-related sub-sectors, as seen in Fig. 3(b).

The "energy trilemma" in Singapore is made up of three objectives: (I) secure and reliable; (II) affordable; and (III) environmentally sustainable in the long run. It is called a trilemma due to the existence of tradeoffs between the attainment of each objective (MTI, 2021a). Therefore, there is a need to reduce the cost cap between conventional and renewable energies to make the latter more attractive to adopt and economically feasible. Rather than providing subsidies for energy fuels, Singapore chooses a more regulatory approach in promoting energy efficiency initiatives (Doshi and Zahur, 2021). This stems from concerns of price distortion (deviation of prices from the marginal social cost) causing inadequate valuation of the environment, asymmetric distribution of benefits and reduced incentive of transitioning to more energy-efficient solutions.[13]

[11] Anthropogenic activities potentially reduce the natural resistance of native species to foreign species.
[12] See https://www.cleanearth.tech/news-insights/the-cost-of-oil-spill-remediation-in-singapore
[13] See https://www.eco-business.com/news/energy-subsidies-not-the-right-thing-to-do/



(a) Singapore's electricity consumption by sector



(b) Singapore's electricity consumption within the services sector

Source: EMA (2021).

Fig. 3.

Hahn and Metcalfe (2021) studied the economic welfare impacts and the equity-efficiency tradeoff associated with an energy subsidy in California based on natural gas price elasticity estimates. They found that overall, no level of energy subsidy can enhance economic welfare. In addition, they also studied the welfare weights required to be assigned to the beneficiaries of the subsidy to equalize the costs to non-benefitting

taxpayers and of environmental damages incurred from increased incentives for energy use. They found that the welfare weights are sensitive to the social cost of carbon (SCC) i.e. the marginal damage generated by an additional unit of CO_2 emissions. Given that Singapore's SCC is likely to remain relatively low-to-moderate for awhile (as will be elaborated in Sec. 3.5) meaning that benefits of energy subsidies will not be weighted heavily by policymakers, it makes sense that the government would prefer the use of cash transfers to offset additional energy costs that are passed down to final consumers as opposed to energy subsidies.

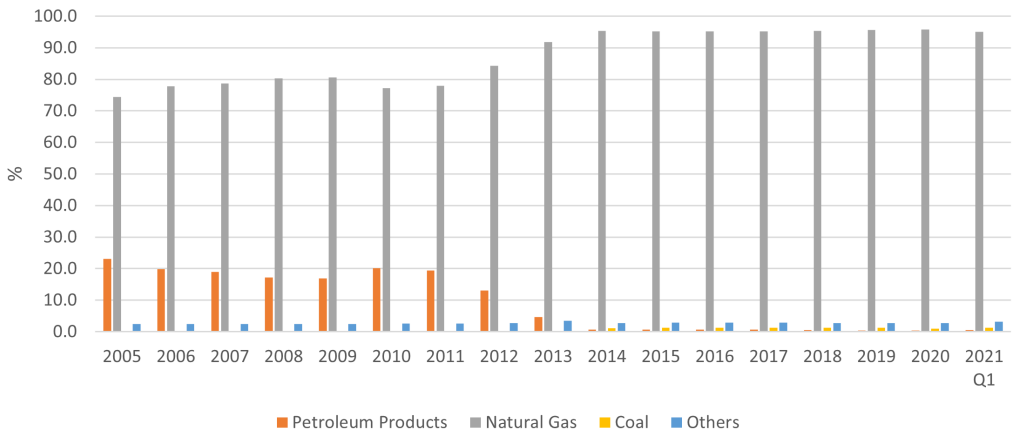
In 2007, the National Environment Agency (NEA) set up an inter-agency Energy Efficiency Programme Office (E2PO) to manage energy efficiency improvements in the five sectors of the economy: power generation, industry, transport, buildings, and households[14] (Doshi and Zahur, 2021). In the case of green buildings in Singapore, the Building and Construction Authority (BCA) has remained the central authority to decide how land should be used and developed for green buildings in accordance with the Green Mark scheme (GMS). For example, since 2009, the government has mandated all new public sector buildings that exceed 5,000 m^2 to achieve the Green Mark Platinum rating i.e. the highest level of the GMS. In addition, they were able to adopt legal instruments and supplementary programs to provide adequate statutory support for the implementation of the GMS where required (Han, 2019).

The Inter-Ministerial Committee on Climate Change (IMCCC), which was established in 2007, "coordinates, formulates and monitors the execution" of Singapore's national plans using a whole-of-government approach to mitigate the effects of and adapt to climate change.[15] The National Climate Change Secretariat (NCCS), which was established under the Prime Minister's Office (PMO) in 2010 under the IMCCC, functions as the executive agency to mobilize planning, development and implementation of Singapore's domestic and international policies and strategies pertaining to climate change. Moving forward, the Public Utilities Board (PUB) is also proposing to lead, holistically consolidate, coordinate, oversee and integrate on-going climate research initiatives from other agencies such as JTC and the Housing Development Board (HDB), and ensure that their projects link back to the key objective of sea level rise mitigation and adaptation.

Recognizing that the strategy of allocating space for landfill sites and building new incinerator plants was unsustainable and costly, the then Ministry of the Environment (ENV) set up a Waste Minimisation Unit in 1991 and upgraded it to the Waste Minimisation Department (WMD) in the following year to spearhead waste minimization and recycling initiatives in Singapore (Ho, 2002). By 1995, the WMD was responsible for establishing 1,225 waste recycling centers within various commercial and public estates in Singapore, as well as 58 independent public recycling centers in appropriate central

[14] Examples of individual energy efficiency programs associated with the office are highlighted in Sec. 3.6

[15] See https://www.nccs.gov.sg/media/speeches/speech-by-senior-minister-and-coordinating-minister-for-national-security-teo-chee-hean-committee-of-supply-2020-28-february-2020



Source: EMA (2021).

Fig. 4. Singapore's energy mix.

locations across Singapore for people not living within proximity of a recycling scheme participating estate (Foo, 1997).

Another example of the state having a direct stake in both economic and environmental issues would be the establishment of Pavilion Energy as a state-owned enterprise (SOE) by Temasek Holdings in 2012 to promote a financially reliable natural gas sector. As seen in Fig. 4, natural gas constitutes about 95% of Singapore's electricity generation mix with a minuscule amount of oil and coal since 2014 and is piped from neighboring Malaysia and Indonesia and shipped as LNG from distant countries such as Australia, the United States, Qatar, and Angola. In 2016, Pavilion Energy was awarded a Liquefied Natural Gas (LNG) importer license by EMA (Doshi and Zahur, 2021). Since then, Pavilion Energy's portfolio of diverse global sources has bolstered Singapore's economic capabilities in LNG by being a regional supplier of LNG as well. In 2021, an agreement was signed with Chinese city gas distributor Zhejiang Hangjiaxin Clean Energy for the supply of small-scale LNG from Singapore to Hangjiaxin from 2023 (Prevljak, 2021). Despite its international expansion, Pavilion Energy continues to prioritize Singapore's energy security and has furthered its environmental efforts by developing a methodology to profile the greenhouse gas emissions of imported LNG cargoes (Tan, 2021).

At this point, one may question, despite the success of Pavilion Energy to date, whether the economic and social risks of SOEs are a cause for concern e.g. inefficient bureaucratic management which leads to coordination issues, crowding out of private firms, anti-competitive behaviors and an uncomfortably high level of public accountability (Doshi and Zahur, 2021). However, given the high quality of corporate, public and political governance, limited state intervention (conditional on whether there is market failure), as well as SOEs operating based on inclusive rather than extractive institutions, it is likely that SOEs in Singapore may generally have greater assurance of financial soundness as compared to

non-government linked companies (Tan *et al.*, 2015). However, whether it remains the optimal solution of relying on SOEs for the future development of Singapore's natural gas sector with regard to energy security and economic competitiveness, is an open question.

To date, Singapore has had formulated three national green plans to address the need to balance both environmental and economic concerns. These green plans serve not as concrete "plans" per se, but rather strategic guidelines and targets that Singapore aims to follow and achieve (Mohan, 2021). The first Singapore Green Plan (SGP) was formulated in 1992. It showcases the nation's first comprehensive proposal which acknowledged that environmental protection should go beyond the provision of environmental infrastructure that is supported by environmental legislation. There was a need to emphasize a more consultative approach with stakeholders and a focus on pollution monitoring and prevention (Yeo, 1994). In particular, pollution prevention measures were shown to be more cost-effective than pollution control measures, but only if the former were in line with an improvement in manufacturing quality (Peck, 1999).

This was built upon with the SGP 2012 which was launched in 2002, setting forth numerical targets for the next 10 years. The SGP 2012 marked the first steps to broadening the green vision of Singapore from one of being "clean and green" to one of attaining "environmental sustainability", as well as transforming environmental challenges to opportunities. Singapore is currently on the SGP 2030 which was launched in 2021. The SGP 2030 put forth more initiatives and targets in the areas of "City in Nature" (e.g. expansion of green spaces), "Sustainable Living" (e.g. encouragement and education on energy efficiency and waste reduction practices, promoting clean modes of commute), "Energy Reset" (e.g. promotion of clean fuels, productions and processes, infrastructure and vehicles) "Green Economy" (e.g. review of carbon tax and lead in green finance) and "Resilient Future" (e.g. adaptation to sea level rise and enhancement of flood resilience, keeping temperatures cool and development of the local agricultural sector) (MOE *et al.*, 2021).

Upon closer examination, Singapore's historical approach in the setting of its emission reduction targets is in fact a strategically and relatively cautious one. In line with its environmental governance motto, Singapore has long emphasized on charting a decarbonization pathway to net zero rather than to set firm deadlines. Absolute emissions reduction refers to a reduction in total emissions while emissions intensity reduction refers to the volume of emissions reduced per unit of GDP. In 2015, Singapore pledged to reduce its emissions intensity by 36% from 2005 levels by 2030. In 2020, as per its enhanced Nationally Determined Contributions (NDC) and Long-Term Low Emissions Development Strategy (LEDS), Singapore switched from an emissions intensity to an absolute emissions target which aims to peak at 65 MtCO2e by around 2030 and to halve this volume to 33MtCO2e by 2050, aiming to achieve net zero emissions as soon as viable in the second half of the century (NCCS, 2020).

The tradeoff of using emissions intensity reduction as a benchmark is that total emissions could still rise as GDP increases. Conversely, moving to reduction of absolute emissions independent of GDP increases the risk of hurting economic competitiveness

(Chow, 2021). However, despite switching from an emissions intensity to an absolute emissions target, a climate research consortium from Germany known as the Climate Action Tracker (CAT) perceived Singapore's targets as of 2021 to be severely lacking in action relative to the expectations of the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC). The consortium noted that Singapore's refinement of its emission abatement strategies might have been more accountable but not necessarily more ambitious in its objectives. In the absence of an objective and firm target of achieving absolute net zero carbon emissions by 2050, Singapore was rated as "Critically insufficient" i.e. the lowest score on a five-point scale in its emission targets along with 5 other countries.[16]

The Singapore government refuted this assessment with the likelihood that the analysis did not account for Singapore's high population density and renewable energy constraints, which limit what Singapore can achieve with its emission targets relative to other developed countries (Tan, 2021). This incident parallels with Singapore being ranked within the bottom 10 countries for environmental sustainability in 2000 by the Environmental Sustainability Index (ESI), the precursor to the more comprehensive ESI, which similarly noted that Singapore's unique circumstances were not factored into the assessment that could have resulted in a misleading score (MND, 2015). Therefore, it is arguable that Singapore not being overly ambitious with its emission reduction targets in view of its stark tradeoffs may be seen as a "win in itself" rather than as a failure. However, faced with growing pressure from international environmental obligations perhaps it would be advisable for Singapore to consider putting forth its own assessment methodologies in a more transparent and structured fashion.

3.2. *Environmental regulations*

At the crux of it all, the rule of law is paramount in ensuring that laws and regulations are adhered to. As Wolf *et al.* (2022) showed empirically, good quality of environmental regulations and rule of law is strongly and positively associated with environmental quality outcomes. Strict enforcement has contributed to reducing corruption and lax attitudes from the early days. Rather than having an overall basic environmental legislation to deal with environmental matters, Singapore instead adopts a more sophisticated and specialized system where legislative Acts are enacted for each environmental field and accompanied by a set of sub-regulations for each Act. Enacted in 1999, the Environmental Pollution Control Act (EPCA)[17] unified individual environmental legislations of the 1970s in air pollution, water pollution, noise, and hazardous chemical substances. The EPCA was accompanied by the Environmental Public Health Act (EPHA) and the Sewerage and Drainage Act (Japan MSE, n.d.). Since then, the number of key environmental legislative Acts in Singapore as administered by NEA and other

[16] See https://climateactiontracker.org/countries/singapore/2020-07-30/
[17] Renamed the Environmental Protection and Management Act (EPMA) in 2008.

environmental agencies such as NParks has grown exponentially to about 17.[18] Most notably, the Energy Conservation Act (ECA), EPCA and EPHA have more than 10 sub-regulations under each of them.[19]

Similar to the Carbon Pricing Act (CPA) for emission-intensive companies (as will be elaborated in Sec. 3.5), the ECA mandates energy-intensive companies to register with NEA and to implement mandatory energy management practices such as the appointment of an energy manager, annual monitoring and reporting of energy use, submission of annual energy efficiency plans and to conduct an energy efficiency opportunities assessment for each relevant business activity. Different types of environmental issues with their associated legal and policy responses demand for specialized knowledge and expertise. Therefore, specialization as a key feature of an environmental legal organizational structure allows for greater flexibility, innovation, decision-making quality and efficiency in tackling each environmental aspect (Preston, 2012).

These Acts are progressively revised to broaden coverage and depth where appropriate. For example, under the Resource Sustainability Act, requirements for the management of e-waste were updated in 2021 based on the Extended Producer Responsibility (EPR) scheme whereby the responsibility of streamlining and managing end-of-life electronic product disposal was partially shifted from the government to producers. To facilitate an efficient and coordinated effort in this regard, ALBA E-waste Smart Recycling Pte Ltd was appointed by NEA as the Producer Responsibility Scheme (PRS) Operator to collect regulated e-waste across Singapore for proper treatment and recycling on behalf of producers who exceed the prescribed supply thresholds for regulated consumer products (NEA, 2021). This is a significant move considering that Singapore is transitioning to a more technologically driven society such as electrification of the mobility fleet, which will result in more e-waste generated.

Legal instruments for biodiversity conservation have existed even before self-governance i.e. the Nature Reserves Ordinance in 1951, followed by the enactment of the Parks and Trees Act in 1975 (revised in 1996 and later again in 2005) and the National Parks Act in 1990 (revised in 1996) (MND, 2015). However, it was noted that legal instruments that specifically address coral reef habitat protection were lacking (Ng and Chou, 2017). In addition, there are also other regulations by other governmental bodies that may not be directly related to the environment but have incorporated environmental considerations over time. For example, in 1996, the Income Tax Act was revised to include a 100% allowance on the capital expenditure incurred for efficient pollution control equipment or devices (The Law Revision Commission, 2020). In 2008, the Building Control Act was revised to mandate the GMS certification for new buildings, with the additional requirement of attaining a Gold rating for buildings that exceed a gross floor area of 2,000 m^2 (Han, 2019).

A special mention should be made here with regard to the land utilization program in Singapore. Pollutive facilities are often coined the term NIMBYs (“not in my backyard”)

[18] See https://uk.practicallaw.thomsonreuters.com/w-026-0105?transitionType=Default&contextData=(sc.Default)&firstPage= true
[19] See https://www.nea.gov.sg/corporate-functions/resources/legislation-international-law/legislation

since despite generating benefits for the economy by providing goods and services, neighboring residents are forced to bear the dis-amenities directly, usually where adverse effects to public health are concerned (Quah and Nursultan, 2020). The Singapore government has made use of zoning regulations, licenses and permits as potential "conflict resolution instruments" for such siting issues. With the enactment of the Land Acquisition Act in 1966, usage of land regardless of purpose became legally supervised by the MND. One of the requirements for processing the application of a building permit obtained from agencies such as JTC and HDB was for it to undergo an environmental investigation by the NEA. If the project was approved, the site of the proposed factory might then be given careful consideration of its proximity to residential areas and other amenities based on whether it is a potential NIMBY according to the amount of pollution it generates.

The relationship between stricter environmental regulations and economic development can either be that of a tradeoff or complementary in nature. Theoretically speaking, it revolves around the pollution haven hypothesis (i.e. some polluting industries to relocate to less developed regions with looser regulations) and the Porter hypothesis (i.e. improved competitiveness from green innovation can offset the cost of compliance) which predicts opposite reactions by firms in response to environmental regulations. There has been some empirical evidence of pollution haven effects in Singapore which signals a tradeoff (Chen and Taylor, 2019). However, well-designed, fair and just environmental regulations may enable the Porter hypothesis to take precedence when firms assess that the costs (benefits) of adhering to regulations in terms of economic competitiveness are lower (higher) than the costs (benefits) of relocation, potentially delivering a win–win situation for the environment and private sector development (Ranocchia and Lambertini, 2021; Wolf *et al.*, 2022). Some empirical evidence of the Porter hypothesis was presented by Pham *et al.* (2019), where environmentally friendly sectors such as renewable energy experienced positively abnormal returns following the announcement of environmental regulations and carbon tax despite major polluting sectors in Singapore experiencing negative abnormal returns.

As the sale of green bonds is the primary mode of financing capital for projects that yield environmental benefits, it would be useful to enforce quality control through the screening and monitoring of applicants with regard to some predetermined environmental criteria that individual projects are required to meet. This would ensure that fiscal and environmental sustainability goes hand in hand, especially when it comes to achieving the objectives of the SGP 2030 (Quah, 2021; Seah, n.d.).

3.3. *Quantification of economic benefits from going green*

Cost-effectiveness analysis, which was widely used in the early decades, gave way to cost-benefit analysis (CBA) from the late 1990s. While the former would look only at choices with minimum cost to achieve a certain objective, the latter, on the other hand, would examine the benefits in addition to the cost of a policy such that there should be a social surplus generated for society. This led to the formation of the Centre for Public Project Management at the Ministry of Finance, requiring proposals above a certain quantum to be

subjected to scrutiny and advice from the center. With good data and careful relevant analysis, Singapore, to a large degree, ensured that selected projects would be sustainable and meet environmental obligations.

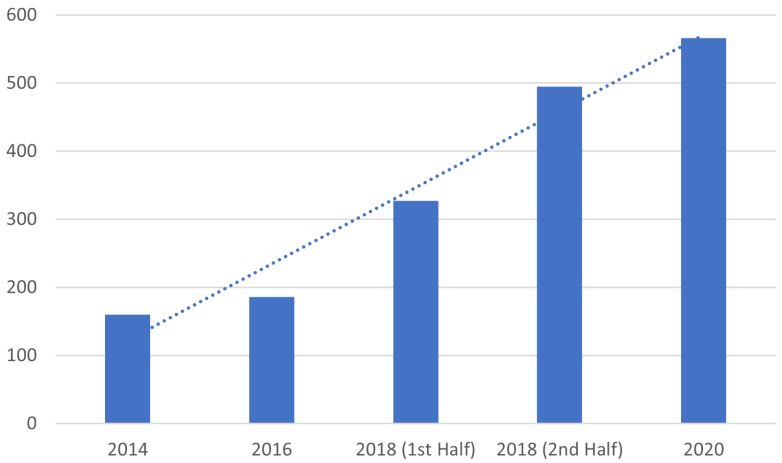
The Impact-Weighted Account Framework (IWAF) that is being developed by the Singapore Green Finance Centre (SGFC) is an attempt to standardize an environmental, social and governance (ESG) accounting framework in the Singapore context by consolidating existing ones that are internationally adopted such as those of the Global Reporting Initiative (GRI), Sustainability Accounting Standards Board (SASB), Global Impact Investing Network (GIIN), Impact Management Project (IMP) and Social Value Principles. The IWAF is intended to be a reliable tool to assist organizations in measuring the negative environmental externalities generated by their primary activities (i.e. environmental performance) in comparable units and integrating them into the composition of their publicly reported financial statements in a standardized, consistent and transparent manner (Chua *et al.*, 2021). The establishment of the Sustainable and Green Finance Institute (SGFIN) in 2022 builds upon this national endeavor of aligning firm value with ESG outcomes. To nurture new talents in these areas, the National University of Singapore (NUS) has also recently launched a new Master of Science in Sustainable and Green Finance as a graduate program (NUS, 2022).

With the Public Sector Taking the Lead in Environmental Sustainability (PSTLES) initiative that was introduced in 2006 and enhanced in 2014, public sector agencies were encouraged to "focus on sustainability outcomes that encompass energy efficiency, water efficiency and recycling and to put in place organisational processes to manage resource use".[20] This was followed by the GreenGov.SG Initiative in 2021 to put forth more ambitious targets such as expedited carbon abatement ahead of the SGP 2030 target, expanding the scope and coverage of business areas for the integration of sustainability measures into their operations, as well as spur public officers to be actively involved in the sustainability movement (MSE, 2021). To do so, there had been a need to convince the private sector that going green is a win–win situation for businesses and the environment. One of the most common concerns to be addressed was the duration of recovering the upfront cost of retrofitting energy-inefficient equipment and infrastructure.

With agencies adopting the Guaranteed Energy Savings Performance (GESP) contracting model when undertaking building retrofit projects, it was found to generate substantial cost savings for the private sector (S$6 million per year) while saving 15% of their total electricity use (Energy Efficiency Singapore, 2017). In 2011 and 2017, BCA and NUS collaborated on two CBA studies on how green buildings can reap economic benefits from multiple perspectives of cost savings, property value and workplace productivity (BCA, 2011, 2017).

With the belief that economic growth and sustainability are inter-dependent, the Singapore Stock Exchange (SGX) has been pushing for their listed companies in recent years to integrate sustainability initiatives in their business operations. SGX, as a regulatory

[20] See https://policy.asiapacificenergy.org/sites/default/files/E2S.pdf



Source: Loh and Thomas (2018); Loh and Tang (2019, 2021).

Fig. 5. Number of SGX-listed companies that submitted their sustainability reports.

body of sizable businesses, facilitates capital flows to meet Singapore's climate goals by providing market liquidity and pricing signals, support and guide the market with appropriate regulations, standards and incentives. In 2016, with a renewed emphasis on corporate social responsibility, sustainability reporting was made mandatory for listed companies on a "report and explain" basis. Since then, the number of reporting companies has increased steadily (see Fig. 5).

In December 2020, SGX has declared a S$20 million plan to strengthen commitments toward sustainability.[21] The portal SGX FIRST (Future in Reshaping Sustainability Together) has been set up for guiding the process further. In 2018, the Singapore Exchange Regulation (SGX RegCo), in collaboration with the Centre for Governance and Sustainability (CGS) at the NUS Business School, reviewed the sustainability reporting performance of Singapore-listed companies, with follow-up reports in 2019 and 2021. As climate change becomes increasingly integral to the financial ecosystem in terms of financial assets and being indicative of price risks, mandatory sustainability reporting for listed firms was slated to evolve into mandatory climate reporting, starting from sectors with the greatest negative climate impact in 2023 based on recommendations of the Task Force on Climate-related Financial Disclosures (TCFD) (Lim, 2021).

In the 2019 and 2021 reports, they developed the SGX-CGIO Sustainability Reporting Scorecard to quantify the quality of sustainability reporting of listed firms with regards to the categories of the general scope of reporting, material ESG factors, sustainability policies, practices and performance, targets, sustainability reporting framework and their board statement. The overall average sustainability reporting score in 2019 was assessed to be 60.6 out of 100 points and increased to 71.7 in 2021, indicating that, for the most part,

[21] See https://www.sgx.com/media-centre/20201215-sgx-strengthens-commitment-sustainability-s20-million-plan

there were encouraging signs that listed firms are feeling the pressure from their key stakeholders to go green. However, listed firms were still lacking in terms of disclosure on longer-term targets, reporting scope, Board of Director's role in the sustainability assessment, material factor selection, risks and opportunities, stakeholder engagement process, as well as adoption of reporting frameworks specifically adapted to climate change (Loh and Tang, 2019, 2021).

Interestingly, the 2021 report found that smaller listed firms tended to perform better in sustainability performance relative to larger listed firms, which differs from the 2019 report. This may appear puzzling on the surface because larger firms have more resources and capabilities to engage in cost-effective environmental innovation. Although reasons for this phenomenon among listed firms in Singapore have yet to be explored in detail, a study of Flemish companies by Andries and Stephan (2019) found that while larger firms gain relatively greater financial returns from engaging in regulation-driven environmental innovation, smaller firms reap larger gains from engaging in voluntary environmental innovation when motivated by customer demand. Contrary to the resource-based view and in line with the stakeholder theory on environmental management, the authors suggest that the financial performance of smaller firms is more dependent on their relationship or reputation with stakeholders. Studying the different types of corporate environmental innovation in Singapore, how it relates to firm demographics and how this interaction translates to financial performance would be a useful area for future research.

The proposal of a domestic corporate environmental performance ranking system or index in Singapore is not novel. Khanna *et al.* (2010) explored the feasibility of designing and implementing such an index based on expert surveys that painted a picture of the corporate environmentalism outlook for Singapore. They confirmed the existence of a demand for such an index with the consensus that the net benefit of having it is positive in the long term. For corporate environmental management to be effective, it is important to initially assess the significant negative environmental impacts that a firm faces to gather some information on how the firm should monitor and act. The challenge next is to ensure that the difference between what the firm should do and what it actually ends up doing is minimal i.e. environmental action should be preceded by monitoring which should then translate to environmental performance (Lannelongue *et al.*, 2014). Any missing link in the chain will result in suboptimal environmental and cost-effectiveness outcomes. Therefore, it is important for firms to regularly conduct both internal and external audits from independent vendors to verify the accuracy and comprehensiveness of disclosed corporate environmental information (Loh and Tang, 2021).

Only then could SGX ensure that the relationships between the performances of a listed firm's intangible and tangible assets (sustainability and market value) and between intangible assets (sustainability and brand value) are genuinely positive ones. Loh *et al.* (2017) evaluated the sustainability reporting level of companies listed on the SGX Mainboard by generating a score using a measurement scheme modeled after the Global Reporting Initiative (GRI). They found a positive relationship between the quality of sustainability reporting and firm value, even after controlling for sector and firm status. Similar sentiments are echoed in Loh and Tan (2020), where they examined the top 100

leading brands in Singapore and found that higher quality sustainability reports led to higher brand value. Fujii and Ray (2019) studied the top 30 SGX-listed companies between 2013 and 2017 and found that although there is a generally positive relationship between market capitalization and the amount of carbon dioxide emissions, about 27% of the firms in their final sample size have achieved growth in market capitalization while improving their environmental performance.

Economic valuation consists of not only the input of market values but also non-market values. Many neighborhoods in Singapore are surrounded by green spaces to which residents may attach values in terms of both use (e.g. ecosystem services and recreational activities) and non-use values (e.g. "feel good" effects from preserving naturistic features for other users and future generations, known as the existence, option and bequest values). The benefits of green spaces are non-pecuniary in nature and usually contain public good characteristics (non-excludable and/or non-rivalry), which render them unpractical to be directly priced in the market. A similar logic applies to the non-pecuniary cost of industrial projects with regard to environmental degradation and urban liveability.

To assess the non-market economic value of green projects and address environmental market failure, revealed and stated preference methods are popular tools used by the Ministry of Sustainability and the Environment (MSE) and academicians (Leong *et al.*, 2022). Stated preference methods commonly elicit willingness-to-pay (WTP) for improvements in an environmental good that enhances welfare (or to preserve its status) or willingness-to-accept (WTA) decrements in welfare from the conversion of a green landscape for industrial activities through survey questionnaires e.g. contingent valuation method (CVM). Revealed preference methods, on the other hand, rely on market-based transactions or indirect methods to elicit environmental preferences through individuals' purchase of market goods that may be related to the consumption of environmental goods e.g. hedonic pricing that controls for the differences in observed and unobserved characteristics and amenities of goods with varying levels of accompanying environmental attributes. For stated preference methods, by summing the various non-use value components and multiplying the WTP or WTA values by the relevant population, the total economic value can be derived and the net present value as well after applying an appropriate discount rate. For revealed preference methods, the coefficients of environmental attributes based on their effect on their associated marketable goods' prices would generally paint a picture of how much such non-market factors are valued.

The discount rate when evaluating green projects should capture the opportunity cost of forgone consumption and forgone private investments. While the private discount rate of going green for businesses and the average consumer is usually higher than the social discount rate, the chances of convergence may have increased in light of the pandemic. Consequently, the choice of an appropriate discount rate becomes simpler. However, it should be noted that preferential discount rates specifically for green projects are ill-advised due to the high possibility of miscounting present benefits and costs when attempts are made to distinguish accounting prices for the same capital good between those deployed in green and non-green projects (Dasgupta, 2021).

Table 2 contains a list of empirical studies done on valuing green developments in Singapore using stated and revealed preference methods. In Singapore, such non-market valuation studies are gaining traction with advances in data collection procedures and quantification methodologies, although it remains to be seen if results from cost-benefit analyses will increasingly be translated into actual policy outcomes. It is interesting to speculate if given more data and such methods at the time whether the Singapore government would have been able to, for example, calculate/estimate reliably and sum up the myriad of various types of environmental, ecological and financial costs incurred by land reclamation projects, and whether projects such as the Semakau Landfill will still be viable then.

In view of the rising and looming threat of climate change and Singapore's vulnerability to it as highlighted in Sec. 2, the costs and benefits of climate change adaptation are also being critically assessed. As of the year 2000, construction and maintenance of coastal hard infrastructure costs such as seawalls were estimated to increase from US$3 million to approximately US$6 million by 2050 and US$17 million annually by 2100. The loss of land value from flooding was estimated to be a substantial US$2 billion in 2100 (Temasek Ecosperity, 2019). Based on the Coastal Adaptation Study (CAS) which was commissioned by the BCA in 2013, it was estimated that Singapore's coastal protection measures could cost up to S$100 billion over the next 50 to 100 years (PUB, 2021). More recently, PUB has also assessed that the total benefits of coastal protection measures that cost about S$23 billion are estimated to be about S$40.8 billion. In view of these, the Coastal and Flood Protection Fund (CFPF) was set up with an initial injection of S$5 billion to fund coastal protection and drainage-related expenditure.

Table 3 shows some studies that attempted to quantify the benefits and costs of sea level rise in Singapore. In present value, these studies found that the costs of damages from sea level rise significantly justified the costs of coastal protection measures when the value of commercial land and less-commercial land with direct use values such as beaches were taken into account. For non-commercial land with low use values such as marshes and mangroves, however, whether the net present value is positive would depend on the methodology used to calculate the associated benefits and costs. For example, Ng and Mendelsohn (2006) found that while the cost of coastal protection was equally justifiable across beaches using both the CVM and travel cost method [TCM (a revealed preference approach)], the WTP for less-visited marshes and mangroves was much higher for the CVM than the TCM due to high non-use values not being able to be reflected in the TCM.

Besides floods from sea level rise and rainfall, there is also a need to assess the cost of damages and adaptation regarding the urban heat island (UHI) effect. However, CBA studies on UHI are currently lacking in Singapore. Borzino *et al.* (2020) attempted to measure the WTP of Singaporeans to mitigate UHI effects and analyze the effect of the derived WTP estimates on the spatial variation of UHI intensity across the island (measured using weather models). They found that the average WTP was US$177.48 and that the WTP is generally higher in parts of Singapore that experience a higher UHI intensity. In addition, demographic and socio-economic characteristics such as income, education, age and even gender significantly affect Singaporeans' WTP. However, the types and the

Table 2. Economic valuation of environmental attributes in Singapore.

Stated preference methods				Revealed preference methods			
Paper	Objective	Approach	Findings	Paper	Objective	Approach	Findings
Quah and Tan (1999)	To estimate the aggregate WTP to preserve the scenic views of East Coast Park	CVM	Aggregate WTP was S $146 million (0.1% of GDP in 1997) Aggregate WTA for a loss in the scenic views was S$451 million (0.3% of GDP in 1997)	Deng *et al.* (2012)	To estimate the economic impact of the GMS on Singapore's residential sector	Hedonic pricing	Substantial price premium commanded by GMS dwellings on property value (15% on average) Premium positively associated with GMS certification level
Heinzle *et al.* (2013)	To determine the WTP of premium property investors for condominium units certified by the GMS	Survey + adaptive choice-based conjoint analysis	WTP for price premium positively associated with GMS certification level Rewarding for both developers and investors to bear the additional costs of developing green buildings	Deng and Wu (2014)	To examine the financial viability of investments in green buildings	Hedonic pricing	Green price premium of green buildings arises largely only during the resale phase relative to the presale stage Not so rewarding for developers to bear the additional costs of developing green buildings

Table 2. (*Continued*)

Stated preference methods				Revealed preference methods			
Paper	Objective	Approach	Findings	Paper	Objective	Approach	Findings
Hwang *et al.* (2017)	To estimate the green cost premium of green building projects	Survey	Cost premiums largest for residential buildings, followed by commercial then office Green building projects generally over budgeted (no effect of building type on cost premium for large-budget projects) Other main contributors to cost premium include cost of green technologies and materials, R&D expenditure and knowledge in utilizing and designing green buildings efficiently	Belcher and Chisholm (2018)	To examine the effect of various types of vegetation on the resale prices for public housing apartments	Hedonic pricing	High use values of managed vegetation (e.g. roadside greenery and parks) Lower use and non-use values for unmanaged vegetation and heritage trails
Leong (2019), as cited in Kuan *et al.* (2022)	To estimate the WTP for construction noise abatement	Choice modeling survey	WTP of an affected individual was S $35 annually for a policy that reduced construction noise by 5dBA[a]	Leong (2016), as cited in Kuan *et al.* (2022)	To examine the non-market value of the Active, Beautiful, Clean Waters (ABC Waters) Programme at the Bishan-Ang Mo Kio Park	Difference-in-differences (DID) method	Completion of the ABC Waters project was associated with higher HDB resale prices for homes in closer proximity to the project site

Table 2. (*Continued*)

Paper	Objective	Approach	Findings
Stated + Revealed preference methods			
Addae-Dapaah and Chieh (2011)	To examine the effect of GMS certification on the market	Hedonic pricing + psychographic survey	Green premium of GMS-certified properties based on hedonic pricing using sales data was significantly higher than the WTP for green premium elicited from survey
Dreiseitl *et al.* (2015)	To examine the socioeconomic value of redeveloping the Bishan-Ang Mo Kio Park with the inclusion of more blue and green spaces	Literature review + Onsite interviews/ observations of public life + socio-economic modelling	Substantial values of time spent travelling to and being in the park (83–100 million SGD annually), as well as the value of physical exercise activities at the park (16–43 million annually) Reasonable increase in real estate value after redevelopment (10–20 million SGD worth of additional tax revenue) Smallest increase in benefits of better air quality due to GHG-absorbing greenery after redevelopment

[a]Participants were presented with actual audio recordings of construction noise of varying loudness, with other attributes such as the days, duration and time associated with construction activities.

Table 3. Cost-benefit studies of coastal protection measures in Singapore.

		Benefits		Costs	
Paper	Nature of site	Method of measurement	Present values[a]	Method of measurement	Present values[a]
Ng and Mendelsohn (2005)	Commercial land	Value of potentially lost land[b] from inundation[c]	**29,090 (in mils of 2000 SGD)** (0.86 m scenario)	Cost of constructing and maintaining flood barriers	**5.55 mil SGD** (0.86 m scenario)
Ng and Mendelsohn (2006)	Non-commercial land	Consumer surplus[d] +Aggregate WTP	Beaches **18,311 mil SGD** by 2100 (WTP); **277,914 mil SGD** (0.86 m scenario) Marshes **5,835 mil SGD** (WTP); **23.81 mil SGD** (travel cost) Mangroves **5,889 mil SGD** (WTP); **0.079 mil SGD** (travel cost)	Cost of sand, construction of underwater hard structures and maintenance cost	Beaches **88.36 mil SGD** (0.86 m scenario) Marshes **1,074 mil SGD** (0.86 m scenario) Mangroves **1,130 mil SGD** (0.86 m scenario)
Giannoustas (2015)	Commercial land	Loss of capital stock in inundated areas	**1,572 mil SGD** (1 m scenario with high tide)	Maximum cost of seawall construction	**113.40 mil SGD** (1 m scenario with high tide)

[a]As per the year that the paper was published (including the conversion of USD to SGD exchange rates). Discount rates used were 4% for Ng and Mendelsohn (2005, 2006) and 2.5–3.5% for Giannoustas (2015) and based on the most extreme sea level rise scenario by year 2100.
[b]Loss of land area was estimated by using spot elevation measurements to interpolate between contours on Singapore.
[c]Value of land does not reflect changing land prices based on the various sea level scenarios.
[d]Measured as area under visitors' demand curve for that site but above their travel costs.

present value of the costs of specific UHI mitigation measures were not taken into account to conduct a proper CBA, which limits the analysis' potential to guide policymakers.

The potential doubling of Singapore's average temperatures by 2100 can lead to an increase in Singapore's energy demands and thus higher carbon emissions, create ideal conditions for the outbreak of vector-borne diseases such as dengue fever, as well as lead to further bleaching and deaths of coral reefs (Temasek Ecosperity, 2019). Widening the standing of the CBA to include neighboring countries and trading partners is also advisable considering that harsh and irregular climate patterns can cause agricultural crop disruption and hence lead to domestic food security issues as Singapore imports more than 90% of its food supply. There are also various types of environmental and economic impacts to be considered. The extent of climate-related damages to different types of locations within Singapore would also differ. For instance, public transportation locations, i.e. Mass Rapid Network (MRT), are prone to flooding due to their use of underground tunnels. Economic disruptions caused by flooding occurrences in those areas could be relatively substantial given the great number of people using it to commute to work daily.[22] In addition, residents near coastal areas such as beaches and in detached and semi-detached houses do not have elevated void decks to buffer against flooding. There may also be equity issues in possible asset and activity relocation in the coastal zone.

In sum, economic damages of floods and the UHI effect should extend to include losses in income (residential, commercial, industrial and tourism), possible travel time delay costs, property values, quality of life and biodiversity, as well as supply chain, health (mortality and morbidity) costs, and weighted accordingly. Proper quantification of the net present value of climate change mitigation and adaptation measures and ensuring that the costs of implementation are lower than the costs of damages would ensure that the government manages the tradeoff between the environment and the economy optimally by not over- nor under-spending on these measures.

In recent years, much interest has also been garnered in the valuation of natural capital i.e. a country's stock of natural resources. Natural Capital Singapore, a collaborative research project funded by the National Research Foundation and hosted by the Singapore-ETH Centre, was launched in 2018, aims "to quantify the economic, social and cultural value of Singapore's environmental assets to aid future policy and urban development". They examined the potential of coastal and marine ecosystems (e.g. mangroves, seagrass, beaches and coral reefs) as well as territorial and freshwater ecosystems (e.g. forests, rivers and reservoirs) on mitigating the adverse effects of environmental and climate change, as resource inputs for industrial processes and subsistence, as well as their less tangible values to society (e.g. recreation, cultural heritage, artistic inspiration, scientific, education and existence values) (Friess, 2021).

The Gross Ecosystem Product (GEP) was developed and released in 2020 to derive a single, aggregated monetary estimate to measure the value of flows of ecosystems in China. The GEP involves a dual-disciplinary approach with the use of "spatially explicit integrated ecological-economic modelling" for predicting the flow of ecosystem services and then

[22] On average, over 2.7 million passenger trips are taken on the MRT daily (Temasek Ecosperity, 2019).

applying the appropriate economic valuation methods that can measure both ecosystem market services (e.g. for provisioning services such as agricultural and fishery products) and non-market services (e.g. eco-tourism and recreation) or services with distorted prices due to lack of clearly defined property rights (e.g. water supply), and even for regulating services such as flood risk mitigation (Ouyang *et al.*, 2020). Laying the data collection groundwork for GEP accounting includes the need to define the technical specification, a well-enforced statistical survey reporting system and an intuitive software for data upload and analysis (Han, 2021). Although GEP is a flow rather than a stock which limits its use to assess environmental sustainability due to a possible tradeoff between adjusting the value of ecosystem services flow and depleting the stocks of natural assets, it is still a useful comprehensive accounting measure for consideration to be applied in Singapore, where proper ecosystem valuation studies are still relatively few and far between in the absence of a standardized framework (Dasgupta, 2021).

3.4. *Active engagement of stakeholders*

To mitigate and adapt to the costs of climate change effectively and sustainably, a multi-disciplinary approach is required to comprehensively quantify climate-related data that includes both the scientific engineering and social sciences aspects, the latter which is often neglected by the public sector or is too disconnected from the former. Economists, climate scientists, engineers, geologists, technicians, food scientists,[23] bank accountants, etc. and even different specializations within the same discipline would have to work collectively and in tandem with one another (Sambhi, 2020).

Environmental impact assessments (EIA), which adopt a systematic framework to determine and mitigate the potential impact of any new development on the environment, have been more formally carried out in Singapore since 1989 in consultation with nature and community stakeholders. Traditionally conducted on an ad-hoc basis as requested by NEA or NParks, the EIA evolved to become an "administrative process to coordinate inter-agency efforts" in 2008 (MND, 2015). From 2016–2021, there have been 11 EIAs carried out by various agencies including Mandai Park Holdings, Land Transport Authority (LTA), HDB and PUB.[24]

As was mentioned, because tangible environmental activities that yield direct benefits to the economy, mostly in the areas of liveability to promote productive activities and Singapore as a regional tourism and services hub were often prioritized, natural habitat and biodiversity conservation projects were inevitably sidelined. Not all cases presented by ENGOs were accepted by the Singapore government. There is the infamous example of Senoko, a nesting site for many species of birds, where urban needs were eventually prioritized over the environment, once again reflecting the immense constraints faced by the state during its early years of development. However, despite most national

[23] Cultiv@te, an innovation in sustainable agriculture initiative of UNDP supported by the Singapore Government, was announced in 2019, as well as the Agri-Food Innovation Park by JTC.

[24] See https://www.ura.gov.sg/Corporate/Planning/Our-Planning-Process/Bringing-plans-to-Reality/Environmental-Impact-Assessment

environmental decisions being concentrated in the hands of the state, the Singapore government has been receptive to pressure from ENGOs occasionally. Over the years, there have been several examples where development decisions were modified or delayed if the tangible benefits of development do not outweigh the intangible costs of clearing environmental spaces.

One example concerns the Central Catchment Nature Reserve (CCNR) and the MRT Cross Island Line (CIL). LTA had received feedback from the NSS that was concerned about the loss of Singapore's biodiversity due to encroachment on the Central Catchment Nature Reserve if the MRT line were to directly pass through it. Instead of proceeding with the original plan and after considering their suggestion to skirt it around the reserve, LTA eventually decided that the optimal solution was to run the MRT line under the CCNR to accommodate both flora and fauna as well as economic considerations (Tan and Tan, 2019). The second example concerns the construction of golf courses at Lower Peirce Catchment and at Mandai Road. The predecessor of NParks, the Nature Reserves Board (NRB), postulated the view that golf courses should serve as buffers and should not intrude in nature reserves causing a loss of biodiversity. PUB eventually agreed to only clearing the area near Mandai Road for a golf course and left the Lower Peirce area unscathed. A third example concerns Tanjong Chek Jawa, unique natural 100-hectare wetlands at the eastern end of Pulau Ubin. Originally slated for reclamation for military purposes in 1992, nature enthusiasts discovered a cluster of coastal and marine habitats and the abundance of biodiversity which garnered a lot of media attention and publicity. Eventually, upon receiving a letter from NSS and faced with an increasing number of onsite studies carried out by volunteers and officials from MND, URA, HDB and NParks that went beyond the scope of the original EIA, the decision for reclamation works at Chek Jawa was eventually withdrawn by the government (MND, 2015).

In view of an anticipated further decline in reef area from an EIA carried out in 2012 for the S$20 billion Tuas Terminal development (completed in late 2021), approximately 80% of coral colonies were relocated to offshore southern sites and coral nurseries with the assistance of volunteers (Lim, 2015). To enhance awareness and propel conservation efforts of the critically endangered Sunda Pangolin, the Singapore Pangolin Working Group (SPWG), was formed by "stakeholders from government agencies, conservation NGOs, private entities, and academic institutions in Singapore" in 2014, which resulted in the Sunda Pangolin National Conservation Strategy and Action Plan in 2018.[25]

The government has also taken initiative to conduct formal training and learning of how to manage ecology and biodiversity conservation within an urban environment. For example, in the 2000s, the Centre for Urban Greenery and Ecology (CUHE) was established in conjunction with the Workforce Development Authority and the Butterfly Garden in HortPark, and in collaboration with a nature enthusiast group to consolidate expertise on greening the urban landscape and implement biodiversity-related assessments and projects. In 2013, the Eco-Link@ Bukit Timah Expressway (BKE), a collaboration between NParks, URA, ENGOs and tertiary institutions that served to restore "ecological connectivity"

[25] See https://www.reversethered.org/stories/sunda-pangolin

between the Bukit Timah Nature Reserve (BTNR) and BKE was constructed after being in the works for seven years. It was noted that more of such ecological connectivity was needed, after several reported deaths of critically endangered species such as the Raffles' banded langur from being run over by vehicles on the roads (Ang, 2021). After being initially inspired by the then head of ARUP, a collective of designers, advisers and experts on sustainable development, NParks and MND developed the Singapore Index on Cities' Biodiversity (SI) as "a self-assessment tool to monitor biodiversity conservation efforts over time". The SI marked Singapore's first significant contribution to the objectives of the Convention on Biological Diversity (CBD) that was ratified in 1995 (MND, 2015).

Although reef restoration programs have been implemented in the 1990s such as substrate modification, artificial reefs, coral nurseries and coral transplantation, Ng and Chou (2017) noted that in the long term, successful restoration and conservation of reefs "requires not only scientific expertise, but also the cooperation and commitment of other stakeholder entities, including policy makers and civil society". For example, they recommended for volunteers to consult scientific expertise from the Tropical Marine Science Institute (TMSI) and DHI Water & Environment on the understanding and execution of reef restoration in Singapore, via social media platforms run by ENGOs or nature enthusiasts and via Southeast Asian international programmes for professionals.

SGFC, Nanyang Technological University's Institute for Catastrophe Risk Management, Earth Observatory of Singapore and NUS Centre for Hazards Research, in collaboration with other regional institutes and regional partners, are dedicated to conducting climate risk-related research for Singapore and the wider region.[26] In 2009, the Integrated Urban Coastal Management Framework (ICUM) was introduced which aims to facilitate meaningful partnerships, synergies and coordination amongst governmental stakeholders to analyze the integration of sustainable coastal resource usage and conservation of coastal habitats in the governance aspects of coastal management strategies (MND, 2015). In 2019, the Monetary Authority of Singapore (MAS) announced the development of a comprehensive long-term sustainable financing strategy called the Green Finance Action Plan that aims to strengthen financial sector resilience to environmental risks, harness technology to enable trusted and efficient sustainable finance flows, develop markets and solutions to reduce transactional costs of green bonds and loans with an emphasis on green investments, as well as build knowledge and capabilities in sustainable finance. As part of this initiative, SGFC intends to develop the green capital market in Singapore by conducting multidisciplinary research and mobilizing talents to transform the future economy and ecosystem into a green one that is functional through sustainable investing channels. To properly calibrate ESG and impact measurement standards for Singapore organizations (as was highlighted in Sec. 3.3), the SGFC has embarked on several stakeholder collaboration initiatives to gather the necessary expertise. For example, in 2021, they organized a panel discussion presented by leading experts (practitioners, academics and regulators in ESG-related fields) on ESG measurements and standards and formed a working group for this purpose with industry partners (Chua *et al.*, 2021).

[26] See https://www.nccs.gov.sg/singapores-climate-action/climate-risk-management/

Recognizing that coastal protection measures that worked out successfully in other countries such as the sand engine[27] in the Netherlands may be inapplicable to Singapore due to differing geographical constraints e.g. coastal vulnerability to long-term environmental shifts, thinning coastline and lack of sand harvesting sources,[28] PUB realized the need for site-specific studies for the various coastlines in Singapore (PUB, 2021). In 2021, to guide the development of the Coastal-Inland Flood Model, which aims to assess the risk factors of flash and coastal flooding due to climate change, PUB launched the Global Innovation Challenge (GIC) to seek innovative and well-contextualized coastal protection solutions from bright minds of the industry and academia. The GIC has seen some success in identifying viable technological alternatives to the sand engine and embodying the principles of accounting for the urban and coastal challenges of Singapore, continuous artificial structural improvements without excessive natural disturbance, soft ecological engineering solutions and sustainable use of materials (e.g. structurally complex breakwater armor units and bio-cement). Friess *et al.* (2020) created a set of unique tiered indicators (according to ecosystem level, location level and context-specific) to differentiate, quantify and spatialize the variation in scientific value of the coastal and marine ecosystems in Singapore, and found that the scientific values of mangroves, open water and coral reefs were ranked among the highest. Reconciliation of these scientific values with their economic values will be necessary to be factored into coastal management decisions.

NCCS has held six public consultations in total so far[29] to seek feedback on Singapore's Long-Term Low-Emissions Development and Climate Change Strategy as well as the carbon tax. Most recently, NCCS gathered public feedback on the possibility of updating the enhanced NDC 2030 target to a more ambitious one and aims to reach net zero by 2050 (Tan, 2022b). The Coastal Protection Expert Panel, which comprises local and global experts, was established in 2020 to advise PUB in coastal adaptation measures (BCA, 2021).

As an overseer of the development of green buildings, the BCA has ensured that the GMS standards were abided by regular conduction of audits by maintaining a close relationship with building developers and owners to coordinate green urbanization efforts. Application of GMS standards was extended to include public institutions as well. The BCA has also engaged a broad range of stakeholders, such as those from the industry and academic community to refine and expand the GMS (Han, 2019). In recent years, BCA has further augmented its green and sustainability efforts through different initiatives, partnerships, and collaborations with industry stakeholders. BCA reached out to a wide group of stakeholders through the Singapore Green Building Council (SGBC) which was established in 2009. Their Build it Green (BiG) Day Out 2016 Carnival was a public outreach program designed to raise public awareness about green buildings and lifestyles

[27] A relatively less nature-intrusive practice of nourishing a coastline with a large amount of sand in one fell swoop and then relying on the natural movement of waves, tides and wind for maintenance.
[28] The extent of sand scarcity in Singapore could perhaps be illustrated by an incident in 2010 where some land developers were accused by ENGOs of being involved in sand smuggling activities from Malaysia to Singapore (Henderson, 2010).
[29] See https://www.nccs.gov.sg/public-consultation/

(Han, 2019). The Super Low Energy (SLE) Challenge was launched in 2018 which brought together progressive industry stakeholders to embark on at least one Green Mark SLE project (BCA, 2021). The latest edition of the Singapore Green Building Masterplan (SGBMP), which is part of the SGP 2030, aims to green 80% of buildings in Singapore by gross floor area, ensure 80% of new private sector buildings to be SLE buildings and achieve 80% improvement in energy efficiency for best-in-class green buildings. As part of the preparatory work to achieve these ambitious objectives, BCA and SGBC consulted more than 5,000 people about their thoughts on green buildings and incorporated their views in the final recommendations of the SGBMP Engagement Report.[30] In the lead-up to the Singapore Green Building Week (SGBW) 2017, BCA convened an International Panel of Experts meeting on Sustainability in the Built Environment (IPE-SBE) to seek experts' (e.g. in the areas of green building management and engineering, as well as behavioral change) views and review Singapore's green building initiatives (BCA, 2017).

At the Eco Action Day in 2019, a discussion was held between industry leaders and governmental representatives on the future of the rag-and-bone men in Singapore (affectionately known as *Karung Guni* in the Malay language) who typically collect used items of economic value and resell them in flea markets, which eventually end up being reused or recycled. It was remarked that as the *Karung Guni* collect practically nine times more recyclable items relative to national recycling initiatives, more public and private sector resources should be directed toward formalizing and modernizing the sunset informal waste recycling sector to enable the *Karung Guni* to continue staying relevant economically and contribute to environmental sustainability efforts simultaneously (Mock, 2019a). In 2021, 51 companies including Chevron, ExxonMobil and Shell have participated in the Jurong Island Circular Economy Study led by JTC, which draws on their integrated ecosystem to map a shared pathway to resource optimization in the areas of energy, water and chemical waste at the system-level in the energy and chemicals industry.[31] Although, as shall be highlighted in Sec. 3.6, the reality is that a deeper policy response and societal change will be required to enhance Singapore's treatment of waste materials to truly enable a circular economy.

Singapore is also cognizant of the environmental efforts put forth by other countries and would follow best green practices where applicable e.g. adopting international standards for environmental management. Together with PSB, the Singapore Confederation of Industries (SCI) had been promoting the ISO 14000 Environmental Management System (EMS)-related activities to the industry as early as 1996. Subsequently, more public and private committees such as the Environmental Management Technical Committee (EMTC) and the National Coordinating Committee on ISO 14000 were set up to assist industries to adopt ISO 14000. At the 26th Conference of Parties (COP-26) to the United Nations Framework Convention on Climate Change (UNFCCC) in Glasgow, Singapore has also demonstrated its international commitment to phase out unabated coal power by 2050 by

[30] See https://www1.bca.gov.sg/buildsg/sustainability/green-building-masterplans
[31] See https://www.jtc.gov.sg/about-jtc/news-and-stories/press-releases/51-companies-jointly-support-industry-first-circular-economy-study-by-jtc-to-optimise-resource-use

joining the Powering Past Coal Alliance (PPCA) and signed the Global Coal to Clean Power Transition statement (MTI, 2021b).

3.5. *Use of market instruments*

Market-based instruments have the advantage of achieving environmental solutions at lowest possible cost. Polluters have the liberty to conduct their own financial appraisals and assess if the costs of investment in better pollution abatement technologies and implementation of management systems are lower than the costs of paying for polluting.

Singapore became a party to several Multilateral Environmental Agreements (MEAs), including the Montreal Protocol in 1989.[32] To meet its obligations under the Montreal Protocol, various agencies coordinated by the Ministry of Environment, including the Trade Development Board (TDB), the Productivity and Standards Board (PSB) the Economic Development Board (EDB) and the and Fire Safety Bureau (FSB), implemented market-based and voluntary programs using technical and economic incentives to control the market for Chlorofluorocarbons (CFC) and Ozone Depleting Substances (ODS) (Peck, 1999). For example, the Tender and Quota Allocation System (TQS), a market-based allocation mechanism where the price that industries were required to pay for ODS was determined by market forces, was established in 1989.

The management of growth congestion using both electronic road pricing, and the issuance of the certificates of entitlement (COE) through an auction system, is unique to Singapore. The COE is closely associated with the Vehicle Quota System (VQS) established in 1990 whereby the government first determines the number of new motor vehicles permitted on the road annually, then distributes approximately one-twelfth of this annual quota to the public monthly based on a sealed-bid uniform price auction.[33] Traffic congestion policies have the advantage of being able to maintain the dual objectives of maintaining environmental quality and productivity. With lesser traffic congestion, workers are more likely to be punctual at work, while good air quality not only results in a better environment but is also good for respiratory health, which could lead to fewer medical leaves taken. Therefore, the social net benefit of traffic congestion policies may be largely positive even after considering the private costs incurred for those not being able to own a vehicle as a result of failing to bid for a COE.

Maintaining good air quality needs not only technology and engineering capabilities, but also differential taxes on sources of emissions. For instance, an ongoing rebate and surcharge scheme (i.e. Enhanced Vehicular Emissions Scheme (VES)) and a recent carbon tax encourage the use of cleaner vehicles. With the implementation of the Weekend Car (WEC) Scheme in 1991, the tradeoff between the desirability of owning a car (which affects the profitability of the automotive market) and the negative externalities caused by heavy road traffic was moderated. This was achieved by making the ownership of a car

[32] Other MEAs regarding controls on chemical and hazardous waste that Singapore ratified include the Minamata Convention on Mercury, Rotterdam Convention, Stockholm Convention and Basel Convention.

[33] A sealed-bid uniform auction is one which bidders submit one or more bids at different prices and the price paid by all successful bidders is uniform and equal to the highest rejected bid price.

Table 4. Past and present traffic congestion policies in Singapore.

Measures to reduce the usage of cars	1975: Area Licensing Scheme (ALS) Park & Ride scheme 1995: Road Pricing Scheme (RPS) 1998: Electronic Road Pricing (ERP)
Measures to restrain the ownership of cars	1972: Additional Registration Fee (ARF) 1975: Preferential Additional Registration fee (PARF) 1990: Vehicle Quota System (VQS) (to bid for COEs) 1991: Weekend Car (WEC) scheme 1994: Off-Peak Car (OPC) scheme (replaced the WEC scheme) 2010: Revised Off-Peak Car scheme (revision of the OPC)
Measures to encourage the adoption of green vehicles	2013: Carbon Emissions-Based Vehicle Scheme (CEVS) 2015: Revised Carbon Emission-Based Vehicle Scheme (CEVS) 2018: Vehicular Emissions Scheme (VES) 2021: Enhanced Vehicular Emissions Scheme (VES)

Source: Fujii and Ray (2019); LTA (n.d.).

more affordable with reduced annual road tax and tax rebates, at the cost of being constrained to drive only during off-peak hours (Fujii and Ray, 2019). Table 4 depicts a history of past and present traffic congestion policies that reduce carbon-emitting vehicles in Singapore.

The Energy Market Authority (EMA) was established in 2001 to regulate and promote competition in the electricity and gas industries. Under the EMA, the National Energy Market of Singapore (NEMS) was established in 2003 to allow prices to reflect supply and demand fundamentals. In 2014, to meet incremental market demand, EMA introduced a competitive licensing framework to provide Singapore with the flexibility to procure liquefied natural gas (LNG) on a tranche-by-tranche basis. This framework relies on an importer-aggregator model, where a single company is appointed based on the level of diversification of their gas supply sources, gas market operation experience, gas pricing strategies, flexibility of contract terms, credit rating and financial performance, to have an exclusive license to import LNG on a tranche-by-tranche basis to meet domestic demands.

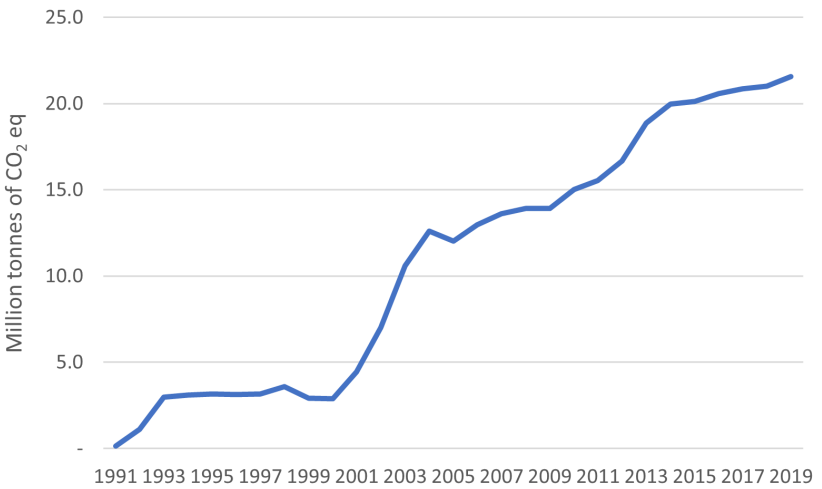
However, a single appointed LNG importer bears a significant degree of corporate finance risk which could only be mitigated if Singapore's LNG demand is large enough to justify the appointment of multiple importer-aggregators taking charge of multiple tranches of LNG. Although it may be argued on theoretical grounds that having an LNG import model resembling that of a natural monopoly would eventually result in cheaper LNG prices for buyers due to economies of scale, it is unclear if prices are inversely related to the volume of LNG purchased. In addition, buyers are unable to engage in collective bargaining in the absence of competition and autonomy. The original LNG procurement framework also received negative feedback about indirectly penalizing a single representative and self-suppliers in the borrowing and lending pool by requiring the representative to underwrite commercial and operating risks for the whole pool and to re-supply to other gas buyers at the expense of their self-consumption under certain conditions (Doshi and Zahur, 2022).

The Open Electricity Market, established in 2018, allows all consumers to have flexibility in choosing which retailer to purchase electricity from besides SP Group. The seven main natural-gas fueled power generation companies in Singapore compete to sell electricity to retailers on the wholesale electricity market and the retailers in turn compete to sell their procured electricity to households. As the result of the global fuel crunch from geopolitical tensions such as the Russia–Ukraine war and upstream production issues in Indonesia, combined with Singapore's reliance on piped natural gas for electricity production and pent-up demand for electricity with the stabilization of the COVID-19 pandemic, gas prices soared up to an 80% increase in the first quarter of 2022 (Tan, 2022b; Lee, 2022a). The ensuing high prices in the wholesale electricity market because of the gas shortage resulted in dwindling profits for electricity retailers in Singapore, which forced 6 of them to exit the open electricity market in 2021. Although ex-gratia compensation was offered to existing consumers for some retailers and EMA claimed to have implemented some safeguards, the actual process to ensure that retailers abide to the Consumer Protection (Fair Trading) Act upon their exit of the market under the purview of EMA was seemingly ambiguous to some retailers and consumers prior to this incident. In addition, businesses with high power consumption are only allowed to purchase electricity directly from the wholesale market, where prices are more volatile to demand and supply changes (Ng, 2021a; Chew, 2022; Tang, 2022a).

These distinct drawbacks of Singapore's LNG procurement framework and Open Electricity Market highlight the susceptibility of market instruments to demand and supply shocks. To ensure that less equity between profit-maximizing market players (buyers and sellers) and economic efficiency needs to be traded off for the assurance of economic stability, there needs to be a greater diversification in primary commodity sources and the range of market instruments being implemented, accompanied by stronger social safety nets. In addition, while cleaner relative to other fossil fuels, achieving net-zero carbon emissions by 2050 would mean hardly any leeway for using fossil fuels of any kind. As seen in Fig. 6, the amount of GHG emissions in Singapore from combustion of natural gas has risen over the years to above 20 million tonnes of CO_2 equivalent. Therefore, overdependence on the cleanest fossil fuel alone within a market instrument framework is not a good strategy in the interests of both the economy and the environment in the long term.

The imposition of an optimal level of Pigouvian tax on fossil fuel emissions could be an effective complementary market instrument in curbing emissions. The CPA was introduced in 2019 which acknowledges that carbon has a price thus requiring moderate carbon emitters to register as a reportable facility and large emitters to be registered as a taxable facility.[34] The fact that Singapore's carbon tax was one of the lowest in the world at a rate of S$5 a tonne also strongly hints at local policymakers' cautious approach to ensuring that the negative impacts on economic competitiveness arising from environmental policies are minimal (Tseng, 2022). In addition, the uses of petrol, diesel and compressed natural gas

[34] Although the CPA is an environmental legislation, it functions as a market-based instrument which puts a price on carbon rather than directly regulating it.



Source: EMA (2021).

Fig. 6. Singapore's GHG emissions from fuel combustion (gas).

(CNG) are also excluded from the coverage of the carbon tax as the government has assessed that existing fuel excise duties are already sufficient in encouraging moderation of fuel consumption (Chen, 2022).

However, any positive effect of the baseline carbon tax on the relative decrease in total carbon emissions and in terms of per capita from 2019–2020 was imperceptible (around 1.2%) (Ritchie and Roser, n.d.). As such, during the recent 2022 Budget speech, it was revealed that, in recognition of the increased momentum in global climate change action and foreseen availability of green technologies, the carbon tax was slated to be significantly increased from the current rate of S$5 to a tonne of emissions to S$25 in 2024 and 2025, S$45 in 2026 and 2027, with the goal of reaching S$50 to S$80 a tonne by 2030. To ensure a reduction of emissions to a societally optimal level, the level of tax should be high enough as a deterrent to excessive emissions and to internalize the external costs to the environment. This could only materialize if the increased costs to society from the carbon tax are greater than the costs of decarbonization and the demand and supply for carbon emission-intensive activities are price elastic. Benchmarking is a useful tool for this purpose i.e. benefit-transfer method. For example, NCCS has noted that the revised carbon tax trajectory will be comparable with regional countries' future carbon prices by 2030[35] and major companies' internal carbon prices (Chen, 2022). Besides better alignment with Paris Agreement goals, a higher domestic carbon tax may potentially lower any carbon border tariffs that Singapore-produced exported goods may face from trade with European Union (EU) countries come 2026 (Fogarty, 2021).

[35] Such as those of China (S$45), South Korea (S$61), though still far from the recommended prices set by the International Monetary Fund (IMF) (S$101) and International Energy Agency (IEA) (S$107).

However, as was highlighted in Sec. 2.1, meeting these conditions is likely to be an onerous task for conventional large emitters from the manufacturing, transport, petrochemicals and power generation sectors. In particular, SGD50-80 per tonne of CO_2 equivalent would translate to costs of SGD220,000 to SGD353,000 for Singapore's specialty chemicals sector,[36] which is responsible for 78% of embodied carbon in this sector. This is because feedstocks and fuel sources that are produced from fossil fuels may not be readily substituted with low-carbon sources and to produce enough in a low-carbon manner to meet current demand (Goh *et al.*, 2022). These estimated costs may be lesser for smaller firms in the specialty chemicals sector which form the majority but disproportionately larger for the larger emitters.[37] Furthermore, it is said that the increase in carbon tax is not expected to translate to additional revenue for the government until at least after 2030 (Chen, 2022). This implies that it may be difficult to set up a decarbonization fund in the short run to aid businesses financially in adopting low-carbon solutions. In addition, if energy costs of production become too high, Singapore may lose strategic advantage over other regional competitors such as Thailand, South Korea, India and China in the oil refining and petrochemicals industry (Doshi and Quah, 2022).

The distributional impact of the tax burden on consumers i.e. increase in cost of living is also worrisome. Although $25 per tonne of CO_2 equivalent is estimated to translate into only about S$4 increase per month in utility bills for an average household, households are already expected to bear the burden of an increase in electricity tariff by an average of 9.8% in mid-2022 (Ng, 2022). As taxes are inherently regressive, a carbon tax increase imposes a greater burden on lower-income households. In addition, a carbon tax increase does not affect only utility bills but also the prices of other goods and services that have carbon footprint embedded in their production supply chain such as the transport and the food and beverage (F&B) sector, which limits the effectiveness of utility rebates (Quah and Tan, 2022). Costs of relocation and upskilling of labor may also be incurred to ensure smooth transition from potential job losses in carbon-intensive industries to new jobs in carbon-neutral sectors. Therefore, increasing the carbon tax may worsen the tradeoff between economic growth and the environment in the short run.

However, the purpose of the carbon tax effectively acts as a market signal for companies to eventually switch to potentially more cost-efficient carbon-free technologies in the long run. Taken together with excise duties, about 90% of Singapore's emissions are faced with a price signal and this effect would only get stronger with the increase in carbon tax (Chen, 2022). The challenge is to ensure that the long-run benefits of the carbon tax increase outweigh the short-run costs. To estimate the total cost burden that producers would pass down to end consumers, it is necessary to figure out their price sensitivities to various household expenditure items that are affected by a carbon tax increase and the cross-price elasticities associated with such items (Tan, 2022c; Hahn and Metcalfe, 2021). Such information on the tax incidence would be useful to determine the optimal amount

[36] Singapore is the 8th largest exporter of chemicals globally.

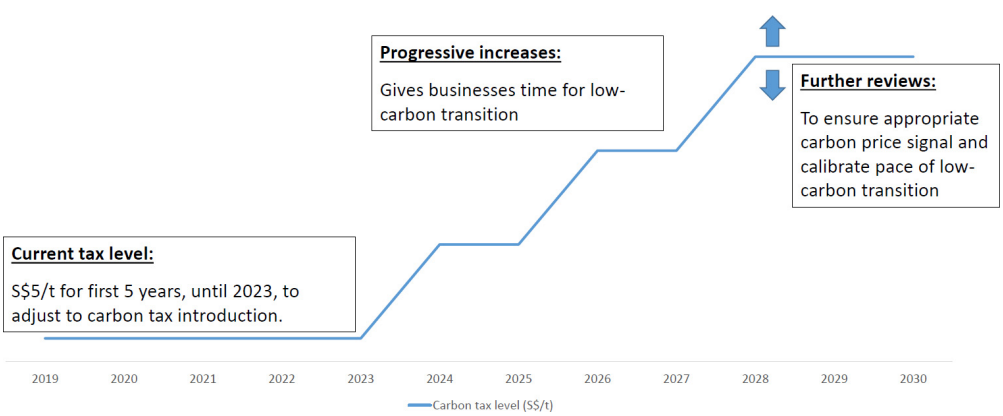
[37] Refer to https://www.specialtychems.com/ebook/scd/latest/mobile/index.html for a list of companies in the specialty chemicals sector.

and types of cash transfers to offset the effects of the rising green premium on end consumers. More efforts to make green technologies more affordable and accessible (also see Sec. 3.7) and giving a reasonable timeframe for businesses to make the transition are paramount in ensuring that the carbon tax's price signal can achieve its intended outcome and avoid driving inflation (Quah and Tan, 2022). Figure 7 shows a timeline of the carbon tax level adjustment from 2019–2030.

To mitigate the impacts of the carbon tax increase, the purchase of offset credits on the new Climate Impact X (CIX) marketplace, a carbon exchange joint venture between Singapore Exchange (SGX), DBS Bank, Standard Chartered and state investment company Temasek Holdings, indirectly allows companies to "offset" some of their carbon footprint up to 5% of their taxable emissions from 2024 (Kua and Aravindan, 2022). Under Article 6 of the Paris Agreement, Singapore is also inking bilateral carbon offsetting agreements with countries such as Papua New Guinea (Lei, 2022).

Private sector initiatives have also started to emphasize carbon neutrality in their energy pricing plans. For example, energy suppliers such as ES Power/iSwitch and Ohm Energy have allowed consumers to offset their carbon emissions from electricity usage via carbon credits (Mock, 2019b). Moreover, grants to assist companies in investing in energy efficient equipment will be enhanced and their application logistics eased,[38] complemented by transitory allowances for more energy efficient facilities (Chen, 2022).

In 2017, Singapore was ranked eighth among the world's major cities and the third-highest ranked Asian city when it comes to sustainable transport (Lim, 2017). More emphasis is increasingly placed on walking, cycling and taking public transport. However, there have been divisive views regarding ridesharing services about whether they do in fact



Source: Chen [from NCCS] (2022).

Fig. 7. Singapore's revised carbon tax trajectory.

[38] See https://www.mse.gov.sg/resource-room/category/2022-03-08-speech-by-minister-grace-fu-at-cos-sgp-joint-segment-2022

reduce negative externalities of carbon emissions and congestion. The introduction and expansion of car-pooling or ridesharing services in Singapore such as GrabHitch, Gojek and Maxi Cab have offered consumers more alternative modes of travel beyond the conventional public transportation and taxis. In recent years, the hike in COE prices across all vehicle categories has increased the private cost of owning a vehicle significantly, with the hike being greatest for large cars and motorcycles (Tjoe, 2022). The 2022 Budget has also announced the addition of a new ARF tier at a rate of 220% for cars with open market value (OMV) in excess of S$80,000 i.e. luxury cars, which is expected to generate an additional S$50 million in annual revenue (Ramchandani, 2022).

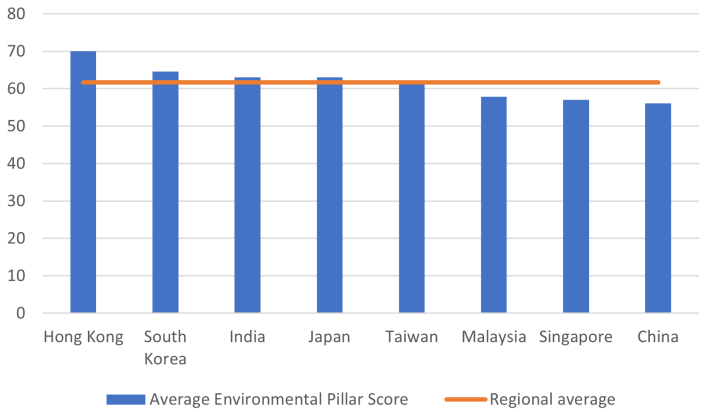
On the one hand, ridesharing services can be said to be indirectly discouraging individuals from purchasing private vehicles for personal use or encouraging them to switch to ridesharing services due to the abundance of more cost-effective and convenient substitutes (as they can avoid the hassle of parking). As the marginal utility of moving from the existing modes of transportation to private vehicles diminishes for the average consumer, ceteris paribus, fewer additional private vehicles on roads may be expected and this may result in lower carbon emissions. Ridesharing companies are also beneficial to productivity growth especially for non-remote jobs and during the pre- and post-COVID-19 pandemic period when work-from-home restrictions were not in place. Wang *et al.* (2018) studied the benefits of ridesharing in Singapore by conducting a comprehensive simulation study based on real taxi booking data from GrabTaxi. They considered various factors such as waiting time, departure/arrival delay, taxi capacity, taxi fare saving, and shared trip surcharge in a practical ride-sharing framework. They found that ridesharing could accommodate 20–25% more taxi booking requests during peak hours with significant travel distance savings, implying that ridesharing could potentially reduce carbon emissions.

On the other hand, they did not allude to the fact that, especially in dense cities, people who would previously walk or take the subway to their destinations may now choose to opt for ridesharing services, and that this segment of the population may be greater than those who switch from private vehicles to ridesharing vehicles. In addition, ridesharing vehicles spend more time cruising around for passengers and thus may produce even more carbon emissions as compared to private vehicles. As this hypothesis has seen some credibility in a study of several metropolitan statistical areas in the U.S.,[39] more studies should be conducted on ridesharing in Singapore as a sustainable transport option.

In line with LTA's goal of electrifying half of Singapore's bus fleet by 2030 and to achieve a 100% cleaner energy bus fleet by 2040,[40] ridesharing companies have pledged to adopt cleaner energies and the imminent electrification of the mobility fleet such as under Grab's Transport Sustainability Goal and funds raised from GrabRental. As such, the tradeoff between productivity gains and environmental concerns of ridesharing may be easier to manage in the time to come (Chan, 2021).

[39] See https://cmp.smu.edu.sg/article/uber-bad-environment

[40] See https://www.lta.gov.sg/content/ltagov/en/industry_innovations/technologies/electric_vehicles/our_ev_vision.html#:~:text=LTA%20will%20electrify%20half%20of,with%20electric%20buses%20by%202025



Source: Refinitiv (2019)

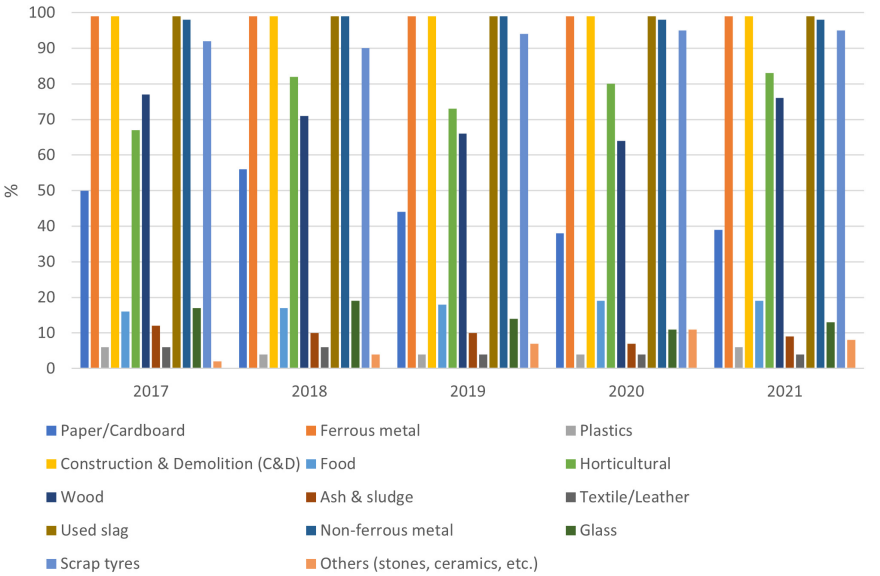
Fig. 8. Average Environmental Pillar Score in Asian economies.

3.6. *Use of behavioral interventions*

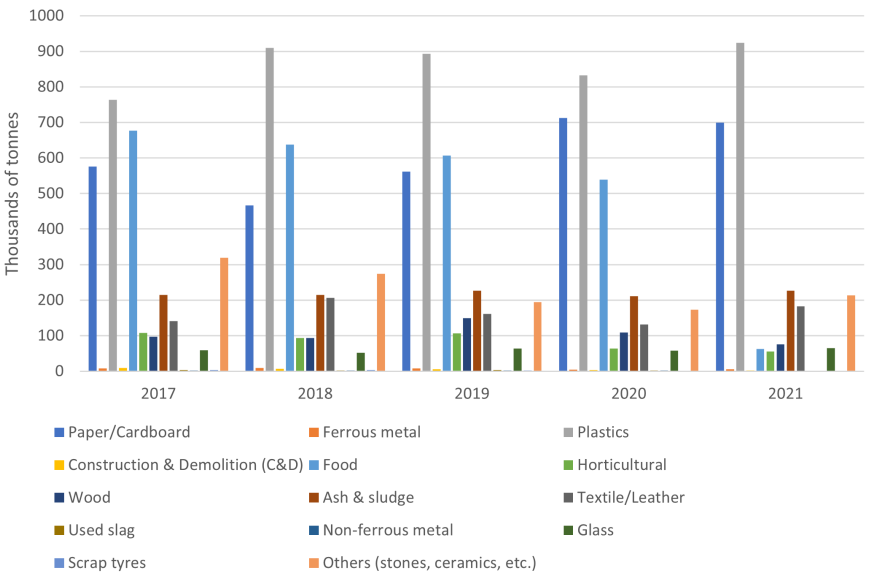
Besides competitive markets, there have also been initiatives from the public and private sector to promote environmental behavior and consciousness among individuals. Individuals refer to both firms and households, whose carbon footprint should not be understated as Singapore has a relatively high carbon dioxide emissions per capita.[41] Although the overall recycling rate improved over the years, upon a closer examination of the recycling statistics by waste type, much must still be done to lower waste generated and disposed by the domestic sector and improve recycling rates in the areas of plastics and food waste. In 2018, Singaporeans reportedly disposed of about 7.7 million tonnes of waste, "enough to fill about 15,000 Olympic-size swimming pools" (Low, 2019).

Among the barriers to the scaling up of energy conservation initiatives (socio-cultural, market, policy and infrastructural/geographical) as identified by van Doren *et al.* (2016), the socio-cultural barrier is probably the greatest with regard to the residential and commercial sector in Singapore which the government is struggling to overcome. This is supported by the OCBC climate index in 2021 which noted that despite a high average climate awareness score among Singaporeans, the average adoption and advocacy scores are still subpar.[42] Refinitiv, a global provider of financial market data and infrastructure, surveyed firms from 8 of the biggest Asian economies in terms of environmental sustainability in 2019 and revealed that Singapore firms were ranked the second lowest and below the regional average (as seen in Fig. 8). This was attributed to subpar resource and waste management, as well as poor compliance with waste reduction policies despite a high adoption rate. Perhaps the most alarming revelation was that Singaporean companies were seemingly unfazed by the particularly bad transboundary haze issue that year with

[41] Singapore is ranked 27th highest in carbon dioxide emissions per capita in the world as of 2018, according to the OECD/International Energy Agency. Also see Fig. 1(b).
[42] See https://www.ocbc.com/group/sustainability/climate-index



(a) Singapore's recycling rate by waste type



(b) Singapore's total waste disposed by type

Source: NEA (n.d.)

Fig. 9.

regard to their environmental management, as they appeared to fare the most poorly in terms of investment in the developing of greener products (Fernandez, 2019).

As Fig. 9(a) shows, food and plastics are consistently among the bottom six waste types in terms of recycling rates in Singapore. Figure 9(b) concludes that food and waste are the

top two highest waste types disposed post-recycling in Singapore, which even the anomaly in 2020 (paper/cardboard waste exceeding the amount of food waste disposed) does not disguise, as the COVID-19 pandemic had forced people to consume takeaways, implying a very strong correlation between paper/cardboard and food waste. For example, during the period of Singapore's circuit breaker in 2020, 1,334 tonnes of disposable cutlery and packaging were produced by the F&B sector as a response to the increased demand for food takeaways due to dining in restrictions (Hill, 2020).

In 2021, upon some economic recovery from the relaxation of COVID-19 measures, waste generation increased by 18% from the previous year and although there was almost a 3% increase in waste generated from the domestic sector since 2020. However, the domestic recycling rate remained unchanged at 13%, with only 6% of plastics and 19% of food waste being recycled[43] (Begum, 2022). Indeed, in 2018, the Singapore Environment Council (SEC) found that 70% Singaporeans did not fully comprehend the recycling potential of various forms of plastics (SEC, 2018). In addition, marine litter, which is washed up on beaches during the monsoon season, contains substances that are harmful to the environment, such as microplastics that are a regular occurrence. Almost 4,500 tonnes of marine debris are collected by NEA and MPA annually in recent years, with the East Coast Park seeing a 90% increase in collected trash during the southwest monsoon (Begum, 2021). Although marine litter is also a transboundary issue, much can be done to inculcate greener consumption and disposal habits among locals beyond intensified cleaning operations by the government and individual volunteers. Meat products, including eggs and seafood, constitute almost 1/3 of an average Singaporean's diet and contribute substantially higher GHG emissions than fruits and vegetables. As such, behavioral changes need to be induced in consumers to shift to a more sustainable plant-based lifestyle (Temasek, 2019).

Singapore has traditionally relied on incineration in achieving the dual objectives of reducing up to 90% of waste volume and converting the heat energy produced as a by-product of the incineration process into electricity.[44] However, given that much of Singapore's paper and plastic waste needs to be exported for recycling due to the under-development of recycling facilities in Singapore that have high cost of maintenance, recent waste import bans or regulations by countries like China, Thailand, Malaysia and Indonesia may have increased the tendency to fall back on incineration as a failsafe (Minh, 2021). Key domestic recycling facilities such as Sembcorp Industries and Plaspulp Union, as well as WTE plants, face the challenge of contamination of recyclable waste with non-recyclable waste which hinder their recycling potential and have little choice but to prioritize the treatment of industrial waste over consumer waste. 40% of the contents disposed in blue recycling bins were unrecyclable due to contamination as of the first quarter of 2022, according to NEA (Ang and Co, 2020). The shortage of recycled materials would generate superfluous demand for virgin materials, thus allocating resources away from

[43] See https://www.nea.gov.sg/our-services/waste-management/waste-statistics-and-overall-recycling

[44] See https://www.nea.gov.sg/our-services/waste-management/overview#:~:text=Incineration%20reduces%20the%20waste%20by,of%20the%20island's%20electricity%20needs.

improving the quality of recycled or converted output and may even impede progress on transiting to renewable energy sources (Trang, 2021). To ensure a sustainable waste management strategy in the longer term for a smooth transition to a circular economy, the government noted that the 3Rs "Reduce, Recycle and Reuse" mindset needs to be inculcated among individuals and businesses to meet the inaugural Zero Waste Masterplan's objective of a reduction of 30% daily in waste volume delivered to the Semakau landfill in an attempt to prolong its lifespan on top of emerging technologies e.g. bottom ash extraction (Ang, 2019; Low, 2019).

Fujii and Ray (2019) noted that the government has used a combination of "normative messages and economic incentives over time to achieve desired economic and social outcomes". The objective of normative messages is to persuade individuals to conform to social and moral norms through various forms of communication channels, while economic incentives serve the same objective but are usually in the form of funding grants, rewards, subsidies, cash rebates and promised bill savings. Various incentive-based policies have been designed for land use, waste management, and transportation. Such policies are closely tied to the idea of using behavioral insights to influence individual actions. The private cost to households for waste collection in Singapore is conditional on house type and location rather than on the volume of wastes disposed by the household, as well as the convenience and anonymity factor of simply disposing waste down a rubbish chute. Therefore, there is little incentive for an average Singaporean household to reduce the amount of waste disposed and bear the opportunity costs of time in identifying recyclable items, walking over to a nearby recycling bin or even approaching the *Karung Guni* (Fujii and Ray, 2019).

Habitual behavior pertaining to inefficient energy consumption and wastage can be perceived as an economic "bad", while good habits, such as turning off lights when not in use, opening windows rather than using the fan/air conditioner and remembering to unplug electrical appliances when not in use, can be considered as an economic good. The opportunity arises for correction when rational utility-maximizing individuals become aware of the consequences of their bad habits due to increased knowledge and a better habit alternative is available e.g. perceived benefits of cost savings from the use of more energy-efficient appliances. Although the expected benefits of forming good habits and that of divesting bad habits in this case can be seen as the transpose of one another, the disposition of the bad habit, which involves time spent to unlearn the bad habit, and the formation of the new habit, which involves time to adjust to lifestyle modifications, would entail separate costs to the individual. For the individual to divest from their old environmentally non-chalant habit and form a new environmentally conscious habit would thus require that the expected benefits of forming/divesting habits outweigh the expected costs of doing both. It is important to note that these costs and benefits of changes in habitual behavior need not be solely accrued to individuals and can extend to include stakeholders such as ministries which have the jurisdiction and incentive to influence habitual behavior of individuals, which is how the concept of behavioral intervention programs come about (Daniel, 1981). There is also often a need to consider how such programs should be

Table 5. Examples of environmental behavioral intervention studies in Singapore.

Initiative	Key Objective	Program Details	Main Findings
Eco-living Programme, organized by Hong Kah North Residential Council with the assistance of community stakeholders (He and Kua, 2013)	To compare and assess the effectiveness of different methods of behavioral intervention, and how behavior and outcomes are affected by values, situational and psychological factors	Treated households were either distributed leaflets and stickers or counselled Collection of electricity consumption data and surveying of energy consumption behavior (actual reductions were compared to self-reported behavior)	Compared to counselling sessions, leaflets and stickers were more effective at reducing electricity consumption Ease of practicing recommended energy conservation actions is a strong motivator to change energy consumption behavior
Project Carbon Zero, organized by NEA, in partnership with SEC (Agarwal *et al.*, 2017)	To evaluate the ability of school children to instill a positive behavioral change in their family members to reduce electricity consumption	Students of the participating schools report their electricity consumption online, with rewards given to school/students who achieved minimum 10% reduction in electricity bills	Persuasion of school children led to significant lasting reduction in household electricity consumption, with neighbor spillover effects, which are also affected by age and housing type
Transformative education for climate change (TrEC) program, 3-months mixed-method study program conceptualized in collaboration with NEA and NCCS (Wi and Chang, 2019)	To study whether environmental education through Residential Committees (RC) can result in pro-environmental behavior	Consists of an introductory video for background on climate change, a discussion on energy conservation tips and a Q&A session, followed by time allocated to practice the things learnt	Individual pro-environmental actions that translated into savings from their utility bill appeared to be influenced by an improvement in their attitudes, which are shaped by their increased knowledge of climate change

Table 5. (*Continued*)

Initiative	Key Objective	Program Details	Main Findings
Food Waste? Don't Waste! organized by MSE, in collaboration with NEA, People's Association (PA) and Tampines Town Council (Huang *et al.*, 2019)	To encourage food waste segregation in households to enable food waste recycling and guide them to reflect on their actions	Radio-frequency identification (RFID) access-controlled food waste recycling bins were placed at each block of the estate with good visibility and accessibility Infographics and reminder posters on recycling guidelines, purpose and impact of food waste segregation, as well as immediate feedback on performance, were provided	Results showed greater knowledge of food waste recycling, sense of environmental responsibility and identity Participation rates were conditional upon waste segregation methods being convenient
Motivating household water conservation: A field experiment in Singapore, organized by NUS researchers on households in Ang Mo Kio (Goette *et al.*, 2019)	To compare the effects of normative and economic incentives in motivating water conservation	Household water consumption was measured via analysis of residential water meters and household survey data Printed leaflets fashioned as door hangers were distributed to provide information and feedback to households	Both normative and economic incentives significantly reduced water usage For households with higher-than-average water usage, normative messages were more effective than economic incentives

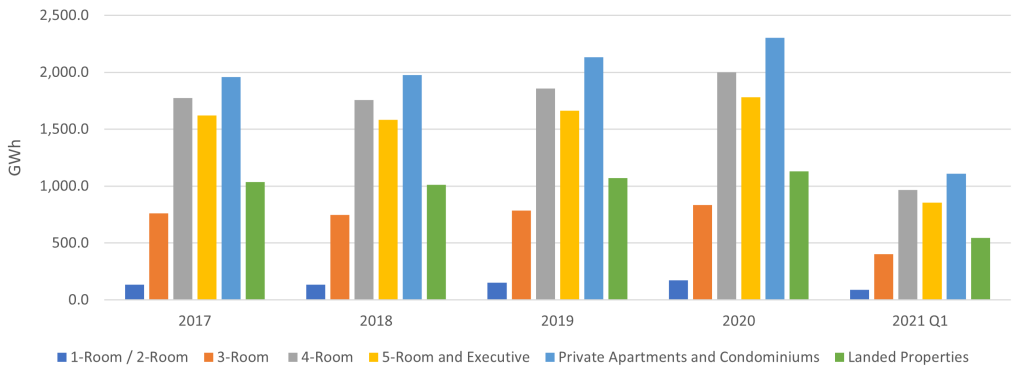
framed, the modes of conveying the intended information, and how choices are designated and presented.

One of the first behavioral intervention studies was launched in 1990, which was a 3-month pilot project to assess public's response toward waste segregation and identify possible challenges. House visits and flyers to disseminate information and encourage residents to participate were carried out, and recycling bins at strategic positions such as lift lobbies were provided. Following the generally positive public response toward that scheme, the trend of recycling schemes continued in rapid fashion across other housing estates in Singapore. Another notable one was the Tanjong Pagar recycling project in 1994, where it was found that non-use values were the most commonly provided reasons for practising recycling, while those against recycling, as expected, cited the "inconvenience, a lack of incentives and unfamiliarity" as reasons for not doing so (Foo, 1997).

Table 5 shows a list of more recent normative message-style behavioral intervention studies in Singapore. Such studies may usually be in the form of a quasi-experiment or randomized control trial where differences between treatment and control groups over time are observed.

Unfortunately, while successful among participating residents at the time of assessment, such behavioral intervention studies that are conducted to assess the efficacy of "nudges" towards reducing energy consumption and encouraging recycling are subjected to the constraint of being infrequent and limited to certain neighborhoods without regular follow-ups beyond the few post-program months. It remains to be seen whether some of the more successful elements from these trials can be implemented on a wider scale indefinitely. In recent years, NEA has addressed the convenience issue by implementing the dual chute system in new public housing projects in 2014 and later extended to include new non-landed private property, where residents can dispose of non-recyclable and recyclable waste separately. This endeavor has seen some success of achieving up to four times the recycling rate. NEA also plans to move beyond better labels on neighborhood recycling bins by distributing recycling containers to households in the latter half of 2022 (Begum, 2022). On the technological side, Pneumatic Waste Conveyance Systems have also been implemented in HDB estates to automate, centralize and optimize waste collection. Although behavioral interventions by themselves are limited, using them in conjunction with existing policy tools that lower the barriers to entry of going green for individuals and industry could yield better results overall.

The power of social norms or loss aversion could be better leveraged, for example, on the printing of the neighborhood's average consumption of electricity in their utility bills or the installation of electric meters that require pre-payment with a credit card. The Pay-As-You-Use (PAYU) Electricity Meter launched by SP Services in 2005 banks on the idea that residents have "invested" in their electricity consumption and would desire to make their remaining credit last as long as possible. In the long run, however, focusing on the policy context with a deeper, more stringent policy response to food and plastics waste to partly compensate for the limited success in the social-cultural context which relies on an incentive-driven, self-regulated and voluntary basis, is probably needed. Mandatory waste



Source: EMA (2021).

Fig. 10. Singapore's total household electricity consumption by dwelling type.

reporting, while only recently gaining more traction in Singapore, should be evolved to mandatory waste recycling or at the minimum, the imposition of a penalty-based system on recycling behavior, much like the EU or countries like South Korea. Although there is the issue of rising cost of living, real wage growth was still exceeding inflation as of 2021 and as such, there may in fact still be a consumer surplus despite having to pay a green premium for plastics and cardboard packaging (Leo, 2022). Therefore, in the meantime, more valuation studies can be done to elicit the maximum WTP/WTA of Singaporeans with regard to the green premium and consider pricing plastic and cardboard packaging, as well as fines for not recycling, above that amount to ensure that consumers and businesses are actually deterred.

Besides waste management, attention is also paid to energy consumption of households. As Fig. 10 suggests, the bulk of energy consumption of households comes from private apartments and condominiums (third-lowest resided dwelling type in Singapore), even higher than the most resided dwelling type in Singapore (HDB 4-room). This suggests that rising affluence may be positively correlated with energy usage and possibly energy inefficiency, once again pointing to the tradeoff between environmental sustainability and economic growth. Helping the public to identify products that meet certain eco-standards and encouraging manufacturers to create such products are essential to promote green consumerism in Singapore. Singapore's first attempt at an eco-labelling scheme, called the Green Labelling Scheme, was launched by the ENV in 1992. Standards to qualify for the displaying of the Green Label on a product are determined by a multi-stakeholder Advisory Committee, including "private organisations, academic institutions and statutory boards" (Peck, 1999). Since then, NEA has introduced the Mandatory Energy Labelling Scheme (MELS) in 2008, Fuel Economy Labelling Scheme (FELS) in 2012 and Minimum Energy Performance Standards (MEPS) in 2011 to help inform consumers' purchasing decisions and promote the use of energy-efficient consumer appliances that are traditionally energy-intensive such as refrigerators, air-conditioners and clothes dryers. In addition, to make

information on cost savings more apparent and easily accessible, NEA also has an online Life Cycle Cost Calculator for consumers to check annual energy costs incurred by an electrical appliance which can be compared with its upfront costs. Launched in late 2020, the Climate Friendly Households Programme allows all 1-, 2- and 3-room HDB households to be eligible for up to S$225 worth of e-vouchers to offset the purchase price of energy-efficient appliances (Lee, 2022a).

On the corporate side, although much has been done in the market and policy context to incentivize companies to embrace sustainability, there is also much work done by the E2PO to address the socio-cultural barriers, at least on the economic incentives aspect. Reports submitted by ECA-regulated firms in 2017/2018 revealed that the second most electricity-hungry industrial appliance system is the water-cooled chilled water system for process and space cooling, with most of them operating inefficiently. This prompted the introduction of the Minimum Energy Efficiency Standards (MEES) to set a threshold for the energy usage of chilled water systems which fulfills the dual objectives of promoting environmental sustainability from lower carbon footprint with lesser fossil fuels burnt for energy generation and economic efficiency from lifecycle cost savings as a result of lower capital, operating and maintenance costs from the retrofitting of more energy-efficient cooling systems that are ample for the firms' needs despite being less energy-consuming.[45] The MEPS also operates in the same vein to promote energy efficiency improvements for industrial equipment and systems in general and the MELS indirectly incentivizes manufacturers to be energy efficient in their production in view of the shift in demand trends to energy-efficient consumer appliances. The voluntary EnergySmart Labelling Scheme for offices, hotels and shopping malls was introduced in 2005 to award the top 25% of energy efficiency buildings with a green brand recognition. In 2015, SGBC introduced the Singapore Green Building Product (SGBP) certification scheme and the Singapore Green Building Services (SGBS) Certification to identify and assist the building industry to select green products and materials as well as building consultants with best green corporate practices.[46]

Companies that join the NEA's Energy Efficiency National Partnership (EENP) receive a range of benefits, including being able to leverage the Energy Efficiency Fund (E2F),[47] gaining more opportunities to gain experience in energy efficiency best practices, and receiving national recognition. Ministries such as MND and statutory boards such as NEA and EDB also set up a variety of green incentives and funds for property developers including the Green Mark Incentive Scheme, Investment Allowance (IA) Scheme, Resource Efficiency Grant for Energy (REG(E)), Singapore Certified Energy Manager (SCEM) Training Grant, Sustainable Construction Capability Development Fund, Building

[45] See https://www.nea.gov.sg/media/news/news/index/singapore-to-extend-energy-efficiency-requirements-to-cooling-systems-in-industrial-facilities

[46] See https://resourcehub.bakermckenzie.com/en/resources/global-sustainable-buildings-index/asia-pacific/singapore/topics/energy-performance-certificates-and-minimum-energy-standards

[47] An umbrella scheme consisting of five different grants: "Energy Efficient Technologies", "Low-Global Warming Potential (GWP) Refrigerants Chillers", "Energy Management Information System" (EMIS), "Energy Assessment", "Resource Efficient Design", with up to 70% funding support for small and medium-sized enterprises that invest in energy-efficient equipment.

Retrofit Energy Efficiency Financing Scheme.[48] For clarification and assistance on energy efficiency initiatives and mandates, companies can consult the Energy Efficiency Promotion Centre (EEPC) which "serves as a convenient one-stop centre for providing industrial energy efficiency related resources". In 2016 and 2018, the Green Buildings Innovation Cluster (GBIC) of BCA launched two R&D grant calls for the development of smart and energy-efficient technology and solutions for commercial buildings.[49]

In the long run, however, it would be best to adopt some sort of behavioral intervention programs that can provide greater insight into the various types of companies' motivations for going green so that policies can be adjusted accordingly to be aligned with their motivations. This is also in line with concerns about how to distinguish between greenwashing and genuine corporate social responsibility. The most common type of motivation that ministries are pushing for is for companies to recognize the benefits of competitiveness from going green in the form of cost savings and product differentiation via R&D. However, some companies may only be compelled to undertake green management measures provided that the cost of investment is lower than the cost of non-compliance, while others may be more compelled to mimic what the rest in the industry are doing with regards to best practices or simply to adhere to voluntary programs and industry standards laid by regulators to maintain their brand image (Lannelongue *et al.*, 2014). In sum, more behavioral intervention studies should be done to quantify the personal social orientation of firms with regards to their economic value (short-and long-term), legal value and ethical value (Klassen, 2001).

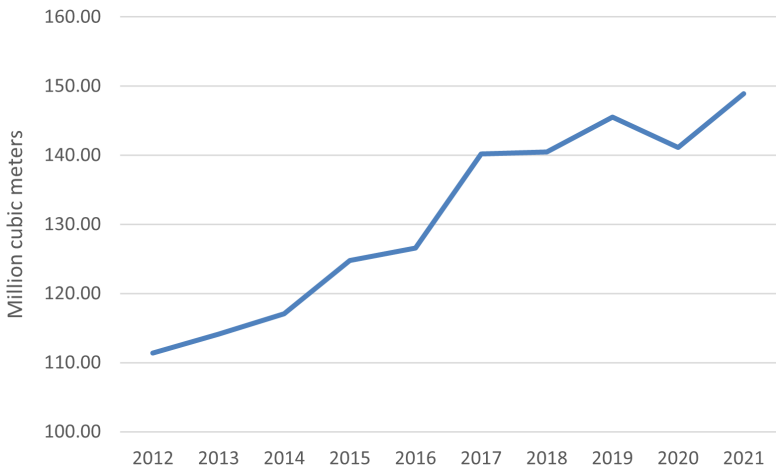
3.7. *Investment in renewable and clean technologies*

The last, and central reason is the integral use of research and development to introduce new technologies into the sustainable development blueprint. Shifting to renewable and clean sources of energy, as well as smart grid systems, is ultimately superior to fossil fuel-based carbon abatement strategies in reducing adverse environmental impacts in the long run for several reasons. Firstly, while technologies such as cogeneration and trigeneration for the power generation sector have seen decent energy efficiency potential, renewable and clean technologies have clear advantages in limiting global warming, better public health, greater potential energy output, skilled job creation and stability of energy prices. Secondly, one common argument among economists regarding the promotion of energy efficiency appliances and vehicles is the rebound effect i.e. inadvertently incentivizing an increase in appliance and vehicle usage due to the lower costs incurred for each unit output of energy. This could nullify the intended benefits of reduced energy usage when promoting energy-efficient appliances that still rely on fossil fuels (Liddle *et al.*, 2020).

Improved desalination and NEWater (highly purified recycled water) technology would make large-scale water recovery cheaper and feasible for Singapore, as seen by the

[48] For more details on these incentives and funds, refer to Building and Construction Authority. (2021). *EMERGING STRONGER TOGETHER through Transformation: Annual Report 2020/2021*; https://www.nea.gov.sg/our-services/climate-change-energy-efficiency/energy-efficiency/industrial-sector

[49] See https://www1.bca.gov.sg/buildsg/buildsg-transformation-fund/green-buildings-innovation-cluster-gbic-programme



Source: Singapore Department of Statistics and PUB, courtesy of Statista (2021).

Fig. 11. Sales volume of NEWater in Singapore.

progressively larger volume of NEWater sold in Fig. 11. Between the two, Singapore will finally achieve 90% water sufficiency in the not-so-distant future. Water reclamation plants, like waste management facilities, also allows for the generation of biogas to produce energy.

However, Hsien *et al.* (2019) noted a caveat after adopting a Life Cycle Assessment (LCA) to study the environmental impact of Singapore's public water supply, which consists of NEWater and tap water. Individual components in the urban water system were analyzed and integrated based on the contributions and losses of each component. They found that, although NEWater supply is more sustainable in terms of water depletion relative to tap water, direct emissions at the wastewater collection and water reclamation phases of NEWater supply have a significant impact on climate change. A tradeoff exists between self-sufficiency in water supply and carbon emission abatement objectives as the process of desalination known as reverse-osmosis is highly energy intensive, with the second highest energy-intensive water source being NEWater production. Despite water treatment processes constituting a minor proportion of Singapore's overall energy consumption, this could change in the future with increasing production to meet 20% more of Singapore's water energy demands. Another tradeoff is that increased dependency on energy production for water could also lead to high prices of water given rising imported fuel prices, which could have significant repercussions on the economy given that water is a basic commodity (Siau, 2016). Nevertheless, new and emerging desalination technologies such as electrodeionization, biomimetic or biomimicry techniques may make these 2 tradeoffs easier to manage. In April 2022, Singapore's 5th desalination plant was also opened at Jurong Island and was touted to be 5% more energy efficient than conventional desalination plants due to its physical integration with Tuas Power's Tembusu Multi-Utilities Complex (TMUC) which allows for co-sharing of resources (Tan, 2022a).

Quek *et al.* (2018) conducted an LCA of both fossil- and renewable-based electricity generation in Singapore based on four environmental impact categories: potential for global warming acidification, eutrophication and human toxicity. Similarly, they found that switching to renewable energy does not unequivocally reduce environmental impacts compared to non-renewables (e.g. switching from natural gas to solar energy increases human toxicity potential). They concluded that policies about renewable energy in the overall electricity mix should be valued by prioritizing the various tradeoffs of their environmental impacts. Therefore, a common pitfall when claiming that new technologies are cleaner in general is that this is assuming an apples-to-apples environmental impact comparison and may not be a "one size fits all" solution. These and the more common cost considerations warrant policymakers' attention when deciding whether, when and how to adopt them.

Imports of renewable energy have seen some recent success with a multilateral cross-border electricity trade agreement which allows up to 100 megawatts (MW) of hydropower to be imported from Laos into Singapore through Thailand and Malaysia's interconnector infrastructure (Tan, 2022a). However, although Malaysia's recent ban of renewable energy exports to Singapore did not affect this agreement,[50] self-interests and geopolitical conflicts will always pose a threat to energy security via the regional grid if Singapore does not diversify its energy import sources or achieve some form of self-sufficiency in renewable energy production.

Therefore, besides tapping on natural gas and regional power grids, Singapore's other priorities in its national energy strategies are solar and other emerging low-carbon solutions such as hydrogen, although solar remains the most attractive source of renewable energy in terms of self-generation potential. Given Singapore's land constraint and high urban density, solar PV panels are currently installed on rooftops and over water bodies (known as floating solar farms) such as the Straits of Johor,[51] Tengeh Reservoir in Tuas, Bedok Reservoir, Pandan Reservoir and Lower Seletar Reservoir. There are even plans to import solar energy from Australia via long high-voltage undersea cables (Tani, 2022).

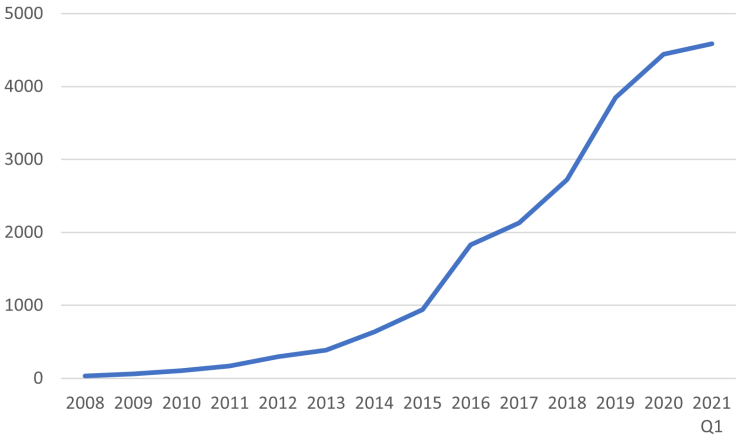
Nevertheless, although EMA has reassured the public that the deployment of floating solar farms does not affect the environment,[52] more EIA studies are needed to quantify the tradeoff of having clean energy over possible disturbances to the natural water habitat (Doshi and Zahur, 2021). Although solar PV uptake progression in Singapore has risen exponentially over the decade in terms of the number of grid-connected installations and installed capacity (see Figs. 12(a) and 12(b)), it is still far from satisfactory as there are still other climate-related issues such as high cloud cover,[53] humidity and temperature which hinder the efficiency of PV cells and accelerate their rate of degradation (Andrews-Speed, 2021). Recycling solar panels is costly as materials used to construct solar panels such as aluminum, glass and silicon are difficult to separate. Considering that

[50] See https://www.straitstimes.com/asia/se-asia/malaysias-energy-ministry-to-limit-renewable-energy-exports-to-singapore?login=true&close=true; https://www.mti.gov.sg/Newsroom/Parliamentary-Replies/2022/07/Written-reply-to-PQ-on-import-of-renewable-energy

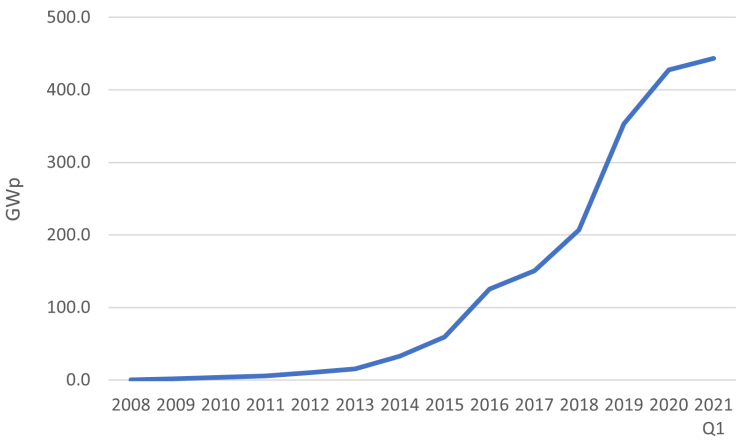
[51] The world's largest floating solar farm that is capable of offsetting more than 4,000 tonnes of CO_2 equivalent per year.

[52] See https://www.ema.gov.sg/reply_to_forum_letter.aspx?news_sid=202106013HEFDpYLQaio

[53] High cloud cover leads to high albedo effect, meaning more solar radiation being reflected into space and thus less of it being absorbed into the atmosphere.



(a) Number of grid-connected solar photovoltaic (PV) installations in Singapore



(b) Installed capacity of grid-connected solar photovoltaic (PV) systems in Singapore

Source: EMA (2021).

Fig. 12.

Singapore already generates more than 60,000 tonnes of e-waste annually, solar panel waste is indeed problematic as 5,000 tonnes of solar panel waste could be generated over the next two years if proper recycling is unfeasible, a sentiment which is shared among Singaporeans (Tan, 2022d; Ho *et al.*, 2022).

Other issues include the variability and inconsistency of solar energy with residential usage patterns, safety issues of battery technologies in a dense environment, structural limitations of different types of buildings and the associated inspection costs, costs of outfitting proper lightning protection on solar panels, shortage of local energy storage facilities, cost of maintenance due to dust accumulation, especially with the occasional transboundary haze issue in Southeast Asia (Park *et al.*, 2013; Bonkaney *et al.*, 2017; Andrews-Speed, 2021; Lee, 2022a). King and Wettergren (2011) calculated the payback

period (net present value) of different technologies over their lifespan where the suitability of solar and wind power technologies to replace the air-conditioning system is tested. They found that solar PV panels could be commercially viable in Singapore if there are technological improvements and reduction of implementation costs. Harnessing of wind energy, however, could only be feasible if the input (wind) to output (electricity) efficiency ratio is significantly improved, which, given inadequacy of Singapore's wind conditions in generating cost-effective electricity, is highly unlikely to be viable. Although hydroelectricity and tidal power remain technically unfeasible options for Singapore regarding self-generation, perhaps more research can be done on the viability of deploying offshore wind turbines amidst hectic maritime activity in the near future (NEA *et al.*, 2020).

To reduce the compliance costs of engaging a Licensed Electrical Worker (LEW) to audit and report on the safety of Solar Photovoltaic (PV) system adoption, EMA and SP have developed a more convenient solution in 2018 which utilizes the power grid to estimate the fault current contribution from solar PV installations. This has resulted in compliance cost savings of S$3,000 to S$15,000 per solar installation for businesses. Since 2017, EMA has also streamlined the registration process for consumers and businesses to produce solar electricity for self-consumption and simplified the technical procedures for payment, resulting in estimated cost savings of 4–5% of the cost of a typical solar installation.[54] In that same year, the Central Intermediary Scheme, which enables remuneration for facilities for selling excess solar energy into the power grid, was also enhanced to include facilities that cannot control or vary their power output e.g. solar and wind energy (EMA, 2018). Nevertheless, these cost savings are held back by the efficiency of commercially available PV cells only currently being between 15% and 21% (Andrews-Speed, 2021).

On the end consumer side, however, affordability of solar energy is a little more optimistic. As of 2 March 2022, Sunseap, the first specialized solar energy provider in Singapore, offers a pricing plan at 32.10 cents/kWh with an estimated monthly bill of S$112.78 for an HDB 4-Room. Comparing that with the pricing plans of Senoko, Tuas, Geneco, Sembcorp, PacificLight and Union Power, the average is about S$84.21, implying that solar energy has the potential to be price competitive.[55] Sembcorp's floating solar farm at Tengeh Reservoir was touted to be able to offset about 7% of PUB's annual energy needs, which is equivalent to powering about 16,000 HDB four-room flats (Sembcorp Industries, 2021). In fact, solar energy was assessed to have already achieved grid parity in 2011, meaning the break-even point at which the average net present cost of electricity generated by a solar PV plant within its life cycle is equal to or less than the fossil fuel-generated electricity tariff rate (Doshi, 2013). Although households' dependency on the national energy grid cannot be completely removed with solar energy, hybrid solutions can be potentially cost-effective given that SP Group allows households to sell their excess electricity generated from solar panels back to the power grid. This can be used to offset the electricity bill from a private retailer that can be depended upon only to cater electricity during the event or period when solar energy is unavailable (Lee, 2022a).

[54] See https://www.ema.gov.sg/PEI.aspx
[55] As deduced from https://compare.openelectricitymarket.sg/#/pricePlans/list

The feasibility of smart grid systems is also being assessed in Singapore, notably the Intelligent Energy System (IES) Pilot, which was conceived by EMA in collaboration with grid operator Singapore Power (SP). The concept of smart grid systems is to facilitate a real-time sharing of market signals pertaining to electricity consumption and prices between a centralized grid coordinator and residential users, allowing end users to track and manage their electricity usage patterns more efficiently. This applies to both the demand and supply side as grid operators can form an agreement with residential users to proactively reduce supply of electricity to residential users during periods of high electricity prices due to shortages thus allowing more stability in optimal market conditions for energy.[56] Therefore, smart grid systems are potentially beneficial from both an environmental and economical perspective. The deployment of advanced electricity meters in Singapore households is gaining more traction, with 650,000 smart electricity meters having been deployed island-wide and all 1.4 million residential households in Singapore estimated to be equipped with smart meters over the next few years[57] (NCCS, 2020). Residential smart meter electricity consumption data may also be useful for predicting behavioral changes during periods of major shocks to society, such as the COVID-19 pandemic (Raman and Peng, 2021).

Huang *et al.* (2015) proposed the idea of an agent-based residential load model which draws on the idea that consumers are subjected to a flat rate electricity tariff by default and can voluntarily participate in the smart grid electricity market through an aggregator agent. In addition, smart appliances have more control features over their energy load which can be altered by the aggregator agent that also participates in the regulation[58] and reserve[59] ancillary electricity markets. The authors consolidated representative energy usage profiles of residential units based on their appliance usage behavior to provide market energy demand data, which was then mapped to historical electricity market data to determine participation rates and financial benefits per smart appliance annually. They found that potential returns for consumer investment in any form of smart appliance technology generated by the agent-based residential load model are minimal and hence smart appliance adoption may not be economically feasible in the short run (Huang *et al.*, 2015).

In 2021, the car population in Singapore still consisted mostly of petrol vehicles (LTA, 2022). Yuen (2018) conducted a cost-effectiveness analysis and financial analysis to calculate the social costs (sum of the vehicle's initial cost, operating cost excluding tax and the external cost to society imposed by tailpipe emissions generated by vehicles) and private costs (sum of the vehicle initial cost and the operating cost including tax) of owning an EV model in Singapore and its comparable internal combustion engine vehicle (ICEV) version. They found that EV adoption is not economically feasible as it incurs substantially higher social and private costs compared to ICEVs. Specifically, the health benefits of EVs from

[56] See https://www.ema.gov.sg/cmsmedia/Newsletter/2012/04/eyeon-emaIES.html#:~:text=Singapore's%20IES%20Pilot%20Takes%20Flight,Energy%20System%20(IES)%20Pilot.

[57] See https://www.spgroup.com.sg/about-us/energy-hub/reliability/Shaping-the-evolution-of-electricity-meters-in-the-past-25-years#:~:text=Over%20his%2025%20years%20with,650%2C000%20smart%20electricity%20meters%20islandwide.

[58] The regulation market refers to the provision of generation capacity that cover the immediate normal temporal variations in load from forecasted load to ensure supply demand equilibrium.

[59] The reserve market takes in the potential amount of power that can be reduced in each time period as determined by the grid operator.

better air quality are lower than the upfront, operating and taxation costs of EVs. The general conclusion was that the SCC would also have to be unrealistically high to justify the use of EVs. However, exempting EV batteries from taxation could be more effective in significantly reducing the upfront cost of EVs. These findings are supported in a pre-feasibility study of EV adoption conducted by LTA in 2014. However, besides the earlier justification of the government's stance against energy subsidies, the nature of EV subsidies is likely to be significantly regressive at least in the short run. More EVs on the roads also means higher electricity consumption, which would entail higher demand for imported natural gas for domestic electricity generation or imported low-carbon electricity. In addition, mass production of EVs will increase Singapore's dependence on a few selected economies, where rare earth minerals of lithium, cobalt and nickel are required to be imported from to produce EV batteries (Doshi and Zahur, 2021).

Another potential challenge of EV adoption is that the formula for calculating the amount of annual road tax of EVs is based on its power rating, which requires some research on the prospective car buyer's part. On the contrary, it is usually a much simpler task to gauge the amount of road tax of an ICEV based on its visual appearance as its physical size is usually a good indicator of its engine size, which in turn is correlated to the amount of subjected road tax. Going by the earlier findings of Yuen (2018) and LTA (2014), whether the potentially higher road tax of an EV may eventually be offset by the lower operating cost of an EV is still up for debate. An interesting way to think about the private costs faced by car buyers is that, according to the concept of loss aversion or prospect theory, car buyers may feel more strongly about upfront, immediate losses more than the equivalent in non-immediate gains elsewhere and so are more likely to be cognitively turned off from purchasing an EV. There are also concerns about unclear information on the resale value of EVs e.g. whether they follow the same annual depreciation formula as ICEVs and the current software limitations of EV charging[60] despite Singapore currently having over 2,200 charging points (1,400 in public carparks) (Lee, 2022b).

Nevertheless, the outlook for cost and convenience of EV adoption is looking to be more optimistic. Although EVs have yet to achieve cost parity with ICEVs, the introduction of the EV Early Adoption Incentive scheme, which provides a 45% rebate off the ARF for purchases of EV cars and taxis from 2021 to 2023 but capped at S$20,000, as well as more competition among EV models, has reduced prices by a fair amount. Doubling the number of EV charging stations to be built as proposed from 28,000 to 60,000 would also help to facilitate societal acceptance of EV adoption to have all vehicles operating on cleaner energy by 2040 (Kok and Lee, 2022).

The completion of Singapore's first hydrogen-ready power plant is expected to be ready by mid- 2026, which can potentially facilitate an annual abatement of 220,000 tonnes of carbon emissions, which is equivalent to removing 47,000 cars from annual road traffic (Ang, 2022). While conventional hydrothermal systems may be unsuitable for Singapore

[60] A common complaint by EV users is that there is no centralized "one-stop" government-licensed mobile application that provides clear and concise information of the location of charging stations in Singapore. Rather, the current iteration of such an application (PlugShare) is crowdsourced, meaning that the information contributed by users is not guaranteed to be accurate.

due to the lack of sufficient hot water and steam resources at shallower depths, newer technologies are making it easier to tap into the potential for geothermal energy, especially since Singapore has a potential geographical advantage of having high subsurface heat flow. EMA is currently conducting a feasibility study of using advanced geothermal systems (AGS) to extract heat from hot and dry rock from deep underground with minimal negative environmental and safety externalities.

Carbon capture utilization and storage (CCUS) technologies are currently still in its infancy phases for Singapore due to the lack of appropriate geological sites such as gas and oil fields for the permanent storage of CO_2 underground, which entails additional transport costs to suitable sites. In addition, the amount of capital investment needed for the extraction and conversion of carbon into fuel (which is also energy-intensive), as well as for plant maintenance, is substantial (Chow, 2021; NCCS, 2020). Nevertheless, the potential for carbon dioxide storage facilities and underground power plant infrastructure is in the midst of exploration. Singapore LNG Corporation (SLNG), a local SOE has recently collaborated with Linde Gas Singapore (LGS) to conduct a feasibility study on the development of a carbon dioxide liquefaction and storage facility adjacent to the SLNG terminal on Jurong Island (Sajeev, 2021).

As one of the busiest maritime shipping ports in the world, Singapore's GHG emissions from the burning of heavy fuel oil in marine engines is substantial in relative terms. Therefore, development of low-carbon marine fuels such as ammonia is underway (Mao *et al.*, 2022).

Following a pre-feasibility 2012 study of the deployment of nuclear energy in Singapore, modern advances in nuclear technology such as small modular reactors (SMRs), floating nuclear power plants generation IV nuclear technologies and nuclear fusion development have since alleviated some of the safety, spatial and environmental concerns associated with conventional large reactor technologies. However, energy efficiency and cost issues are still apparent (Ang, 2022b; Ang, 2022d). Besides solar energy waste, Singaporeans are also found to be concerned about potential geopolitical tensions in the event of nuclear energy deployment due to increased reliance on others for nuclear energy materials which may compromise Singapore's energy security (Ho *et al.*, 2022). Finding materials that can withstand a nuclear fusion reaction would once again risking our dependence on other countries for the necessary raw materials. Singapore being densely populated also means that any accidents, even if the risks are minimal, could have massive health and economic ramifications. Therefore, the net present value of nuclear energy deployment, accounting for both tangible and intangible costs and benefits, is unlikely to be positive in the short run (NCCS, 2020). Nevertheless, nuclear energy has been considered in one of the energy transition scenarios for Singapore as it is able to supply about 10% of Singapore's energy needs by 2050 (Ang, 2022c).

Scientific advances in building design and new technologies have complemented tree-planting initiatives to provide shade in mitigating UHI effects. The petal-like structure at the crown of CapitaGreen[61] and the north-south orientation of buildings at the upcoming Woodlands Health Campus Hospital with underground campus roads serve to improve the

[61] A 40-storey office building constructed by Singapore's biggest property developer CapitaLand Ltd, Commercial Trust and Mitsubishi Estate Asia.

flow of cool air and reduce heat retention. District cooling networks and piped chilled water installations in buildings are also being explored (Mokhtar, 2020). As a pilot project under the HDB Green Towns Programme in 2021, 130 HDB blocks in the Tampines district were coated with heat-reflective paint to promote a cooler environment (Ng, 2021b). The recently developed Punggol Digital District is equipped with many state-of-the art green design features such as deliberate orientation and positioning of buildings to maximize sunlight penetration and optimize wind circulation, a smart grid to facilitate real-time tracking and managing of energy usage allowing 30–40% increase in energy efficiency relative to conventional buildings, autonomous buses and electric vehicle (EV) charging infrastructure, as well as recycling of food and horticulture waste into fertilizer and collection of rainwater for irrigation.[62]

Currently, regarding sea level rise, challenges in robustly quantifying the risk of coastal extremes include limited historical data for coastal and oceanic processes and the reliance on stationary as opposed to dynamic assumptions to account for the risk impacts of spatial and temporal coastal and oceanic phenomena. As such, efforts by PUB to incorporate artificial intelligence (AI), machine learning and other smart digital solutions into coastal protection infrastructure to enhance monitoring, regulating and forecasting capabilities are also underway. Because of deforestation activities to accommodate the construction of residential buildings, Singapore, once a net absorber of carbon in 2012, had become a net emitter in 2014. Therefore, PUB is also exploring the integration of nature-based solutions with coastal engineering solutions due to its potential to contribute to multiple objectives of adaptation to sea level rise, biodiversity protection and enhancement, as well as in carbon sequestration, while being cost-effective compared to artificial carbon sequestration technologies such as carbon capture and storage (Tan and Fogarty, 2019). For example, eco-friendly modified seawalls can not only prevent coastal flooding but also promote the creation of new marine habitat substitutes (Giannoustas, 2015). This somewhat parallels to PUB's implementation of habitat cells along the Ulu Pandan waterway, which softens concrete canals and helps to channel water flow into more narrow areas to allow biodiversity to thrive (Woon, 2022). Importantly, gaining a comparative advantage against other Asian countries in successful innovative coastal protection measures could also result in positive economic externalities such as through industry R&D expenditure, creation of employment opportunities and exportation of urban coastal protection services.

4. Conclusion

Singapore understands that urban solutions have been a pillar of growth and an element of sustainability will enhance its growth potential. Singapore continues to support related industries through research and development, infrastructure and, most importantly, the building of human capital. Existing policies such as higher building bases to prevent flooding and regulation on coastline development will be expanded. Buildings will be built further inland in response to higher expected sea levels, and land reclamation may be

[62] See https://www.edb.gov.sg/en/business-insights/insights/5-things-you-should-know-about-punggol-digital-district.html

curtailed until it becomes clear that reclamation does not contribute to adverse environmental impacts such as loss of natural habitats and flooding. Urban green infrastructure will also be increasingly enhanced to provide ecosystem services and facilitate artificial habitats for biodiversity to flourish alongside dense economic activity. To reduce dependency on natural gas for energy production, management of the national energy grid and the retailing of electricity will require significant reform to prepare the nation for the inevitable transition to renewable energy.

The focus is to manage the challenges in sustaining economic growth and the environment, and this involves tradeoffs. While science and technology can go a long way to improve the quality of life, economics and rational thinking about costs and benefits, and about tradeoffs, make a difference as to whether an innovation would be accepted by governments and societies. Fundamentally, it is an exercise in optimization. What amount of economic growth is Singapore prepared to accept with corresponding higher levels of carbon emissions, waste, greenery loss and environmental degradation? Would further increase in real GDP bring more social utility? Some "weaknesses" of Singapore's environmental governance may be framed as circumstantial tradeoffs as there may be various justified costs and considerations that merit caution in proceeding with best practices despite recognition of these challenges. However, which weaknesses of Singapore's environmental governance are a result of recognizing the choices and tradeoffs that must be made, and which are due to obvious shortcomings of the policy approaches? We have attempted to tease out some answers to this question indirectly but future studies should attempt to address it in a more rigorous and focused manner.

While Singapore has taken steps in the right direction in making greater use of CBA in resource allocation, what the country lacks is a systematic gathering of data and solicitation of public preferences for non-market goods such as green spaces and fresh air. These valuation studies are needed to derive the society's preferences so that the tradeoff between economic growth and environmental conservation can be determined optimally. Furthermore, the act of obtaining public preferences gives stakeholders a greater influence and gives decisions greater transparency.

Singapore's environmental landscape in the future is likely to differ much from today's landscape. There will likely be changes to the energy mix to include cleaner and renewable fuel alternatives in the industrial, services and transport networks, more aggressive market instruments but with stronger safety nets along with smart grid systems for better climate change risk management and promote stability of market forces in the energy market. In addition, there will likely be changes made to waste management strategies to enable a circular economy and a renewed emphasis on protecting and restoring marine habitats for Singapore to continue to position itself as a tourist destination. Advanced technology, pragmatism with CBA at its helm, and efficiency-based decision making, along with good governance, regulating and coordinating policies that can maintain a healthy state-private relationship, as well as the changing mindset of the Singapore society at its core, could allow Singapore to embrace a new modern landscape, together with continued economic development.

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