Vision 2050: Towards a People's Climate Action Plan for Singapore

Response to National Climate Change Secretariat Consultation
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350 Singapore

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350 Singapore is a ground-up volunteer group that aims to inspire the public, policymakers, and industry to get Singapore on track to a world within 1.5 degrees Celsius of warming, through a just transition to a net-zero carbon future by 2050.

Introduction

We welcome this opportunity to present our research and recommendations to the National Climate Change Secretariat (NCCS) as part of its consultation on Singapore's long-term low emissions strategy.

We are acutely aware of the severity of the climate crisis which has arisen from human-caused global warming. We are already seeing the effects of global warming today — every day, news of uncontrollable forest fires, unprecedented ice melts and record-high temperatures fill global headlines. The world must remain within 1.5 deg C of warming to avoid the worst consequences of climate change to human life (IPCC 2018).

Singapore is vulnerable to a host of direct and indirect risks from climate breakdown. Amongst them are sea-level rise, extreme heat that threatens human health and a society's ability to conduct activities on a normal basis, and food shortages as the global food-production capacity is affected by climate change.

We must take more ambitious action on emissions reductions and climate change mitigation measures, to give adaptation measures a better chance to succeed.

Cross-cutting themes emerging from 350 Singapore's research across subject areas show the need for Singapore to ground our approach to climate change mitigation in the following key principles:

1. Set science-based targets for reducing carbon emissions
2. Identify high-impact solutions through transparent, holistic approaches
3. Plan for an orderly and just transition to a net-zero carbon economy

We outline the importance of these three themes below. Two special inserts at the end of this introduction (Box 1.1: "Pathways to our shared carbon future: Singapore in 2050" and Box 1.2: "Towards a Singapore Zero-Carbon Stimulus Package") offer examples of possibilities for a Singapore that has successfully transitioned from its place in the existing system of dependence on resource extraction and open-ended consumption to a flourishing player in a regenerative and connective global economy in which our descendants thrive.

Set science-based targets for reducing carbon emissions

Emissions mitigation is not a long term but rather an immediate imperative for all nations of the world. Singapore must set absolute emissions reduction targets in line with the pathway recommended by the Intergovernmental Panel on Climate Change (IPCC), to reduce absolute carbon emissions by about 45% from 2010 levels by 2030 and reach net-zero emissions by 2050. Science has identified this pathway as giving the world a chance to remain within 1.5°C of warming and avoid the worst consequences of climate change to human well-being. We propose 1) a regular review of Singapore's Nationally Determined

Contribution (NDC) over the next two years to keep abreast with industry changes, and 2) emphasise an incremental set of steps in industry and economy that brings us towards these absolute reduction targets with clarity and purpose. Such absolute emissions reductions should be the basis of our 2020 NDC, which is currently defined in terms of emissions per dollar of Gross Domestic Product (GDP) and highly insufficient (Climate Action Tracker) in limiting warming to less than +1.5°C.

We need both mitigation and adaptation measures to tackle the climate crisis. We call on the Singapore government to step up policies that support mitigation measures. If carbon emissions continue unchecked, adaptation measures will likely become more costly as climate change impacts escalate. Human and natural systems may even reach limits beyond which adaptation is not possible, for example due to climate threshold effects or tipping points.

It has been suggested that emissions reduction efforts in Singapore would not arrest global warming, given that we contribute only 0.1% to global emissions. On ethical grounds that every nation must do its fair share on climate solutions, we reject this rationale for low ambition on emissions reductions. We also cannot ignore our contribution to emissions beyond our borders arising from our position as one of the world's top five oil trading and refinery hubs (National Environment Agency [NEA], 2018), making us very much complicit in driving the climate crisis. Furthermore Singapore has both the technological and financial means to achieve the targets.

Singapore is faced with a unique opportunity to showcase a just transition to a zero-carbon economy, as a city-state with considerable technical and financial resources. The NCCS points to Singapore's international ranking of 27th in per capita emissions (based only on territorial emissions). However, we are ranked 7th in per capita income as at 2018 and our efforts should reflect our ability to address the global problem. Trade and Industry Minister Chan Chun Sing has highlighted Singapore's size balancing scale with speed to market, and its position “as a microcosm of the kind of challenges” faced by other cities, as advantages for test-bedding of ideas (Tanoto 2018). Singapore will be in a position to export viable zero-carbon technologies and policy expertise to other cities and nations, securing our economic relevance in the zero-carbon world that will inevitably need to emerge for human civilisation to continue.

Furthermore, Singapore needs to expand its carbon accounting to recognise the full scope of our responsibility and influence over carbon emissions embodied in our imports and exports, beyond our Scope 1 territorial emissions. The Global Carbon Project estimated Singapore's per capita consumption-based emissions (which includes net imported emissions) to be the 6th highest globally as at 2016. Another study estimated Singapore's consumption-based emissions to be approximately two times our territorial emissions using 2004 data (Davis and Caldeira 2010). Singapore also has influence over exported emissions in global logistics value chains, as an international air and maritime hub. In addition to the nearly 5,000 ships that sail under the Singapore flag, we supply aviation and marine fuel, which generate almost three times the greenhouse gases of our territorial emissions (NEA 2018). Taking all these metrics together, the moral imperative for Singapore to take more ambitious action on emissions reductions grows even stronger.

The only way to preserve human civilisation is for the global community to come together to reduce greenhouse gas emissions. Prime Minister Lee Hsien Loong said in his 2019 National Day Rally speech: “Although Singapore may not be able to stop climate change by ourselves, we can contribute to solutions, and we must do our fair share. Then we can be credible asking others to reduce their emissions too, and work towards a global solution to climate change.” (Lee 2019)

350 Singapore commends and shares this clear-eyed view of our obligation to pull our weight, if not more, in reducing emissions. Singapore’s survival as a small island state under the climate crisis depends on concerted efforts in other nations to bring their share of global emissions to net zero. We must do our share, regardless of how small it is, to demonstrate that climate solutions are within the realm of human capability.

Identify high-impact solutions through transparent, holistic approaches

The scale of the climate crisis calls for transformative systemic change. While individuals play a critical role in the transition to a zero-carbon economy, it is no longer adequate to place an emphasis on action by individuals through diffuse, voluntary consumer choices. We view the opportunity to write a new narrative of Singapore’s carbon pathway until 2050, as a co-creative project led by the government with active action-oriented inputs from industry, NGOs and the wider community.

We identify potential high-impact solutions that seek to address Singapore’s most significant sources of carbon emissions: industry, transport, and buildings. We suggest that i) high impact solutions must target the big emitters, and ii) they need to occur in a transparent way that allows people to see that systemic change is underway. Only then will meaningful systemic change take place.

Target biggest contributors to emissions

According to the latest NCCS consultation document based on 2014 data, industry constituted 60% of Singapore’s combined carbon emissions including electricity consumption. While much of these emissions come from producing goods and services that are ultimately consumed by households, system-level changes are required for individuals’ behavioural and consumption choices to involve only low-carbon choices. Furthermore many of the final consumers from these industries are outside of Singapore, hence driving low-carbon solutions at the producer level would be more effective than at the consumer level.

In addition to industry-specific recommendations we make in the subsequent sections, we also recommend the adoption of approaches such as life-cycle analysis and extended producer responsibility across sectors and industries to drive holistic climate solutions that ensure our mitigation and adaptation strategies do not exceed our remaining carbon budget or create other unintended negative consequences.

Drive alignment through setting transparent science-based emissions targets

To drive alignment of policy across all areas with these objectives, transparency of information and accountability for achieving science-based emissions targets must be embedded as key tenets in policy-making processes. The Government should be transparent about whether specific climate solutions and policy measures being communicated to the public are mitigation or adaptation measures, which scope they are targeted at, and the expected emissions avoided or impacts addressed. Increasing granularity and frequency of emissions data would also facilitate entrepreneurs and innovators' R&D of climate solutions.

Accountability for achieving emissions reductions could come in the form of target allocations down to the ministry level to be commensurate with their areas of oversight. The Government has made commendable efforts at timely and full submission of the Biennial Update Reports, and these efforts can be built upon—with private and people sectors—to form an annual update and outreach programme to Singapore residents.

Institutions—including government bodies and businesses—must take the lead and responsibility to create spaces for transparent discourse between individuals and groups on the challenges and opportunities of climate change. Collective action approaches that enable people to come forward with their ideas would focus beyond the institution. We give four examples of collective action at work, and what collective action involving individuals, households, organisations and institutions looks like. Such approaches would signal space, and then leave the space open for people to come forward and engage as equal participants in the narrative-building and ground-sensing process (see Section E - Collective Climate Action). Programmes that combine community-centred, on-ground sensing with innovative work across industries can identify convergent lay and expert imaginations, and move society as a whole towards optimal capacity for collective action.

Plan for an orderly and just transition to a net-zero carbon economy

The transition to a zero-carbon economy and its attendant trade-offs will bring transformative and potentially disruptive change to our society. Societal disruptions emerging from climate change are more likely to impact the disadvantaged rather than the middle class or affluent, and as such this has to be managed carefully to ensure social stability. We view the climate crisis as an opportunity to address, and redress, societal imbalances in a way that repositions Singapore's economy and society for the better.

Economic transformation is not new to Singapore, which shifted from export-led industrialisation in the 1960-80s towards a growing share of service industries' contribution to economic activity. As this transformation continues, the relevance of GDP as a metric of economic activity becomes ever more questionable. GDP was invented in the 1930s in the context of manufacturing-led economies; nations did not measure their well-being based on GDP before then. Its inventor, Simon Kuznets, stated that the measure has no relationship to well-being (Pilling 2018). The World Bank, in its definition of GDP, states that “GDP does not make deductions for depletion and degradation of natural resources.” We need to broaden how Singapore defines prosperity and well-being beyond GDP, for instance taking into account the importance of residents’ happiness and wellness, and a sustainable relationship with the physical environment.

Even if we were to accept the logic of GDP growth, delaying emissions reductions to prioritise short-term GDP over long-term GDP is shortchanging young people today and future generations yet to be born. Senior Minister Tharman Shanmugaratnam remarked at the Institute for Government’s 10th anniversary conference: “It cannot be good for democracies anywhere, and cannot inspire confidence in the political centre, if we keep evading today’s problems - if we keep pushing the burden of funding today’s healthcare and social security systems into the future, and if we keep postponing actions to arrest the crisis of global warming. It is inequitable, it is irresponsible, and in the case of global warming, it will have crippling consequences on future generations globally.” (Tharman 2019)

A planned and orderly transition to a zero-carbon economy that takes place sooner rather than later has multiple benefits. Many mitigation measures are “no-regrets” solutions that have ancillary benefits, such as lower pollution, less reliance on fossil fuels whose prices fluctuate with geopolitical risks, and jobs creation in growth industries that will spring up to deliver climate solutions. As skills required may not fully overlap with existing worker qualifications in today’s economy, it is imperative that Singapore conducts comprehensive skill mapping and starts re-training, leveraging the well-provisioned infrastructure in place today through SkillsFuture and Workforce Singapore. A just transition could also take the form of a fee-and-dividend approach to carbon pricing, which would leave the majority of households tax-neutral, while it would also soften the impact of the higher cost of fossil fuel-driven energy use during the transition to a zero-carbon energy mix.

Clear communication of robust long-term climate mitigation and adaptation policies would send supportive policy signals to channel financial investment flows towards climate solutions and away from riskier carbon-polluting investments. Exiting sunset industries and stranded assets ahead of the curve could mitigate potential losses by limiting our exposure to the scenario where investors seek to dispose of these investments within the same time horizon.

The Government could also consider tapping on the resources of the GovTech department, not only to support innovation in business and entrepreneurship, but also in select public consultations on policy regarding climate, industry, and society. Transparency that involves the public in understanding our situation sets up a just society for the coming decades of Singapore’s maturity. As we are at a turning point, the foundations we set up now will support us and the generations that come after us.

There are multiple models that we can look to and adapt to Singapore's circumstances. For example, Gov 0 in Taiwan started with the provision of infrastructure for open communication during the Sunflower Movement (where they stepped back and let the deliberative process continue amongst citizens): an example which has invited more members of the public into the governance process with the government *and each other*, increasing a sense of connection, public engagement, hope and empowerment.

Such modes of engagement tap on a very important facet of human motivation and connection in tumultuous times. Bridge-making enables subgroups to understand one another in the language they understand; the opposite to this would be tribalism. In the challenging times ahead, deepening our social and cultural capacity will be more important than ever in forging the solidarity and resilience that will be needed to confront the climate crisis head-on.

Box 1.1. Pathways to our shared carbon future.

Pathways to our shared carbon future: Singapore in 2050

It's 2050. The international community is celebrating some wins, big and small, and mourning losses it did not prevent. In Singapore, the mood is also one of mixed pride and loss. There are many things to be proud of. Buoyed by the growing global momentum to address the climate emergency in the late 2010s, the runway cleared in Singapore in just six years for the introduction of commercial CCUS (Carbon Capture, Utilisation and Storage) technologies (see Section D - CCUS). This occurred as three primary sectors (retail, transport and logistics, and consumer packaged goods) began to connect downstream and upstream services with a range of other sectors (chemicals, telecommunications, travel, banking, and agriculture). These new connections arose from the unexpected combination of embedded, latent capacities and interests within the rising young consumer class in Singapore and Southeast Asia.

First, CCUS technologies grew together with rising innovations around artificial intelligence (AI) from companies located in Singapore, propping up the three main sectors already predicted to gain billions of dollars in impact from AI: retail, transport and logistics, and consumer packaged goods (Chui et al., 2018). Carbon taxes created incentives to cap driverless car fleets, and as better public transport changed the face of transport in general, traditional car manufacturers began to diversify their products (Section J - Transport).

Second, as climate concerns mounted with campaigns and interlinked efforts by non-governmental groups and social enterprises, increased networks of collaboration across people, public and private sectors enabled an alignment of several embedded interests and directions: first, the desire for conscious travel and leisure, with authentic connection and broadened horizons; second, the rising desire for consumption choices to support sustainable land investments for world food security; third, the gradual pivot of banking and finance to divest from fossil and oil portfolios, and to expand sustainable investment portfolios in Asia.

In the early 2020s, as it became clear that Singapore's food security depended heavily on regional food security, the introduction of new funding to push technologies in this area spurred emergent waves of interest by a younger generation bred on social media connectivity and a regional consciousness. Consumption (in retail, F&B, travel, and consumer packaged goods) steered towards sustainable land investments and conscious travel in the region. Low-input, low-risk conversion to sustainable land investments for agroforestry, pastureland and peatland reforestation became part of a new transborder partnership pattern (Section H - Land Use). This was backed by city mayors and supported by an ASEAN Inter-city Small-scale Innovations-for-Climate Investment Fund. Together with the implementation of the ASEAN Regional Power Grid, this contributed to landscape restoration and livelihood regeneration, simultaneously decreasing urban overcrowding and informal settlement expansion (see Section C - Reducing Emissions from Power Generation). While the effects weren't immediately clear, this set up long-term sequestration and cooling patterns that by 2030 began to have a small effect, and by 2045 had achieved a stable level of passive, low-input carbon drawdown.

In international climate policy, it became clear that Scope 1 and 3 of the Paris Agreement could be addressed simultaneously. As tech companies enabled traceability and certification through blockchain, they aligned stakeholders' equity interests in both direct emissions (from direct assets in property, farms, land, and processing facilities) and indirect upstream and downstream emissions (including partners in the certification network). This conversation became clear in a few leading tech and R&D knowledge centres across the world. In Singapore, the potential for this technological shift to support greater interreligious and intercultural cooperation amongst regional nations was observed, prompting its insertion as reconciliation-via-trade policy within international environmental mediation led by the Singapore Convention on Mediation, signed back in 2019. By 2025, the unveiling of leading consumer goods companies with well-audited and certified regenerative supply chains drove mass consumer awareness, while playing both the direct and indirect emissions cards in business strategy paid off. The upswell of interest from middle-class urban consumers tipped the balance and pushed a larger group of signing nations into Scope 1 and 3 agreement.

By 2030, the ASEAN Regional Power Grid and ASEAN Emissions Dashboard had spurred inter-ASEAN cooperation and created connectivity for young and mature decentralised work-communities across ASEAN (some of which initially began as start-ups for decentralised collectivity and technology). Renewable energy in 2030 powered 23% of the power needs in ASEAN. In 2050, it now powers 50% (see Box 1.2 - Towards a Singapore Zero-Carbon Stimulus Package).

CCUS continues unabated in this time, achieving its peak around 2035. On the back of CCUS technologies that were exported across the Southeast Asian region, a new inter-regional coordination platform was built, which enabled deeper coordination of regional job markets (in travel, cross-border carbon sequestration, and the exchange of chemicals and basic materials for local agricultural production). This grew the sector potential of sequestration in 2040, leading Singapore to where we are now.

**For data predictions supporting this scenario, please refer to Towards a Singapore Zero-Carbon Stimulus Package, Box 1.2.*

Box 1.2. Towards a Singapore Zero-Carbon Stimulus Package

Towards a Singapore Zero-Carbon Stimulus Package

Fiscal stimulus packages are not new to Singapore, a notable example in recent history being the Resilience Package that was structured as part of the 2009 Singapore Budget in the wake of the global financial crisis. The Singapore economy has also undergone continuous restructuring in its modern history (Menon 2015). Many emissions reductions solutions are already existing technologies that need to be scaled up, generating new opportunities and jobs in the process. As global economic growth momentum slows, there is a window of opportunity for Singapore to support workers and businesses in our transition to a zero-carbon economy.

In this box we present only one of multiple potential pathways to a zero-carbon economy for Singapore. While the onus remains on policymakers and institutional actors to create and implement responsible climate action policies, we use high-level conservative assumptions and imaginative visioning of positive climate outcomes to outline a possible baseline pathway to a net-zero carbon Singapore economy.

This exercise assumes that:

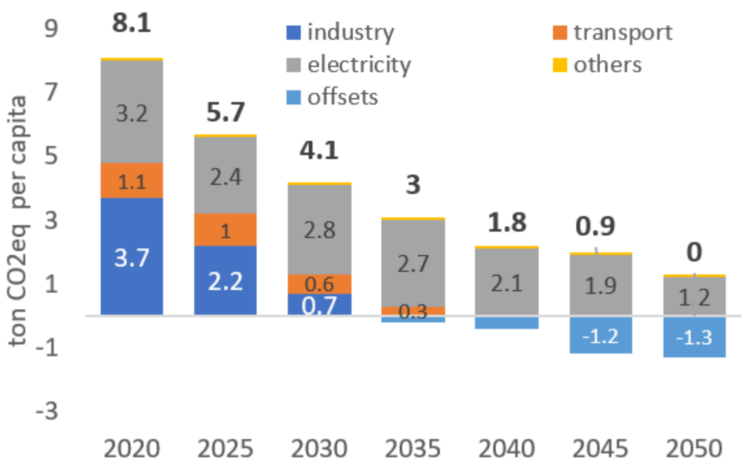
A. There will be no changes to transport modalities, industrial mix or consumption levels and patterns that could drive emissions reduction;
B. Carbon capture, utilization and storage (CCUS) is financed by public spending rather than emitters in absence of regulation or meaningful carbon pricing;
C. Land-based sequestration measures are conservatively deployed, not fully maximising the potential of regional land area.

This forms a possible ‘worst-case’ baseline for public capital expenditures from which we can build on to develop more ambitious scenarios for more optimal emission reduction pathways. Shifts in behavioural patterns as well as growing appetite for private finance and investment in climate solutions have enormous potential for lowering and re-distributing the total cost of emissions reduction measures.

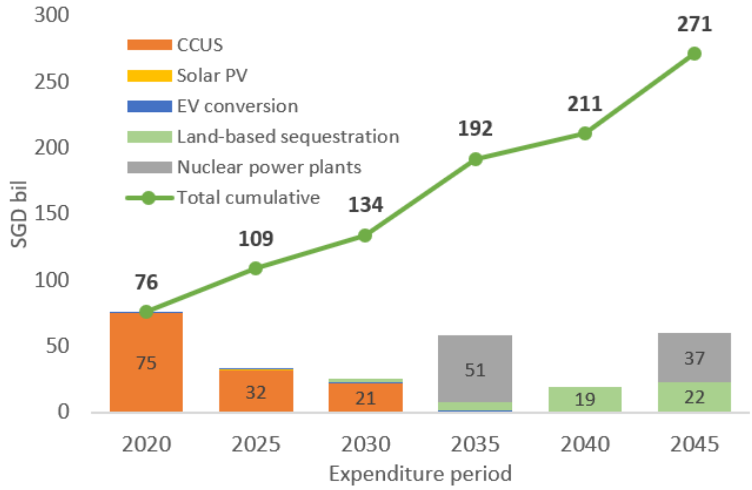
Zero carbon investments	**Sectors impacted**
1. Invest in building capacity of workers and communities, such as training and re-skilling programmes for workers in affected industries	All
2. Invest in CCUS to enable conversion of fuel source from natural gas to hydrogen for industry and thermal power plants	Industry, Electricity generation
3. Expand solar photovoltaic electricity generation capacity in Singapore and the region	Electricity generation
4. Ramp up ASEAN Power Grid interconnectivity to enable power purchases from ASEAN and other regional neighbours with at least 23% renewable energy mix by 2030 and reaching 50% by 2050	Electricity generation

5.	Convert all public and private vehicle fleets to electric vehicles	Transport
6.	Financial sponsorship of land based sequestration in other countries	Offsets
7.	Build two Generation III / Generation IV nuclear power plants to service Singapore's remaining electricity needs	Electricity generation

Sample Singapore carbon drawdown pathway by sectors



Sample public capital expenditures



1. Carbon Capture Utilisation and Storage

What we know: Carbon capture utilization and storage (CCUS) captures carbon on-site, either before or after combustion, and then transports it to a sequestration facility. Sequestration likely would not be in Singapore and can be done either using geological features such as spent oil fields or in open ocean at depths of 1000-3000 m. The technology of CCUS is an active innovation area with potential to reduce the additional fossil fuel energy input required from the current range of 30-50% to <15%. The cost for the installation of CCUS equipment is estimated at SGD833 per ton of CO_2eq captured and is likely to drop over time, but these technological advances are not incorporated in this analysis. The capital investments required would be generation facilities that convert natural gas into hydrogen or syngas, transport logistics terminals, and sequestration facilities. Some of the network infrastructure for delivering the hydrogen to the natural gas burners is already in place and most modern burners can operate on hydrogen or natural gas; they may even have a longer run length burning hydrogen. For financing, the base case assumes that there are 0% private sector funds available for the transformation.

Policy considerations: CCUS is a potentially scalable, complete solution for achieving net-zero emissions in manufacturing and electricity generation. It poses minimal disruption to residual manufacturing processes which will still require burning of fossil fuels to drive thermal processes, since hydrogen is a complete substitute for natural gas burners. We expect the associated costs to come down rapidly if innovation continues apace; this process can be accelerated by supportive policies such as significant and meaningful carbon pricing as noted by the International Energy Association.

2. Solar Photovoltaic Systems

What we know: Singapore currently gets about 1.4% of its electricity from solar and this fraction is forecasted to expand. Solar Photovoltaic Systems (PV) are already economically viable. We here assume a price SGD3.8/kWh/yr; 90% of the costs can be raised by the private sector. The estimated productivity output for solar panels is 142 $kWh/m^2/yr$; the maximum area available within Singapore is 50 km^2, which has been identified in prior reports by Singapore-based entities. Singapore's total territorial area is 1,400 km^2, of which 720 km^2 is land area, so more solar capacity is theoretically possible.

Policy considerations: Solar PV is a well-established and relatively low-cost technology (if grid upgrades are not considered) that is already a key part of Singapore's climate action plan. Risks are lower and well-understood relative to nuclear power and CCUS, resulting in a higher level of political acceptance by the general public and environmental groups. Singapore should expand policy options to address land scarcity and potential competition with land-based solutions, such as interconnection with solar PV capacity beyond our borders (explored below under ASEAN Power Grid Interconnectivity) and floating panels in territorial waters. The latter should be weighed against potential impact to marine ecosystems, fishing and port activities. In addition, long term feasibility must take into account sustainable manufacturing practices and maintenance. There may be ancillary costs such as smart grid upgrades and integration of electricity storage solutions such as batteries to address variability issues.

3. ASEAN Power Grid Interconnectivity

What we know: The ASEAN Power Grid (APG) is a network of power shared in the ASEAN region; for the current analysis, it also includes purchases from Australia, provided to Singapore through subsea cables. While the ASEAN grid currently has a low percentage of renewables, our neighbours in the ASEAN region have a considerable opportunity to expand their solar capacity, because of the larger land area available to them. Lao PDR has further promoted the ASEAN grid as a way of monetizing its hydroelectric capacity. Singapore would require an expansion of its planned grid connection capacity, and may also need to be intentional about increasing renewables investments as a contingency for purchase agreements. All of the financing for the new infrastructure is assumed to come from either offshore or private funds and not shown in the investment curves. The current commitment of the ASEAN grid is 23% renewable by 2030.

Policy considerations: The APG expands the potential for Singapore to tap on solar powered electricity generation by creating indirect access to APG members' combined larger land area. The key issues that need to be addressed concern navigating the political feasibility of ramping up the renewable mix of the APG, the potential need for financial subsidies and other policy supports, and the need to increase capacity for grid interconnection. Singapore should facilitate regional efforts, for instance through diplomacy and finance, to align the targets for renewables mix to match the IPCC recommendation of 65% by 2030 and 87% by 2050.

4. Nuclear power plants

What we know: Nuclear power has proven to be a reliable method for generating a large amount of steady baseload electricity and Generation III and IV technology performs significantly better in terms of inherent reliability and safety. The substantial reduction in waste generated from next-generation plants makes disposal within Singapore's territory, using underground storage, a potentially feasible long-term solution. The estimated installation costs are USD5,500 per MWh per year; here we assume that 60% of the costs can be sourced from the private sector (including domestic and offshore development finance institutions). Two nuclear plants would be sufficient to meet Singapore's residual electricity needs, to be operational in 2040 and in 2050. This allows the time to build them, as well as the option of forgoing the projects, in case consumption reduction and industry transformation options are realised before the projects are committed.

Policy considerations: Nuclear power offers highly scalable electricity generation with relatively low land footprint that does not require grid modification and produces hydrogen as a byproduct that can be used in manufacturing. Generation III technology is operational at a number of sites. However, there are high upfront capital costs and steep learning curves in the absence of technology transfers. Perhaps more significantly, negative public perception poses a significant obstacle due to serious incidents that have resulted in severe consequences ranging from loss of human life and long-term health impacts to environmental damage. Public distrust has been heightened by a history of mismanagement and official concealment of information in the nuclear industry. Trust and credibility must be restored by regulators instituting and enforcing stringent and transparent safeguards, learning from the mistakes and failures of past nuclear incidents.

5. Electric vehicles

What we know: Electric vehicles are well suited for urban transport since there are many available charging stations. Singapore has demonstrated good control of vehicle fleet with the COE programme and should be able to effectively convert large numbers of private and public cars within a short period of time. Incremental costs of fleet conversion are assumed to be SGD2,000 per vehicle, although this cost is a high estimate and should not require large capital investment since most of the parts of the car are the same. In case there is no market to buy back the used vehicles, special conversion facilities may be setup to help to smoothen the transition.

Policy considerations: Walkable cities and public transport powered by renewable sources remain our lead recommendation. Residual needs for motor vehicles should be minimised as the manufacture of electric vehicles still constitutes embodied emissions which have to be factored into our carbon budget. Hence, the COE, ERP and parking systems should be leveraged to reduce the number of motor vehicles on our roads concurrently with fleet conversion to electric vehicles.

6. Land based sequestration

What we know: There are several sources of residual emissions which cannot be fully avoided. In this scenario, the purchases from the ASEAN Power Grid can only contribute to emissions reduction to the level that the grid is renewable. Other sources of fugitive emissions or slow progress on planned reductions may inevitably result in the need for offsetting. Offsetting would be difficult to achieve at scale using only Singapore territory and would need to be done in coordination with overseas partners, either in ASEAN or globally. Land based sequestration by reforestation and forest carbon sequestration is likely the most practical way of achieving offsets at scale. Other methods such as direct air capture and sequestration may be possible, but at this point of time, these are not readily available. The costs of sequestration are here assumed to be the same as CCUS at SGD800/ton and need to be completely financed by the public.

Policy considerations: Regional diplomacy and financing can be used to incentivise conservation and reforestation, and to put restrictions on deforestation. Singapore can also increase domestic food production which will achieve the dual goals of improving food security and freeing up land in ASEAN and beyond for carbon sequestration. Policies could also support scaling up of proven methods for carbon sequestration such as biochar. Singapore could contribute substantially to a regional fund to subsidise and develop curricula for skills training in ecology conservation and biological carbon sequestration.

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Table of Recommendations

Section	Recommendations/Overview **For sections that deal with topics requiring more collaborative decision-making, we depict several pathways across the sections instead of raising concrete recommendations. For these, co-narrating is our chosen recommendation (see Section E, Table E1).*
Section A: Energy Efficiency of Buildings ***In response to NCCS "A) Improving Energy Efficiency across all Sectors"***	**Recommendation A1:** Raise the standard for building efficiency from Green Marks to the latest Passive House standards **Recommendation A2:** Consider investments in district cooling and desiccant based cooling to reduce the carbon intensity of cooling **Recommendation A3:** Use land and floor area incentives through Urban Redevelopment Authority (URA) and Building and Construction Authority (BCA) to give priority to carbon-light, social and community activities, and disincentivize energy-intensive consumption lifestyle-based activities, through controls on the use of space **Recommendation A4:** Prioritize rollout of aggressive building efficiency-upgrade programs for residential, office and retail **Recommendation A5:** Promote more moderate definitions of indoor comfort to 26-28 °C and lower lighting intensity **Recommendation A6:** Plot area ratios and urban geometry that promote a continuous urban-canopy design feature that simultaneously achieves fill-in for walkable cities and more sunlit surface area for solar PV capacity, while also providing shading and rain cover between buildings for further energy and rainwater-capture efficiency improvements
Section B: Encouraging Responsible Climate Action through Carbon Pricing	**Recommendation B1:** That the carbon tax rate be raised to a more appropriate level of at least USD40-80 per tonne. **Recommendation B2:** That the current flat-rate, no-exemption approach to all large emitters be strictly retained even as the carbon tax rate is increased. **Recommendation B3:** That the carbon tax be part of a suite of supporting decarbonisation policies, and not the main plank of a mitigation strategy. **Recommendation B4:** That revenues from the carbon tax redistributed back to citizens through a progressive carbon dividend, which is used to ensure a just transition to a green economy.

Section C: Reducing Emissions from Power Generation	**Recommendation C1:** Commit public funding of up to SGD200 billion for the complete decarbonization of electricity generation through a blended technology approach of solar, nuclear, natural gas with CCUS and ASEAN Power Grid. **Recommendation C2:** Commission an electricity decarbonization masterplan program to develop the design basis and resource requirements - land, materials, labor, funding for the infrastructure projects. **Recommendation C3:** Integrate regional renewables investment as a top priority in foreign policy and ASEAN regional diplomacy. Aim for targets to achieve 23% renewables mix by 2030 and 50% by 2050. Consider direct financial support for overseas land-based renewables investments in neighboring countries, and commit to grid infrastructure and transmission linkages investments. **Recommendation C4:** Pioneer CCUS end-to-end, point source to the ground accelerated technology program with the intention of proving the technology at scale and exporting the IP regionally and globally. **Recommendation C5:** Commission a technical review of state of the art for Gen III / IV Nuclear to identify risks and opportunities, and use public engagement tools with focus groups and public media campaigns as a decision making tool for moving forward on the technology opportunity. **Recommendation C6:** Commission a review of all existing building codes and land use regulations to identify bottlenecks and legal barriers to faster deployment of solar PV within the island. Review opportunities for accelerating deployment through land grants of public lands, financial incentives and green infrastructure banks.
Section D: Carbon Capture Utilization and Sequestration ***In response to NCCS "D) Deploying Emerging Low-Carbon Technologies"***	**Recommendation D1:** Commission a report to evaluate the risks and advantages of industry decarbonization pathways between managed phase-out of traditional burner facilities vs continuation of normal operations with CCUS add-on modification **Recommendation D2:** Commission a report to screen the least cost options for permanent sequestration - deep ocean vs spent fossil fuel well geological formations **Recommendation D3:** Set up public-private joint ventures in CCUS technology in four main areas - conversion of fossil fuels to carbon free hydrogen, logistics for storage and transport of captured CO_2,

	permanent large scale storage from among the available techniques and a research program to improve costs and efficiency in long term **Recommendation D4:** Setup industry association for CCUS to develop standards in areas such as engineering specifications, performance benchmarks, procurement and safety **Recommendation D5:** Incentivise technology development through competition among the major industry participants through schemes such as grants, early adopter incentives subsidies and participation in industry standards development **Recommendation D6:** Set CCUS access rights in international and direct offshore territorial waters as an agenda item for international negotiations with Brunei and Indonesia - two sites that are closest to deep ocean trenches > 3000 m depths.
Section E: Encouraging Collective Climate Action	Collective action is *the connecting point* of all the segments proposed in this Consultation. However, collective action approaches that enable people to come forward with their ideas must move beyond separating individuals and institutions. Institutions need to signal that space exists for people to engage as equal participants in the policy-making process--including as facilitators, decision-makers, and in refining policy. With the urgency of impending food crises and a global food shock predicted to occur by 2023 and 2027, our ability to expand the range of collaborative formats now--by building up cultural competence and actual exposure and connection across groups--will mean four years of practice by the time the first shock hits (or if it comes earlier). In this section, we: ● suggest why and how programmes that combine community-centred, on-ground sensing with innovative work across industries can truly identify lay and expert imaginations, and move society as a whole, towards the optimal capacity for collective action, ● emphasise that collective action must recognise the unexpected outcomes that policy-makers and planners working alone cannot foresee, ● assert that sound green policy that elevates people's needs for autonomy, competence and interpersonal belonging can truly empower individuals to do the best they can in personal and organisational capacities, ● propose executable opportunities close at hand, and domain-crossing approaches that will nurture long-term collective action,

	● and finally, give three examples of collective action at work. Singapore's institutional stability has given it the capacity for long-term planning, a quality most nations and states lack. Looking ahead four years, the challenges we face are those of building latent capacities for transformation, towards a model of decentralised and flexible decision-making across scales, that empowers people to nurture and support the communities they know best. Just as with building soil, nurturing latent capacity means investing in a trust / bank of competencies and resilient networks for the future ahead.
Section F: Tapping on Green Growth Opportunities	**Recommendation F1:** EDB to commission a report to identify the short and long term economic risk impacts of late vs early adoption of progressive climate mitigation given the global and long term trends presented in this section **Recommendation F2:** EDB to develop partnerships internationally to identify high potential direct foreign investment channels for green industries and jobs growth, and to identify export markets for new green technology IP **Recommendation F3:** EDB to research the new jobs creation potential in at a minimum each of the green sectors presented in this section **Recommendation F4:** MOM to map the skills requirements for each shortlisted industry and create the necessary education programs through partnerships with polytechnics and universities **Case for transitioning now** New sea routes in the Arctic means Singapore needs to have an alternative source of competitiveness other than its role as a geographic trading route hub. We see this as realistically within reach if Singapore leverages on the following: international carbon market are beginning to mature and strengthening international and domestic political pressure for decarbonizing New demand for local manufacturing capacity for renewables infrastructure Focus on long-term trends as urban and millennial consumer preferences shift away from material consumption and towards people, causes and experiences Jobs growth opportunity through directed economic stimulus.
The following sections expand on sectoral focus areas beyond the NCCS consultation paper:	

Section G: Maritime, Logistics & Aviation	**Recommendation G1:** Developing a stewardship framework (with both voluntary and co-regulatory components) for the shipping and warehousing sectors, under which the industry takes ownership for its own emissions and recommends specific incentives or guidelines for emissions abatements. This could begin with Singapore-based firms, and other regional countries can be invited to take part. **Recommendation G2:** Taking the lead in funding research and designing incentives to encourage firms towards adopting low-carbon technologies in the logistics and transport sector. **Recommendation G3:** Developing a set of national/regional standards for emissions from logistics activities such as warehousing and shipping feeder services. **Recommendation G4:** Working with international and regional organisations such as the IMO, Global Maritime Forum and ASEAN on shaping the long-term direction for any a cap-and-trade regime for the logistics and transport sectors such as the Getting to Zero Coalition initiative (Global Maritime Forum, accessed Sep 2019) which aims to introduce zero emissions vehicles into operation by 2030. **Recommendation G5:** Adopting a national governance framework for emissions from maritime terminals (encompassing the container, bulk, oil and cruise terminals). **Recommendation G6:** Inclusion of Maritime and Aviation carbon emissions in national greenhouse gas inventory accounting reporting. **Recommendation G7:** Shift consumers and businesses travel behaviour to limit air travel only for essential and emergency purposes through a variety of incentives and policy actions such as surcharges on all flights such as proposed in the EU (Sustainable business, accessed Sep 2019) or for multiple trips in a year. **Recommendation G8:** Voluntary participation in ICAO carbon emissions reporting and reduction scheme CORSIA.
Section H: Land Use and Food Production	Singapore is often described as an island with a net food import of more than 90%, highly food secure through its diversified food imports. Another view of Singapore considers it as part of an “agri-pelago of cities linked through food trans-boundaries” (Diehl, Sia, and Chandra 2019). This section looks at the implications of the alternative view, for climate policy and practice relating to adaptation, mitigation, and hybrid response options, particularly in the context of Southeast Asia. Expanding and growing the long-term fertility of its land portfolio is essential to ensuring food, and specifically nutritional security for Singapore, but also the adaptive capacities for nutritional sovereignty, amongst its regional partners.

	In this section, we examine food security and regional resilience through land use, and summarise findings from three reports: the IPCC Land Use Report Summary for Policymakers (2019), the EAT-Lancet Report (2019), and the HLPE Report on Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition (2019), prioritising them in order of relevance to Singapore's spatial considerations. **Recommendation H1:** make the food value chain (e.g. food waste and diets) an area for technical expansion and education about emissions reductions. **Recommendation H2:** achieve land degradation neutrality through integration of multiple responses across local, regional and national scales, including a range of flexible farming arrangements within the city. **Recommendation H3:** encouragement of low-input agroecology in Singapore's land investments in agricultural R&D, food production for domestic imports and technology and urban planning knowledge exports. **Recommendations H4-H10:** We also include 4 specific policy improvement areas for urban farming, and 3 recommendations for inter-agency regulatory sandboxing.
Section I: Manufacturing	**Recommendation I1:** Systematic identification and classification of manufacturing processes ranked by emissions intensity to the individual business and sub-process level **Recommendation I2:** Empower the Ministries to translate the NDC commitments into emissions reduction targets for individual sectors and business entities **Recommendation I3:** Set legal barriers for entry of new carbon pollutive business entities and processes **Recommendation I4:** Create legal responsibility for the highest carbon polluters to producer to develop decarbonization plans **Recommendation I5:** Setup transition fund to provide financial support for industries that chose to voluntarily decommission and transition out of certain sectors via M&A, spin-off, write-off via a state facilitated buy-out program **Recommendation I6:** Promote transition to alternative low carbon intensity methods of production such as hydrogen, electrical/mechanical, biochemical, general energy efficiency improvement via a range of incentives and regulations

	Recommendation I7: Setup industry education programs for decarbonization led by local universities
Section J: Transport	**Recommendation J1:** Enhance existing plans for a "car-lite" society to a "post-car" society **Recommendation J2:** Redirect infrastructure development from roads and highways to further enhancing the MRT rail network **Recommendation J3:** Expand pathways and infrastructure for walking, cycling, and PMDs
Section K: Financial Risk and Financial Transformation	**Recommendation K1:**That the sovereign wealth funds take the lead in financing low carbon investment and infrastructure development **Recommendation K2:** Set standards for risk analysis that factors in long-term climate risks, and ensure that all institutional investors follow these standards **Recommendation K3:** Revise monetary policy to dis-incentivise brown investments and incentivise green investments through adjustments in capital requirements **Recommendation K4:** Divest all public institutions from fossil fuel-related assets **Recommendation K5:** Create a Green Investment Bank of Singapore to provide low-interest loans for green projects

Section A: Energy Efficiency of Buildings

Author: Taylor Hickem, Dave Lommen, Sylvester Siew

Summary for policymakers

The way that Singapore currently uses electricity can be optimized to give more priority to human development needs in residential, healthcare and education. Land and building use should consider promoting wellness and socially enriched use of space and add more barriers to carbon intensive consumption and lifestyle uses in sectors like retail and high-end consumer goods.

Policy recommendations

- Raise the standard for building efficiency within the Green Marks to reflect the latest Passive House standards

- Invest in district cooling and desiccant based cooling to reduce carbon intensity of cooling

- Use land and floor area incentives through Urban Redevelopment Authority (URA) and Building and Construction Authority (BCA) to give priority to carbon-light / social and community activities and disincentivize energy-intensive consumption lifestyle-based activities through controls on the use of space

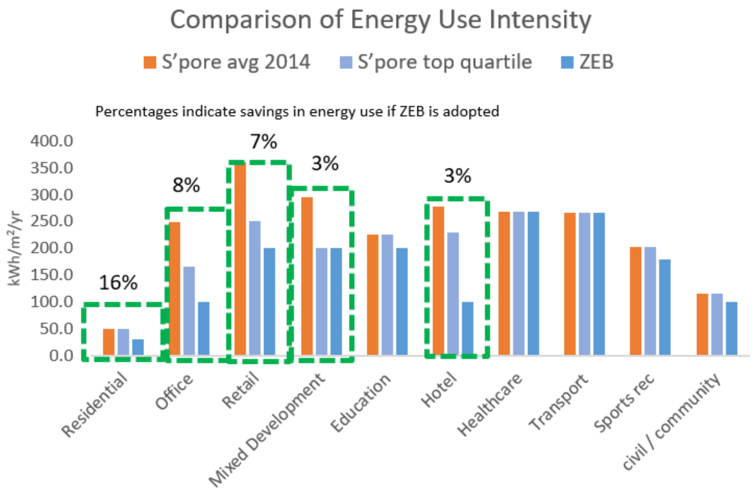
- Prioritize rollout of aggressive building efficiency-upgrade programmes for residential, office and retail

- Promote more moderate definitions of indoor comfort to 26-28 C (Appendix B) and lower lighting intensity

- Plot area ratios and urban geometry that promote a continuous urban-canopy design feature that simultaneously achieves fill-in for walkable cities and more sunlit surface area for solar PV capacity, while also providing shading and rain cover between buildings for further energy and rainwater-capture efficiency improvements

The total energy savings potential of buildings (without accounting for material lifestyle shifts) is estimated to be 960 kWh (348 kg CO_2eq) per person or 4% of Singapore's carbon emissions.

The chart below shows a comparison of Energy Use Intensity (EUI) between the current average Singapore building (orange bar), Singapore buildings that are in the top quartile of best performance for EUI (light blue bar) and indicative EUI based on international Zero Energy Building (ZEB) standards (analogous to Passive House standards). Sectors where significant EUI improvements can be made are boxed in green. There is potential to reduce EUI by 37% by adopting ZEB standards across all Singapore buildings, of which 16% is contributed by residential, 8% from office and 7% from retail.



	Annual energy use	Energy savings
S'pore avg 2014	2,570 kWh	
S'pore top quartile	2,334 kWh	-9%
ZEB	1,609 kWh	-37%

Figure: EUI in kWh/m²/yr for each building type evaluated (BCA, 350 Singapore)

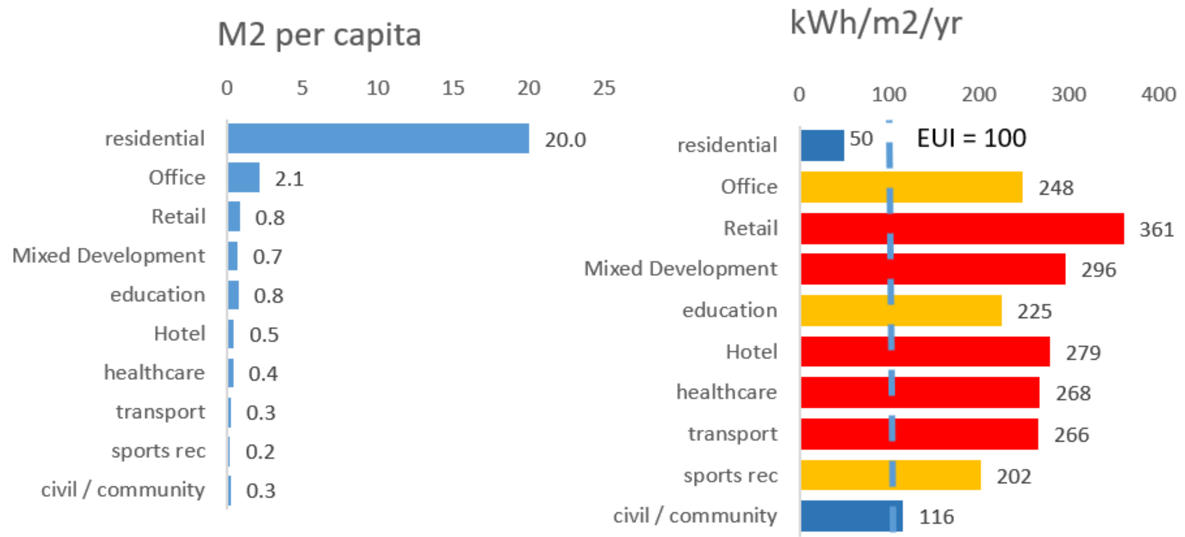
Benchmark: Energy Use Intensity

Energy Use Intensity (EUI) is a measure of the energy intensity of a building per unit floor area in kWh/m²/yr. The major source of electricity in a tropical climate like Singapore is cooling. A growing area of energy demand is from IT and IoT smart-control systems, which should receive equal consideration for moderation together with other lifestyle-based energy consumption sources. The range of energy intensity varies widely between and within types of building usage - residential, office, retail, hotels and mixed-use. New building energy efficient designs - PassivHaus (Passive House Institute, 2015), ZEB provide engineering standards for achieving lowest possible EUI.

EUI by Building Type (kWh/m².yr)	Top Quartile (1%-25%)	2nd Quartile (26%-50%)	3rd Quartile (51%-75%)	Bottom Quartile (76%-100%)
Offices	164	164 - 218	218 - 280	> 280
Hotels	232	232 - 292	292 - 359	> 359
Retail Buildings	259	259 - 405	405 - 554	> 554
Mixed Developments	212	212 - 264	264 - 357	> 357

Figure (BCA, 2014)

The largest total electricity consumer is residential. However, on an EUI basis, the intensity of residential is low at only 50 kWh/m^2/yr. Even so, much of the electricity usage in residential is not optimized and can be reduced further. In this section a target of 30 kWh/m^2/yr is presented as a realistic and achievable goal. There is high variability in EUI in office and retail spaces, which represent different levels both of efficiency and of consumption usage. Retail in particular is an intensive electricity consumer and utilizes bright lights to advertise consumer goods, which further fuels waste and consumption.



Policies that call out and recognize that retail is of lower priority of national interest in comparison to the threat of climate change could encourage building tenants to allow less spaces, for tenants to reduce the use of lighting for advertising and goods display and to shift retail away from the high traffic prime real-estate spots and out further away and at higher floors to encourage less consumption.

Energy improvement opportunities for buildings

- Cooling requirements and thermal comfort (Appendix B)
- ZEB best practices benchmarks
- Cooling technologies - district and desiccant
- Green roofs
- Floor area per resident - (Appendix A)
- Solar PV output potential
- Walkable urban design

ZEB Best Practices benchmarks

A case study is presented here using performance benchmark information from (Jung et al. 2018). Some of the important concepts are:

1. Higher indoor temperature setpoints 26-28°C at the limit of comfort

2. State of the art insulation, using 2 layers and air gap (U-values in W/m^2*K - 0.15 walls, 0.45 for windows)
3. Windows to be designed with smaller area incorporating use of shading
4. More compact floor densities to minimize total footprint
5. Minimise building external surface area to internal volume ratio by limiting the number of floors with larger built-up portion of parcel

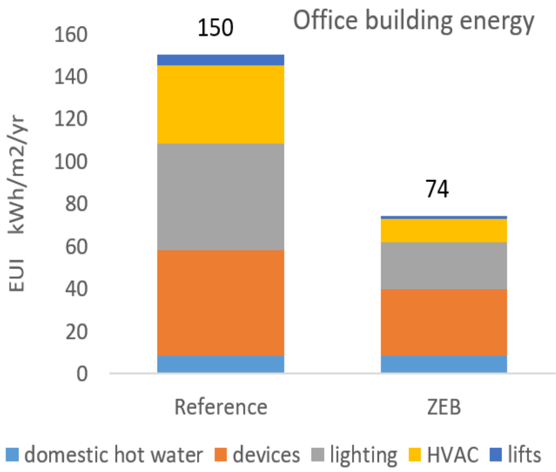


Figure (350 Singapore)

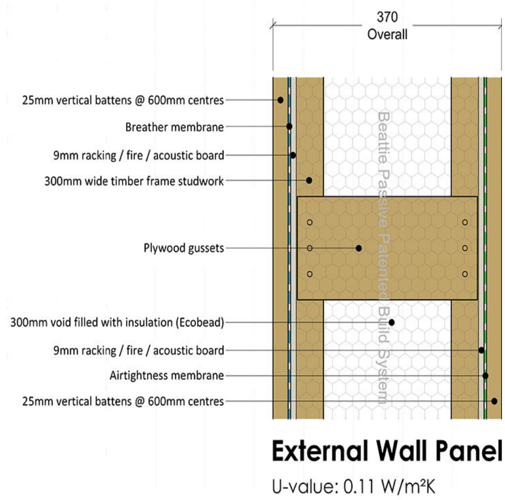


Figure (Jung et al.)

The tables below illustrate an example of how EUI can be improved through adjusting some design parameters. First, the floor area per person is reduced from 25 to 12 m^2 to maximize utilization. Next, several consumption based metrics are reduced by applying the same metrics from Jung et al. (2018) for devices, lighting intensity and lifts. Based on the indoor comfort guidelines, it is possible to maintain comfort at 28°C with sufficient local air velocities so the temperature is increased from 24°C to 28°C. (Air circulation , windows and walls heat transfer, and area coverage parameters are taken from Jung et al.)

Design conditions

		Reference	**ZEB**
Density	m^2/pax	25	12
Device usage per person	W/pax	500	150
Lighting intensity	W/m^2	20	9
Lifts	kWh/m^2/yr	5	1
Indoor temperature	C	24	28
Air circulation	m3/h*m^2	5	0.6
Window coverage	%	90%	50%
Window U-value	W/m2/K	1.5	0.45
Window shading g-factor	%	0.6	0.2
Wall and roof U-value	W/m2/K	1	0.15
Refrigeration COP		3	3.5

General building conditions

Number of floors	20
Aspect ratio (L/W)	6
Built-up area	10,000m^2
Daytime average window irradiance	200 W/m^2

Cooling technology - District and Desiccant

District cooling systems can achieve higher overall coefficient of performance (COP) through economies of scale. In District cooling, the cooling is centralized and the temperature is shared among many users. Frequently water pipes are used as fluid carriers since it is a more efficient form to transport heat due to the higher heat capacity and density of water vs air. District cooling can utilize additional efficiency gains through heat integration with other industrial and commercial services. Furthermore, if heat storage is utilized, heat storage combined with a heat pump and rainwater collection could leverage rainwater as a large heat sink. In this scenario a heat sink is “charged” with reject heat during normal operation and “re-charged” during heavy downpour. Refrigerants with boiling points just above the temperature of rainwater 30-34 °C may be ideal for this purpose.

Desiccant systems remove humidity by adsorbing water vapor from the air onto a physical surface. Once the surface is saturated, the desiccant is regenerated using a hot gas. The dry process air is then cooled by evaporative cooling to produce a cool moist air stream. The advantage of desiccant systems is they require minimal electricity and run mostly from thermal process. Desiccant cooling systems could be a great opportunity for Singapore which has an excess of waste heat from industrial processes. Desiccants systems can integrate with industrial processes to take waste heat and upgrade it into heating, ventilation and air conditioning (HVAC) production for building operators without the need for additional grid electricity. Disadvantages of desiccant systems are high capital investment and a low coefficient of performance (COP) of 0.7 - 1.0 (Barlow, 1982). Newer technology versions, based on liquid desiccants vs solid desiccants, have been researched. They give a COP as high as 5 and are able to utilise waste streams at temperatures of 50 - 80 °C (Liu, 2014).

Green roofs

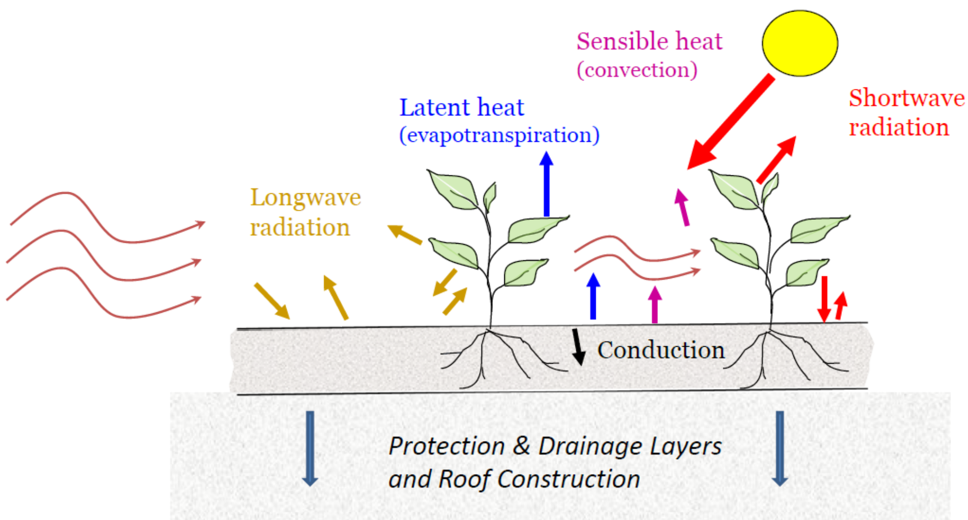


Figure (Sailor, Elley and Gibson 2012)

Green roofs can achieve a 25% reduction in heat transfer compared to conventional roof designs (Becker, 2011). Plants remove heat in the form of transpiration and have an overall positive moderation against the effect on urban heat island in the surrounding urban area through evaporative cooling. Designs that have deeper soil depth and larger leaf area index favor better insulating performance (Sailor et al. 2012). Green roofs and solar panels both utilize energy from sunlight for different purposes. Green roofs have the added benefit of potentially producing food if the plants are agriculture crops, which further helps to reduce the total urban carbon footprint. Depending on the more critical needs of the city, a mix of rooftop spaces may be utilized for both electricity and food production, with both offering shading and energy-efficiency improvements for the building beneath.

Solar PV electricity generation

Solar PV technology is presented in the renewables section of this report. For Singapore a reasonable output capacity is 154 $kWh/m^2/yr$. By applying this value together with an EUI of 74, a net positive building design can be achieved by maximizing the ratio of rooftop cover to parcel plot area, and reducing the number of floors. The canopy ratio is defined as the solar PV area that is exposed to the sun over the plot area of a building or installation. The figure below shows the net excess solar energy in $kWh/m^2/yr$ that can be produced for a given combination of canopy ratio and number of floors in a building.

Canopy ratio	0.5	1	1.5	2
# floors				
1	3.0	80.0	157.0	234.0
2	-35.5	3.0	41.5	80.0
3	-48.3	-22.7	3.0	28.7
5	-58.6	-43.2	-27.8	-12.4
10	-66.3	-58.6	-50.9	-43.2

Figure (350 Singapore)

Walkable city design - filling in the gaps

Reducing the number of floors has an added benefit of an urban design that prioritizes filling in the spaces between buildings instead of rising vertically into the sky. For Singapore, the main climate challenges and opportunities are the intense solar radiation and the downpour of tropical rain. However, Singapore also has the added challenge of a high population density of 7,804 inhabitants per square kilometre as of 2018 (Department of Statistics Singapore).

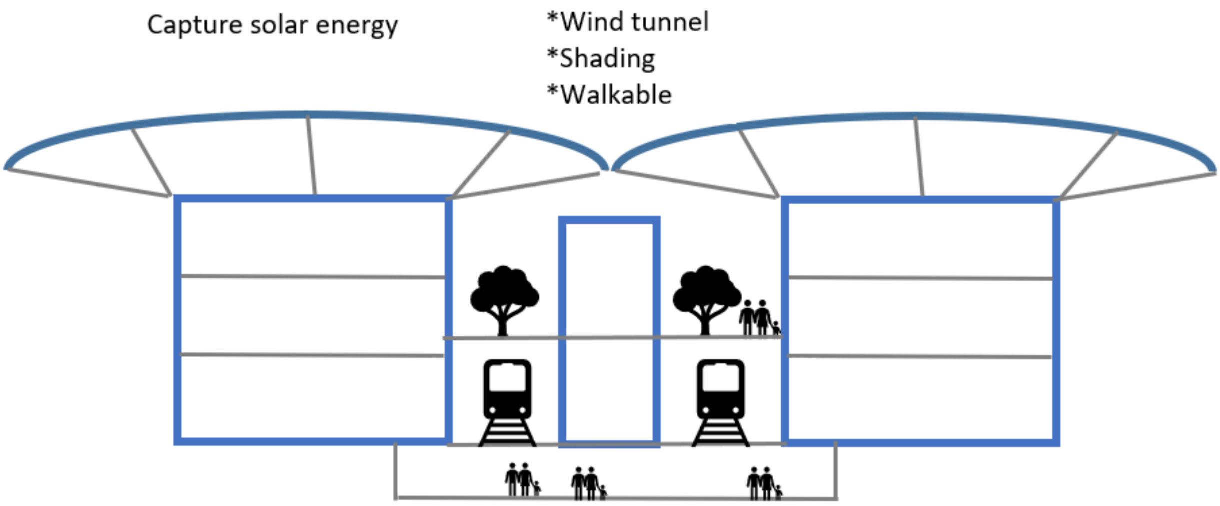


Figure (350 Singapore)

By creating a network of an urban canopy, several design objectives in sustainability are achieved.

1. Replacing land area previously used for cars with continuous connectivity corridors are key design feature of walkable cities. Examples include Singapore's CitiLink Mall and J-Link, and Hong Kong's Central area.
2. Creating protected microclimates ideal for pedestrians that have cover from intense solar radiation creates wind-tunnel effect that enhances comfort and dried-in protection from downpours.
3. Maximizing sunlit rooftop area available for solar PV energy, urban agriculture and rainwater capture.
4. Reducing the solar load on buildings and decreasing the surface-area-to-volume ratio of the cluster.

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Section B: Carbon Tax

Author: Bertrand Seah, Tim Min Jie

Summary for policymakers

Recommendation 1: That the carbon tax rate be raised to a more appropriate level of at least SGD50-100 per tonne.

Recommendation 2: That the current flat-rate, no-exemption approach to all large emitters be strictly retained even as the carbon tax rate is increased.

Recommendation 3: That the carbon tax be part of a suite of supporting decarbonisation policies, and not the main plank of a mitigation strategy.

Recommendation 4: That revenues from the carbon tax redistributed back to citizens through a progressive carbon dividend, which is used to ensure a just transition to a green economy.

Recommendation 5: That the carbon pricing scheme be managed through a simple taxation scheme based on verified emission values of taxable entities.

Singapore's SGD5 per tonne carbon tax is commonly regarded as a key mitigation measure. In general, putting a price on carbon has been a heavily politicised issue in many countries, and as a result has taken different forms owing to the different social and political dynamics in each country. Here, four main points will be made: Firstly, that there is no "optimal price" of carbon as such, and that this price will always be based on a set of political trade-offs and normative assumptions. Secondly, that nonetheless, Singapore's carbon price falls way below most guidelines of an acceptable carbon price requisite with the environmental costs of carbon. Thirdly, that while having a substantial, wide-ranging price on carbon is important and necessary, its mitigating potential should not be overstated, and that a carbon tax needs to be part of a broader policy framework that is aimed at decarbonisation. Lastly, that the process for the formulation and implementation of carbon tax policy is transparent and follows the principles of fairness and distributive justice. This is particularly so in determining where the bulk of tax revenue comes from, and how the revenue from the tax will be spent.

Numerous figures have been proposed as guidelines for an "optimal" carbon price. A report by the High-Level Commission on Carbon Prices, chaired by Joseph Stiglitz and Lord Nicholas Stern, recommends that a tax of at least USD40-80 per tonne by 2020, rising to USD50-100 in 2030 is necessary in order to meet the targets of the Paris Agreement (Carbon Pricing Leadership, accessed 2019). Pioneering environmental economist William Nordhaus, in an analysis of 13 models on carbon prices, found an average carbon price of approximately USD30 per tonne in 2020 rising to USD55 in 2030 in order to keep to a 2.5°C target (Nordhaus, 2013). In his economic modelling of the social costs of climate change, suggests in his “optimal” scenario, which is projected to reach roughly 3.5°C of warming in 2100, that the 2015 social cost of carbon is USD30 per tonne, rising to USD42 in 2025. Adjusting the model to a 2.5°C warming projection, by contrast, brings this social cost of carbon upwards of USD200 per tonne from 2020 onwards (Nordhaus, 2018). Others suggest that the carbon price should be pitched at a level that incentivises utilising negative emission technologies, which optimistic estimates say are possible at approximately USD100 per tonne.

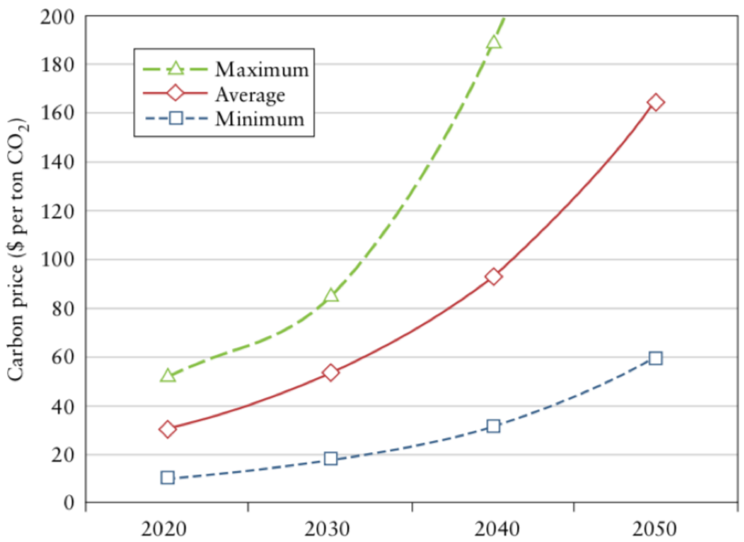

Figure (Nordhaus, 2013)

From these figures, it is clear that Singapore’s carbon price is set at too low a level, even if the price is increased to SGD10-15 per tonne in the coming years as planned. Nonetheless, it is praiseworthy that Singapore’s policy applies to all large emitters without exception. On the other hand, it is set at a level where it is uncertain if it will lead to substantive mitigation measures. The carbon tax thus has benefits and weaknesses compared to other countries, and it is in these trade-offs that we should focus our attention.

At a basic level, a much higher price will always be much better at dis-incentivising the carbon emissions than a lower price, but will accordingly be less amenable to businesses, producers, or consumers for whom costs will rise. In the Singapore case, it has been outlined in parliamentary debates that the price is starting at this low SGD5 level because of a need to maintain Singapore’s competitiveness and attractiveness to business (Tan, 2018). Such a low level might even be counter-productive in generating broad-based support for the carbon tax. A study of the behavioural impacts of a carbon tax suggests that the “nudge” approach, promising lesser benefits but starting at a lower price to “nudge” individuals towards such policies, could ultimately diminish support for more substantive policies, as they help to cultivate the false hope that a quick fix can be implemented without imposing any considerable costs on society (Hagman et al, 2019).

In other countries, however, different kinds of compromises have been made. The most common compromise has been in the implementation of differential tax rates to different industries, and the use of tax relief for affected sectors. These forms of tax exemptions on the carbon tax have curbed the mitigating potential of carbon taxes, particularly in places that have implemented a relatively high tax rate, because in practice they have tended to be used for carbon-intensive sectors.

A study of five early implementers of the carbon tax from – Denmark, Finland, Netherlands, Norway and Sweden – from 1997 to 2008 found that only Finland was shown to have succeeded in achieving emissions mitigation to a significant level through its carbon tax policy, in spite of a lower carbon price than other countries (Lin, 2011). The reason that the carbon tax policies in these four other countries were not as effective in mitigating emissions came precisely down to measures to cushion dirty industries from the tax. In Denmark, businesses were reimbursed 50% of the standard rate, with further reductions in the rate the higher the carbon intensity of the firm. In the Netherlands, the energy intensive industries were given tax relief for large scale consumption of natural gas and certain types of residual fuels. In Norway, mitigating potential of the carbon tax was negated by the push to grow its oil and gas export sector.

The last case of Sweden is particularly noteworthy as Sweden has seen the dramatic rise of its carbon tax to about USD139 per tonne today, the highest in the world. However, exemptions and differential rates have also reduced its mitigating impacts. In the early years of implementation, a lowered rate was kept for industry, while later years saw about two-thirds these industries become exempt from the Swedish tax in lieu of the EU-based European Trading System, which has maintained a far lower carbon price than Sweden's. Over the period of 1991-2014, total emissions dropped by almost 24%, but emissions from iron and steel, two of the dirtiest industries, rose about 10%.

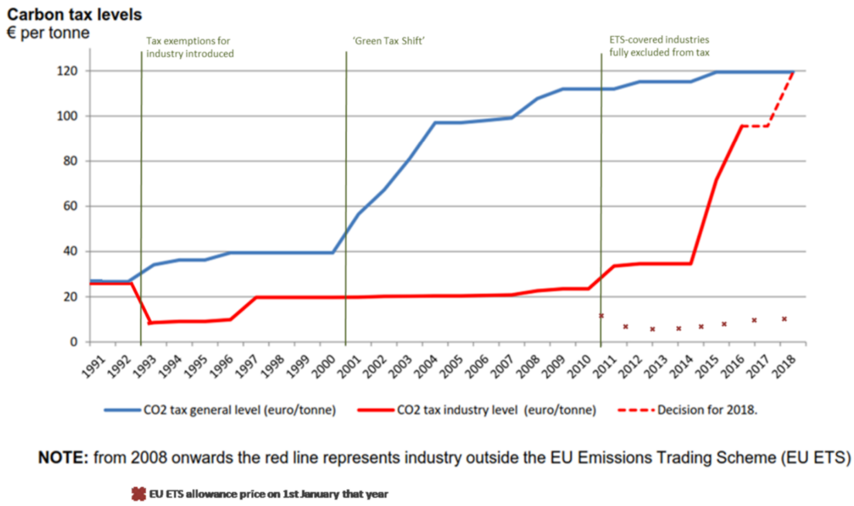

Figure (Ackva and Hoppe, 2018)

From this, it should be deduced that the carbon tax does not by default lead to increased emission mitigation. In most cases, exemptions and differential rates have severely negated impacts on dirty industries, On top of market mechanisms such as the carbon tax, additional policies also need to be implemented to direct firms to decarbonise. Even in cases where there is a high carbon tax, if the costs for decarbonisation still exceed this high tax rate, dirty emitters will still find it preferable to absorb the costs of the increased tax rather than move to low-carbon options. In such cases, the supply becomes price inelastic, and the tax serves more as a way of extracting rent from a profitable industry than to decrease emission-heavy activities. A recent study on the incidence of a carbon tax on global CO_2 emissions shows this in rather stark terms: a carbon price even as high as USD200 per tonne would only reduce cumulative emissions from oil by 4%, and a carbon price of USD600 would be needed to reduce cumulative emissions by 60% (Heal et al, 2019). The implication from this is that reducing emissions cannot just be reduced to market-based measures, but that there has to be a comprehensive plan for decarbonising society in order to achieve widespread emissions mitigation.

Given the ubiquity of exemptions for carbon-intensive industries, it is indeed praiseworthy that Singapore's carbon tax has from the start kept a flat rate for all, and it must be emphasised the importance of keeping to this no-exemption approach even as the carbon tax is raised. Even then, however, the carbon tax would still not be a sufficient measure. Ideally, it should be pitched at a higher level of at least SGD40-80 per tonne, but it should not be the main pillar of the emissions reduction strategy. Rather, it must come as part of a suite of measures that takes comprehensive steps towards decarbonisation.

Lastly, it should not be forgotten that a carbon tax is also ultimately a fiscal measure, and how the revenue is earned and spent needs to be determined in a just and transparent manner. As underscored by the examples of the four countries mentioned above, the carbon tax should be aimed at penalising most severely the dirtiest actors, and not redirecting the revenues towards them. There are two possible ways in which this can be done – a decarbonisation fund and a carbon dividend.

A decarbonisation fund would mean that the revenues gained from the tax are committed firmly towards decarbonisation and low-carbon innovation. This would exist as part the Singapore budget and be jointly administered by the finance and environmental ministries. Such a fund would then act as the medium where all revenues from the carbon tax goes, and where strict guidelines are set on the permissible use of the funds.

The carbon dividend would entail the redistribution of tax revenues straight back to citizens, meaning that measures for decarbonisation would be funded fully through conventional revenue sources. This is potentially be the preferable option for a number of reasons.

Firstly, taxes have tended to be a politically fraught issue, as we have seen from the Yellow Vests protests, and more generally the intense opposition to taxes of all forms demonstrated in sections of American society. Secondly, if there is to be a serious intent to decarbonise fully, the carbon tax would only be a short-to-medium term solution, as the amount of revenue generated by the policy would gradually decline as emissions are reduced. The large amounts of investments required to green the economy should be funded by more consistent forms of revenue, and not by a policy whose revenue would decrease the more successful it is in achieving its objectives. Thirdly, a carbon dividend can be tailored and distributed in progressive ways, and be channelled more towards poorer and lower-income households. It can also be directed more towards workers affected by the phasing out of carbon-intensive industries, ensuring that there is a just transition to a green economy.

Lastly, a carbon dividend would potentially generate more political support. A redistribution of this carbon dividend back to citizens would help to defray the potential added costs on consumers for the carbon tax, and give them a stake in supporting an ambitious carbon tax policy while maintaining the onus on producers to reduce emissions. A large study of participants from five different countries (albeit each with much different contexts from Singapore) showed more consistent public support for a substantial carbon tax across these countries if the revenue from the tax was directed straight back to citizens, as shown in Figure.

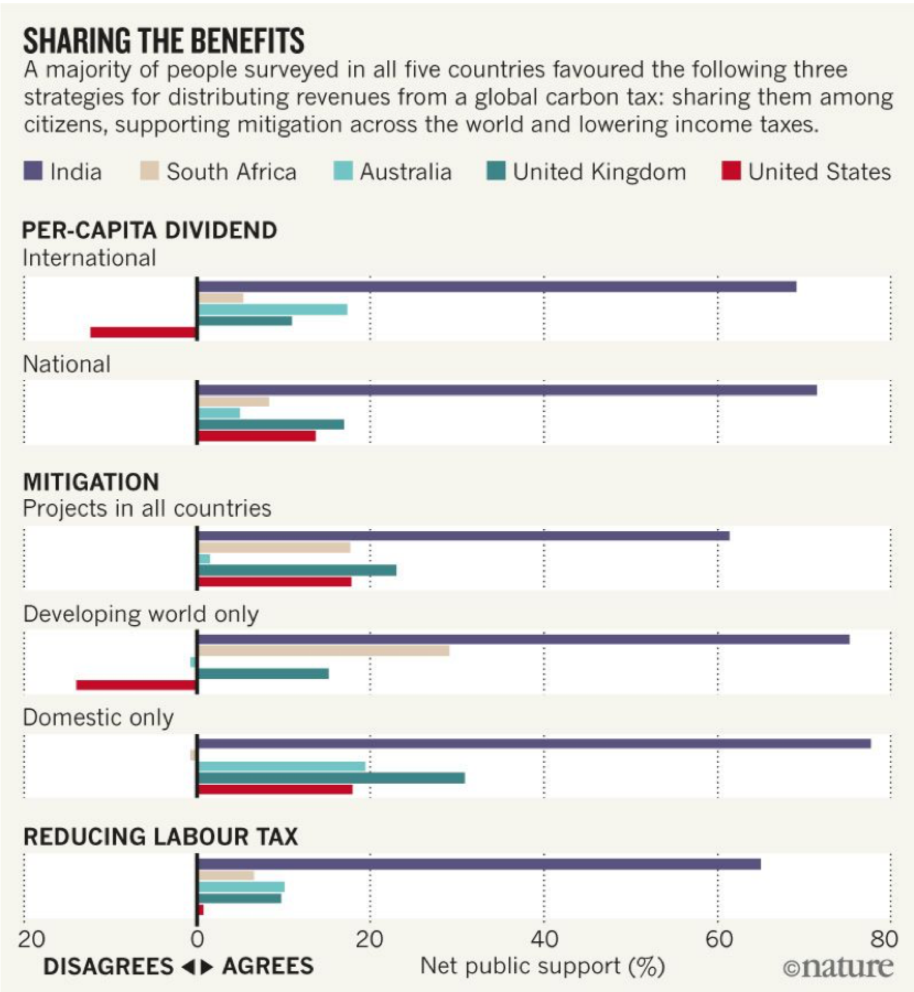

Figure: Support for a Carbon Tax across five countries.(S. Carattini et al, 2019)

More specifically, carbon pricing should be managed through a simple taxation scheme, as opposed to the current framework that hybridises the carbon tax and carbon credit trading scheme. The latter necessitates taxable facilities to estimate the number of carbon credits they require for the year ahead. While this may encourage more careful planning, it also runs the risk of taxable facilities overestimating the number of carbon credits they actually require and having left-over unutilised carbon credits. Compounding this problem is the fact that the current Carbon Pricing Bill prohibits the sale, transfer, assign or other disposal or refunding of their unutilised credits. Thus, taxable facilities with left-over credits may end up using less energy-efficient technologies that produce greater emissions in order to use up their remaining carbon credits. Evidently, such an outcome goes against the intended objectives of the carbon pricing scheme. A simple taxation scheme that requires taxable facilities to pay off their taxes based on their verified emissions values is therefore a more effective and straightforward approach (Chua et al., 2018).

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Heal, Geoffrey "Alternatively, because taxes have tended to be a highly politically fraught issue, as shown by the Yellow Vests protests, and more generally the intense opposition to taxes of all forms as seen in sections of American society, some have suggested instead that the revenues from the carbon tax be distributed directly back to society through a carbon dividend, and that the measures for decarbonisation be funded through conventional revenue sources"

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Section C: Reducing Emissions from Power Generation

Authors: Taylor W Hickem, Dave Lommen

Summary for policymakers

While Singapore's electricity mix today is heavily reliant on carbon intensive methods, there are several pathways to fully renewable electricity mix by combinations of Solar, Nuclear, Natural Gas with CCUS, ASEAN Power grid and Australia at affordable tariff rates and total investment cost of SGD 100-200 billion.

Policy recommendations

- Commit public funding of up to SGD200 billion for the complete decarbonization of electricity generation through a blended technology approach of Solar, Nuclear, Natural Gas with CCUS and imports from ASEAN Power Grid/Australia.

- Commission an electricity decarbonization masterplan program to develop the design basis and resource requirements - land, materials, labor, funding for the infrastructure projects.

- Integrate regional renewables investment as a top priority in foreign policy and ASEAN regional diplomacy. Aim for targets to at a minimum achieve current pledge of 23% renewables mix by 2030 and 50% by 2050, and to push for more ambition to match IPCC recommendation of 65% by 2030 and 87% by 2050. Consider direct financial support for overseas land-based renewables investments in neighboring countries, and commit to grid infrastructure and transmission linkages investments.

- Pioneer CCUS end-to-end, point source to the ground accelerated technology program with the intention of proving the technology at scale and exporting the IP regionally and globally.

- Commission a technical review of state of the art for Gen III / IV Nuclear to identify risks and opportunities, and use public engagement tools with focus groups and public media campaigns as a decision making tool for moving forward on the technology opportunity.

- Commission a review of all existing building codes and land use regulations to identify bottlenecks and legal barriers to faster deployment of solar PV within the island. Review opportunities for accelerating deployment through land grants of public lands, financial incentives and green infrastructure banks.

In the first quarter of 2019, 97.1% of Singapore's electricity generation came from fossil fuels (95.3% natural gas, 0.7% petroleum products and 1.2% coal). Only 2.9% came from other sources, which includes waste-to-energy and solar photovoltaic (PV) (Energy Market Authority, 2019).

Of the available renewable sources of electricity, geothermal, hydroelectric and tidal have not been identified as accessible in the near vicinity of Malaysia and Indonesia, hence this submission will focus on solar PV and nuclear. CCUS is covered in another section of this report. The ASEAN Power Grid may utilize a wider range of renewable electricity sources including wind. By strict definitions, nuclear is not technically renewable as it is sourced from a finite resource, however it has one of the lowest lifecycle carbon emissions and the latest generation technology promises to have minimal waste generation.

The figure below presents compelling evidence that nuclear, solar and wind have significant potential to replace electricity in a carbon tax environment of less than USD40/ton of CO_2eq and represent 15% of global abatement opportunity identified.

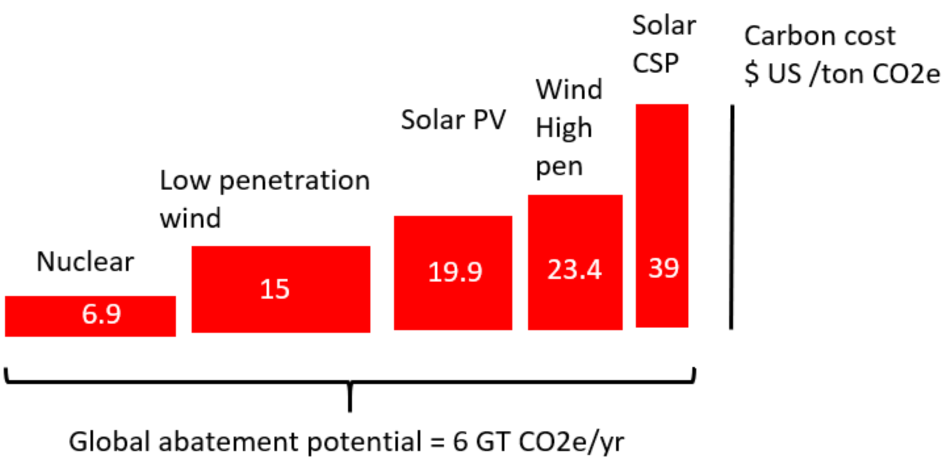

Figure: Adapted from report on greenhouse gas abatement cost curve (Enkvist et al., 2010)

Solar photovoltaics

Solar has the potential to meet a substantial fraction of Singapore's energy mix if the whole range of opportunities are considered. Solar Photovoltaic (PV) converts solar radiation to electricity at efficiency range 10-15%. Electricity prices are already economical for Solar PV and forecasted to continue to drop in the coming decades. Solar is most effective in regions with ample amount of annual sunlight. Singapore's latitude on the equator is an advantage, but offset somewhat by the disadvantages of the irregular urban landscape with limited flat unobstructed surface areas and frequent cloud cover. Solar panels are rated in terms of peak output kWp at mid-day. Singapore conditions are 625 W/m^2 vs the standard condition is 1,000 W/m^2 .

Fill urban space with solar electricity capacity

An environment with heavy investment spending in solar infrastructure can create new IP opportunities in novel technologies in Solar PV through research institutes like SERIS. Examples include BIPV wall-mounted solar panels (Solar Powered World, 2017) and solar windows (EnergySage, 2019). Although these may not be ideal for a country on the equator, they offer an alternative to traditional roof- or ground-based solar panels and have the added benefit of reducing cooling load to improve building energy profile. Similarly, there are many flat surfaces that can be covered with solar panels. This has been done for some factories, HDB flats and companies, but much is yet to be gained. Electricity generation can also be integral in the design and implementation of any new structure. As a simple example, Singapore is in the process of building hundreds of kilometres of covered walkways. If these were immediately covered with solar panels, they could supply electricity for thousands of HDB flats.

Floating solar farms to close the energy needs gap

Looking beyond the built-up urban area, Singapore is actively testing floating solar panels. These tests were successful and the technology is now being sold to other countries. However, locally, the implementation still has room to grow. Two floating solar PV systems, each running at 1.5 megawatt-peak (MWp), will be deployed by the Public Utilities Board (PUB) in 2020. As of June 2019, PUB was further seeking proposals to design, build, own and run a solar farm at Tengeh Reservoir. Planned to be operational by 2021, it would operate at 50 MWp. Together, these three solar farms would occupy just over 200,000 m^2 (Liu, 2019). However, Singapore's reservoirs cover an area in access of 15 km^2, even if MacRitchie Reservoir (extensively used for recreational purposes) and reservoirs located in restricted zones are not taken into account. Only covering half of this area with floating solar PV systems would allow for the generation of some 1.7 TWh per year. This corresponds to about 5.5% of Singapore's total energy consumption in 2018. Furthermore if the 700 km^2 offshore territorial waters are also considered for floating farms there is ample space available for solar panels to meet Singapore's electricity needs.

Next Generation Nuclear

One of the leading opportunities for fast renewables transition for a land constrained state like Singapore is nuclear energy. Nuclear was promoted by Lee Kuan Yew as Singapore's best option for transitioning out of fossil fuels and reiterated again recently by Temasek CEO Ho Ching (Stolarchuck, 2019) as quoted below:

> *Newer nuclear options are on the horizon, not eminent, but within decades. Overall, for a greener earth and to reduce carbon emissions, we must master and adopt nuclear energy as a key solution. For now, it is better than developed and more capable nations step up their nuclear power capacity. This will reduce the demand for fossil fuels, and lower the overall carbon emissions. At the same time, developing economies can do their part to switch away from coal to cleaner gas or greener renewables.*

Nuclear energy has been mooted as an option for Singapore in the past. In an interview at the 2008 Singapore Energy Conference, Lee Kuan Yew mentioned nuclear as the obvious response to decarbonization (Lim, 2017). For older generations Gen I/II one of the reservations is the required 2km uninhabited zone and 5km radius low density zone in case of an unintended release according to TS Gopi Rethinaraj, assistant professor and nuclear energy expert at NUS Lee Kuan Yew school of public policy (Strait Times, 2012). While this concept is out-dated and not considered a necessary design limit for modern plants, if Singapore decided to apply this precaution it is still feasible to site at a nearby territorial unpopulated islands and four sites have been proposed in addition to floating and underground sites (Palmer , 2010). The approval for any new nuclear facility must be tied to an environmental impact assessment (EIA).

Other potential locations considered by Cheema (2009) are:

1. Western Water Catchment Area (around Tengeh, Poyan, Murai and Sarimbun reservoirs, west of Lim Chu Kang road), which covers approximately 50 km2;
2. the Central Water Catchment Area (around Bukit Timah);
3. Pulau Tekong and other outlying islands;
4. Pedra Branca

In case risk perceptions of nuclear are considered too high for facilities in close proximity to an urban area, the nuclear facilities may be set up in remote areas with international partners such as the deserts of Australia. In order to diversify the sources, bilateral arrangements may be made with multiple siting installations regionally. In this scenario, the imported fuel may be either hydrogen, or another basic chemical form such as ammonia or methanol that can readily be synthesized from a hydrogen source.

A short overview of Gen III / IV Nuclear technology safety and waste improvements is presented in Appendix C.

ASEAN Power Grid and Australia

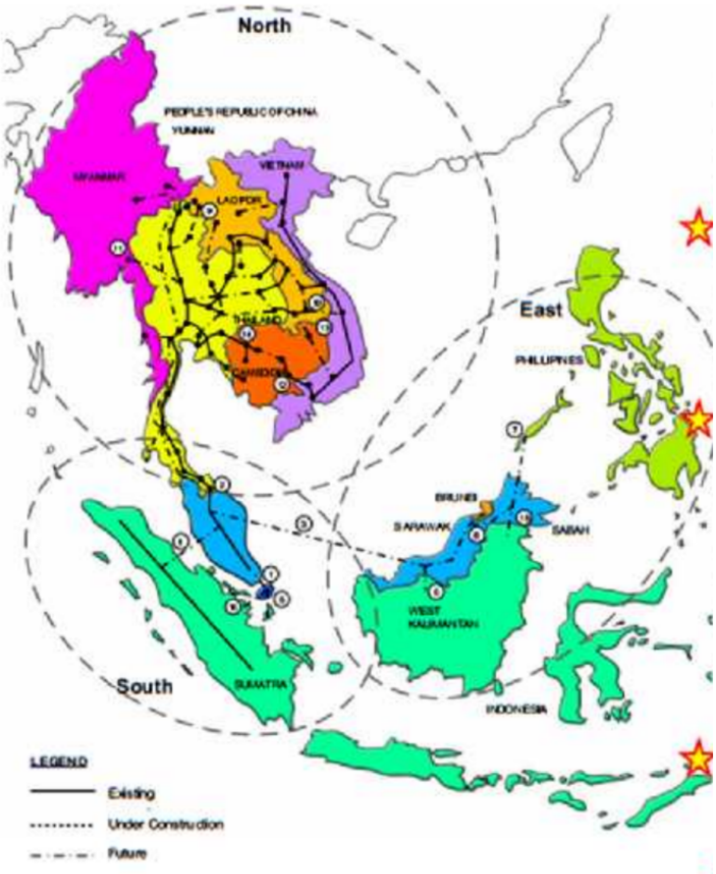

Figure (Finenko, 2016)

The ASEAN Power Grid (APG) could be a promising opportunity for greater regional leadership by investing in links with neighboring countries such as Indonesia and Malaysia to benefit from investments in land based renewables such as solar PV, geothermal, hydroelectric, wind and potentially nuclear. Australia is another potential partner for land-based low-carbon electricity generation. Interconnection, in conjunction with smart grid infrastructure, expands the coverage area for renewable energy production, which can reduce the variability of electricity production from solar and wind energy and create additional opportunities for production spillover and backup supply (Hawken, 2014). The APG also creates more flexible land siting locations for nuclear power plants. Projects for inclusion in the APG should also undergo environmental impact studies to assess their net carbon footprint and ensure negative impacts are minimised, for example by building on brownfield sites rather than clearing forested land.

To realize these opportunities Singapore must be an active participant in the ASEAN Power Grid (APG) initiative which seeks to improve grid interconnection between member nations. While Singapore has joined the pilot initiative 2014/15, the actual energy agreement signed in 2017 was between Malaysia and Lao through the Thai grid (Bernama New Straits Times, 2017). Current projected renewables share of the APG is forecasted to reach 23%, but could be nudged higher with greater incentives and direct investments through Singapore's leadership as a financial and technology hub in the region. To fully utilize the potential of the APG, Singapore would need to invest in increasing the capacity of the proposed links which currently are proposed at max 1,200 MW or 16% of total electricity.

Lao hydroelectric power supply

Strong investment in adding to the APG renewables capacity has been led by Laos, who is well positioned as an exporter and consumes must less than the hydroelectric capacity generation potential. Hydroelectric dams if implemented irresponsibly can have a disruptive ecological impact to sensitive natural areas and downstream communities. In Thailand, environmental groups have raised concerns about the ecological impact of the Lao PDR hydropower projects (Straits Times, 2019), as well as efforts to protect the livelihoods and homes of local communities that dam projects routinely displace (e.g. by International Rivers). The inclusion of such projects into the APG should only occur on the basis that environmental impact studies are done, including net carbon footprint, and protocols are established to minimise negative impacts, such as retrofitting existing dams to provide hydroelectric power.

Solar PV from Australia

Another possible source of internationally purchased electricity could come from Australia. Australia along with the Sahara are one of the most abundant sources of ideal solar PV conditions with low cloud cover and close to the equator and is currently approaching an oversupply of PV electrical capacity (Edis, 2018). Reports in the news media is that Singapore Firm, Sun Cable is considering an AUD20b project to supply up to 20% of Singapore's electricity needs via undersea power cables (The Guardian "just a matter of when, 2019)

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Section D: Carbon Capture Utilization and Sequestration

Author: Taylor W Hickem, Sylvester Siew

Summary for policymakers

Policy recommendations

- Commission a report to evaluate the risks and advantages of industry decarbonization pathways between managed phase-out of traditional burner facilities vs continuation of normal operations with CCUS add-on modification

- Commission a report to screen the least cost options for permanent sequestration - deep ocean vs spent fossil fuel well geological formations

- Setup public-private JV in CCUS technology in four main areas - conversion of fossil fuels to carbon free hydrogen, logistics for storage and transport of captured CO_2, permanent large scale storage from among the available techniques and a research program to improve costs and efficiency in long term

- Setup industry association for CCUS to develop standards in areas such as engineering specifications, performance benchmarks, procurement and safety

- Incentivise technology development through competition among the major industry participants through schemes such as grants, early adopter incentives subsidies and participation in industry standards development

- Set CCUS access rights in international territories for disposition into oil and gas fields and territorial waters as an agenda item for international negotiations with neighboring countries - Malaysia, Brunei and Indonesia. Examples of sites include the Natuna gas fields and deep ocean trenches > 3000 m depths in Palawan Trench and off the southern coast of Sumatra.

CCUS technology highlights

- The process can either be applied pre or post combustion and is economically viable in a price environment of USD80-100/ton of CO_2 including the capture, logistics and sequestration costs.
- Hydrogen fuel can be applied as a replacement to natural gas through pre-combustion for existing burners, proven steam reforming technology and existing hydrogen pipeline infrastructure on Jurong Island. In parallel to the implementation of point source capture facilities, pilot trials can be initiated to test the effectiveness of long-term storage and sequestration.

- What remains open for the technology to be proven at large scales is effective long-term storage and logistics from the capture point sources to the storage locations which should be piloted and scaled up as a strategic national technology research agenda.

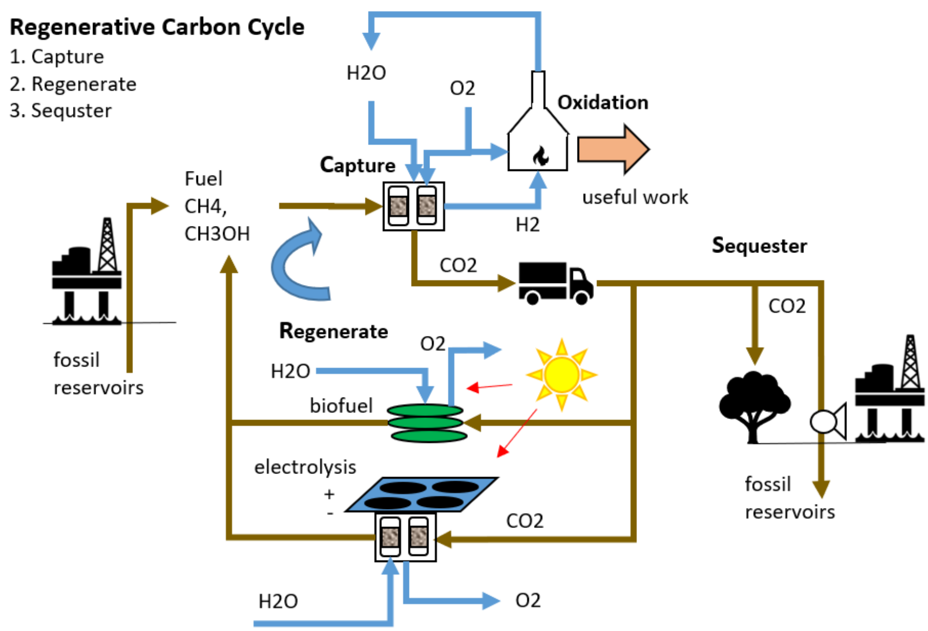


Figure (350 Singapore)

The regenerative carbon process utilizes three new technology additions to the current manufacturing process - catalytic CO_2 capture, scalable sequestration, and solar carbon based fuel regeneration.

The chemical pathways and technological means for each of the steps of capture and regeneration have been demonstrated both at laboratory, pilot and commercial scales (Herzog, 2000) since as early as 1978. For thermodynamics considerations, the additional step of capturing the carbon dioxide comes with an additional expenditure of energy in the range of 10-50% depending on the technology deployed. The capture technology is an area of active research and newer technology including catalytic methods may be able to further drop the cost of capture.

Capture

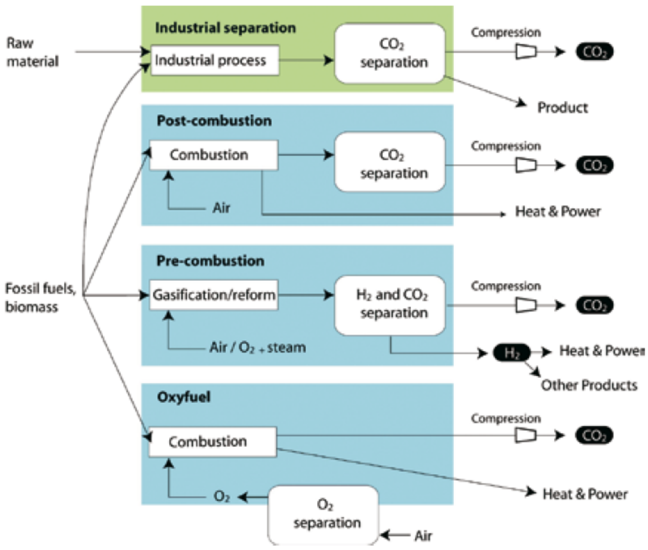
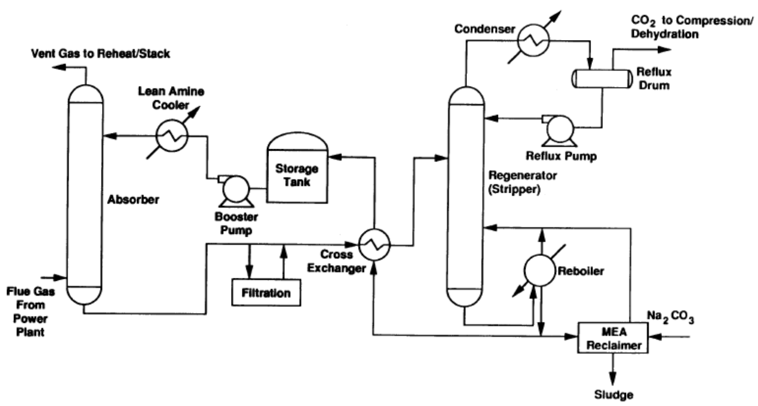


Figure (IPCC, 2010) Illustration of range of capture methods for point-source emissions

Catalytic capture of carbon dioxide by adsorption onto surfaces or by selective solvents has been demonstrated and used at scale for many industrial processes. The only barriers to widespread adoption for control of carbon emissions is the right policy and economic incentives. The additional costs for power generated from facilities with CO_2 capture vs without is estimated at +20% (Herzog, 2000).

The carbon may be captured before or after combustion. In both pre and post combustion capture, the most popular method of CO_2 separation from a gas stream is via amine solvent extraction and regeneration. The process is two steps with an absorbing tower and a regenerator. The energy inputs are mostly thermal from the reboiler in the regenerator, some refrigeration/cooling energy in the condenser and lean amine cooler and circulation pumps. This process is deployed in many natural gas facilities for a similar purpose of removing sulfur oxides SO_x. Another method of CO_2 separation that is more compression (electrical work) intensive is by utilizing membranes. The figure below illustrates a CO_2 separation process.

Figure (Herzog, 2000)



Transportation

Sequestration of compressed carbon dioxide requires a logistics infrastructure to transport from the point source to the final storage location. The overall process efficiency is minimized where the storage is as close as possible to the capture point since transport of gases is more costly than for liquids. The estimated cost for transport is reported as USD7.80/ton based on 500km pipeline (Doctor, 2001)

Sequestration

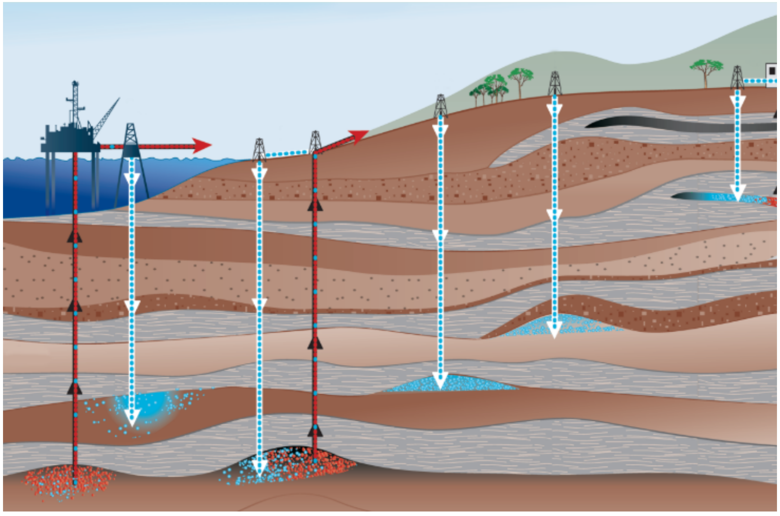


Figure (IPCC special report on carbon capture and sequestration)

The last stage of CCS is sequestration. Some of the challenges are how long the geological structures will hold the CO_2 and how to setup the logistics infrastructure from the point sources to the geological sinks. The process of injecting CO_2 into deep underground structures has been in operation at 0.9 Mt/yr scale since 1991 in Norway at USD 17/ton. At atmospheric temperatures CO_2 is a gas, so it needs to be compressed and chilled for effective transport. CO_2 is distributed and sold to beverage manufacturers so an existing model already exists, and also modern LNG networks can provide another useful model reference. The technology and skills required to implement the solutions has a large overlap with the fossil fuel exploration and production industry.

Five generic strategies are presented in Appendix F, all of which are feasible technology opportunities for Singapore to develop and test close in the region in South China Seas or Indian Ocean for later export and large scale deployment with overseas partnerships.

1. Underground storage - Terrestrial
2. Mineralization
3. Deep ocean
4. Bio-assisted terrestrial
5. Bio-assisted open ocean

Regeneration

In a post fossil fuel economy, hydrocarbons may still be an important part of many processes and thus a need for a carbon regeneration process from CO_2. Two broad methods for regeneration are biological using plants, and synthetic. Hydrocarbon feedstocks may be required where either the high temperatures from combustion is required for example in steel manufacturing or the chemical carbon material base is a necessary part of the manufacturing process, such as in the manufacture of polymers for plastics.

There are a number of proven technologies for regenerating carbon based fuels using solar energy. Algae are a popular biological source for solar regeneration with a final product of dead biomass as a solid/liquid fuel alternative. The biomass can also be further fermented / digested into methane or other simple liquid fuels. The technology of electrolysis has been around since the beginning of the 20th century and an active research area for renewable fuels. An important consideration for regenerative fuel capacity is the availability of space and sunlight.

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Section E: Collective climate action

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Collective action approaches that enable people to come forward with their ideas would focus beyond the institution. It needs to signal space, and then leave the space open for people to engage as equal participants in the policy-making process.

Programmes that combine community-centred, on-ground sensing with innovative work across industries can truly identify lay and expert imaginations, and move society as a whole, towards the optimal capacity for collective action.

With the urgency of impending food crises and a global food shock forecasted to occur by 2023 and 2027 respectively[1] (and the climate crisis already underway), the urgency of experimenting and finding new models of collective action that push past institutional inertia is paramount. We need to get to the goals--whichever they may be--much faster. But we need to get there by empowering every one to believe they can be their best, not through a single hero's voice. Collective action is about moving past the narrative of the single hero/ine. Our ability to expand the range of collaborative formats now--by building up cultural competence and actual exposure and connection across groups--will mean four years of experience and practice by the time the first shock hits (or if it comes earlier).

Singapore's institutional stability has given it the capacity for long-term planning, a quality most nations and states lack. Looking ahead four years, the challenges we face are those of building latent capacities for transformation, towards a model of decentralised and flexible decision-making across time scales, which empowers people to nurture and support the communities they know best. Just as with building soil, nurturing latent capacity means investing in a trust / bank of competencies and resilient networks, necessary for the turbulent future ahead.

For further discussion about ideas presented here please contact 350 Singapore.

We address and seek to provide additional value to the following questions raised in this consultation: ● What other actions can you as an individual or a member of the community undertake to drive climate action? ● What are the challenges individuals face in taking climate action in their daily lives? ● How can we further encourage individuals to reduce, re-use, and recycle? ● What would encourage you to take up active, shared, and public transport for your journeys, especially peak-period journeys?

[1] In 2017, Gro Intelligence (TEDGlobal, 2017) estimated that markets would tip as food demand outstrips production capacity in just a decade, by 2027, and that tip occurs as Africa's population overtakes that of India's and China's by 2023, and India gradually becomes a net importer of calories.

- Are you prepared to bear some additional costs/inconvenience to contribute to a low carbon Singapore? For example, higher utility bills from switching to greener fuels or methods of generation, paying more for waste disposal, paying more for products that have been produced in a carbon neutral way etc.?
- How can we encourage businesses and organisations to take climate action and practice 3Rs within their operations?

Collective action, we propose, is the **connecting point** of all the segments proposed in this Consultation: it is collective action that will enable the big businesses to take steps forward as they see consumer trends shifting, supported by regulatory signaling mechanisms. We also observe that collective action as discussed within this consultation has an overt focus on individual action. This loses much of the spirit of collective action as it has been practised and used in other contexts elsewhere.

Instead, we would like to show how collective action becomes a means to address key, existing gaps that exist within government and across sectors--including the lack of insight into behavioural change, and the inertia of transforming industries, organisations and behaviour.

Governments across the world are facing complexity challenges in sustainability--not fully understanding how citizens / residents change, creating situations where a "rebound effect" arises (e.g. energy efficiency measures leading to lower cost and higher energy consumption, thus negating the environmental benefits of improved efficiency). People make unexpected choices, and truly understanding people's motivations, and what it takes to construct new worldviews, is more important now than ever.

Fundamentally, people want autonomy, to belong, and to feel competent and heard. Collective action that truly empowers individuals to do the best they can, in personal and organisational capacities, can arise with sound green urban planning around the place-based city (Newman, 2011).

We make the following suggestions on how collective action might take place, focusing first on executable opportunities close to hand, and then domain-crossing approaches that will nurture long-term collective action:

<u>Big picture, domain-crossing approaches to collective action</u>

- **Incentivise government agencies to collaborate with community groups** – Collective action should be about creating momentum to **align the interests and directions of multiple groups.** Government officers while earnest may not be fully aware of the ground circumstances especially as our society becomes more complicated and behaviour becomes harder to predict. One way is to provide incentives for officers and departments in statutory boards (AVA, NParks, NEA) to work with groups on the ground to develop solutions and scale them up with supportive policy. The National Volunteer and Philanthropy Centre (NVPC) is a good example as its staff regularly engage interest groups of 2 or more people. This approach would help government agencies to gain a stronger collaboration with a diversity of voices, introduce initiatives with better ground-level support and thus higher organic growth of interest, and be more effective by leveraging external networks and resources.

One example of this model in the education sector would be how Halogen Foundation was founded from the ground up to provide education leadership to youth. Despite not being government linked, Halogen has provided ground up support to youth leadership in Singapore and is now an integral part of the youth engagement landscape of Singapore. Forward thinking and comprehensive governmental support, say in legal, financial and infrastructural domains *at all levels and across industries*, would seed and grow groups that wish to nurture forms of innovation across levels of expertise and sectors.

- **Emphasise facilitated 3P partnerships to tackle specific problems, with a strong focus on identifying convergent narratives with the power to shift collective actions** – A second way of encouraging collective action is to identify a specific challenge or problem statement, the existing approach or narrative taken to resolve it, and then -- workshopping this with a few representatives from the people, private and public sectors -- identifying a few key narratives that would align the different stakeholder groups. For instance, at present, a large amount of inertia exists in moving company and individual interests in waste management. On one hand, a lot of attention is paid to recycling. However, recycling is the final and least recommended of the “4 Rs”. Refusing, reducing and reusing should take precedence. Thus, a problem statement could be on how to educate and nudge the public to act on the 4 Rs. While this challenge is not new, the 3P partnership and providing a sandbox environment to experiment could lead to new and effective solutions. Such a sandbox should begin with an alignment meeting/workshop where the existing set of interrelated, embedded practices are revealed. An example (Table E1) follows:

*This can reasonably take place in a single day, or across two half-day sessions with 2 experienced co-facilitators to 15-25 people.

Situation/ Challenge	● A large amount of inertia exists in moving company and individual interests in waste management. On one hand, a lot of attention is paid to recycling. However, recycling is the final and least recommended of the “4 Rs”. Refusing, reducing and reusing should take precedence.
Problem statement	● How to educate and nudge the public to act on the 4 Rs
Current, predominant narrative / worldview + effect on	● The waste problem is often perceived more as “we are not the best but still doing marginally well”. Thus most Singaporeans do not see the urgency to change their behaviour.

behaviour	● This individual belief applies to individual action, collective impact, as well as individual agency to push collective action.
Facilitating identification of new convergent narratives in a group session	Bringing representatives from the people, private and public sectors to identify: i) current Practices and Motivations, ii) Reinforcing lifestyle patterns, physical or social infrastructure, iii) Obstacles and Barriers to change. Next, to identify iv) a feasible shared goal / end-point, and v) narratives that can shift people's behaviours towards these practices.
Further alignment	Once a set of shared narratives and practices are identified, further alignment will involve diving into the Obstacles and Barriers to change to identify vi) Institutional and Personal barriers, and vii) Shared points of convergence (of goals, practices, physical or institutional resources)
Reconstructing narrative and identifying key institutional partnerships	The final part of this will include reviewing the narrative to refine and adjust it. Working from the new alignments, groups will identify key institutional partnerships and commitments that will facilitate convergence toward the goal.

Table E1. Identifying convergent narratives for transition. *Credit: 350 Singapore.*

- Current approaches have focused on bringing institutional stakeholders to the effort. However, most stakeholders, including NTU, NUS, CDL, have been policy makers, academics, and observers, rather than people with direct hands-on experience. Put another way, while we have a lot of information about waste management from university and public sector research, implementation has been the key barrier that public agencies, start-ups and enterprises have not addressed. Many commercial groups also remain disinterested in the conversation. However, community groups and civil society have been working in the area of environmental communication and practices and have built a strong network of actors informally involved in the area. It is a good opportunity to look at how their efforts can be made more sustainable (sustainability of operation rather than immediate scale in number). More incentives for collaborative efforts with commercial groups can also bridge the community-commercial sectors.

  NCCS could for instance approach collaboration in a similar fashion to the Tripartite Alliance for Fair and Progressive Employment Practices (TAFEP) for issues related to environmental sustainability. By setting up an agency that allows flexible internal and external work arrangements with people, resources, and representation of government, corporates and civil society, this would create an organization that would provide balanced insights, action and messaging. An organization like this could also be a better ground-sensing entity that can provide externally-validated research through the use of citizen science technologies.

- **Tap on individuals and community networks with hands-on experience**–Second, to engage those who already have direct and hands-on experiences. This may mean looking beyond the apparent solutions. Shopping malls and retailers could, for instance, outsource recycling to *karang guni* networks - "adopting" networks in the area, which will maximise efficiency for waste redirection and sorting. The Honk! app under development as a partnership between an SUTD research group and the app development company LDR is a good example of a research design process that includes application, user-centred design and research. Supporting them to work with partnering groups they have already been in discussion with, to extend the app's functions to food waste, and to identify community partners to do this with is a natural progression that expands existing technological resources and builds community capacities. Further, household engagement is incrementally creating a tipping mass of support that accelerates implementation efforts. Most food waste that biodigesters process is dehydrated, but requires an additional step to become useful as fertiliser, and this is where household-level knowledge becomes relevant. In other words, by spotting small gaps in each of the areas of decarbonisation that relate to consumer preference, and exploring how they can be bridged by bottom-up pilot programmes, the community (i.e. individuals, social enterprises, community groups) can be involved in the process of co-creating green initiatives.

Executable opportunities close to hand

- **Support existing efforts at collective action.** We give examples of collective action approaches already in progress on the ground (see ***Examples from the ground*** section below), where NCCS and extra-institutional support would enable scale to collective action in useful ways.

- **Develop a national emissions dashboard** – We agree that there must be a whole-of-society effort to enable Singapore's transition to a sustainable, low-carbon economy and bring our country's emissions in line with the global pathway necessary to remain within 1.5°C of warming by 2100. To measure whether our collective efforts are adequate and complementary, we suggest that the government should set and communicate absolute GHG emission reduction targets from now to 2030 and beyond, consistent with the IPCC's recommendation of emission reduction of 45% below 2010 levels by 2030 and net-zero emissions by 2050. Singapore's actual GHG emissions can be tracked against these targets, so that individuals and businesses know whether our climate action efforts have been effective. Furthermore, we ask that this include maritime and aviation emissions. Such a clear, transparent account of the urgency and need for change across industries will send a strong signal to people in the different roles they carry, of the short-term costs and sacrifices if they know that there is a larger and longer-term objective. This can also set an example for other countries to follow.

- **Prioritise greening of industries** – Because environmental impact is an economic externality that goes beyond the narrow and short-term focus of individuals and businesses, we take the view that the government has to set the national strategy for climate action and institutionalising systemic changes from businesses, institutions and individuals. In particular, collective climate action must go well beyond encouraging members of the public to reduce their own energy consumption, bearing in mind that household emissions account for only 6.4% of total emissions, in contrast with 60% attributable to industry. Thus, the priority should be on greening our industries.
- **Inform commuters on how to travel green** – While reducing air travel, personal car ownership, and implementing carbon tax on consumption are priorities that take precedence, the taxi fleet also needs to be capped (See Section J - Transport). Singapore aims to "increase the modal share of public, active, and shared transport to 9 in 10 of all peak-period journeys by 2040. This includes public transport such as trains and buses; active mobility such as walking, cycling, and use of Personal Mobility Devices; as well as shared transport such as taxis, Private Hire Cars, and car-sharing." This suggests an ongoing trend, where Singapore is increasing its fleet of taxis. However, taxis driving 24/7 - with or without passengers, looking to pick them up - emit a lot more greenhouse gases than a car that is only used twice a day for 30 minutes each.

- A significant amount of industry emissions can be attributed to individual decisions and preferences in their workplace, which are shaped by existing infrastructure. Regulatory change does what individual persuasion alone cannot in shifting companies to the adoption of energy efficient technologies and practices. **With transparent regulatory signals, accompanying encouragement and reminders on an individual level become powerful**: such as the use of AC only when needed, encouraging the use of natural lighting as well as allowing time for staff to use public transportation for work-related travels.

- **Nonetheless, by signalling space, the government can provide avenues or clearer pathways for individuals and communities to take collective action** to push for systemic change from businesses, institutions and policy makers to bring Singapore's emissions in line with the pathway necessary to remain within 1.5°C of warming.

Examples from the ground

Collective action approaches that enable people to come forward with their ideas would focus beyond the institution. It needs to signal space, and then leave the space open for people to engage as equal participants in the policy-making process. Newman (2011) highlights the importance of rich understandings of locality and networks amongst members of the community for green urban policy to flourish.

We see potential for the NCCS to support stronger connections with on-ground field research by local groups, that understand context and have strong community connections - collective action (and ground sensing) that pre-empts and prevents the rebound effect. There are few avenues at present for projects with an applied, social, and community research focus to find support and funding; research funding tends to prioritise the generation of high value innovation products that overlook the complexity and labour of creating seamless, thoughtful and well-facilitated social processes to bring together multiple diverse groups.

We also see the importance of the NCCS supporting flexible arrangements with local groups to encourage and evolve ground-level sensing, as we have earlier suggested.

We give 3 examples of collective action at work:

Example: Farm-to-table, community farming movement to close the food loop
The City-wide Soil Regeneration Project
The soil regeneration project is a pilot project by CRUMB, an upcoming food research network based in Singapore to seed new social-soil communities in urban centres. The project works to develop an evidence base for the benefits of soil restoration in cities - focusing on social and ecological impacts and implications for urban planning and development. It uses a community-led research process that develops research questions and methods with a target community. Prioritising co-learning and synchronised resonance within the community, the target community then works with a network of collaborating scientists, social scientists, artists and makers to collect and analyse a range of qualitative and quantitative material, interpreting its findings, and deciding how to disseminate them. It is currently in its 6-month (June-November 2019) research pilot phase.

Example: Reduction of Plastic Waste
Straw-Free Singapore
At only 17 years old, Hwa Chong Institute-student Ang Zyn Yee initiated the Straw-Free Singapore campaign to rid Singapore of single-use plastic straws through partnerships with companies and small businesses. Through her efforts more than 270 Food & Beverage companies have switched to either not providing or providing only by request single use straws. While some debate the impact of this, the success of this initiative shows that both Singaporeans and Singaporean businesses have responded well to ground-up initiatives for greater sustainability. (https://www.facebook.com/StrawFreeSG/)

Example: Compost, Food and land policy
Foodscape Collective
Urban food growers have shown themselves highly reluctant to waste available food-growing land, and a lifestyle that incorporates food production is highly connected with more conscious use of food. Compost, soil-making, and food growing are practices that develop adaptive capacities for urban food resilience and food waste reduction. The Foodscape Collective has observed this through its work from 2015 and works through education, well-being, research, and community-building to create spaces for people to move towards a

just and inclusive regenerative food system, together. In 2018, concerned about impending land changes and the strong Singapore narrative for high tech farming solutions over more traditional or small-scale farming farming solutions, a letter and concrete suggestions was co-written by a group of individuals with the support of Foodscape Collective, and sent to Minister Masagos Zulkifli and officers in NEA, AVA, and NParks on 28 May 2018. This exchange saw a response and follow-up meetings with officers from the then-AVA and NEA. As of 2019, ongoing work includes: preparations to run a biodiverse edible community garden space in a park with the support and invitation of the National Parks Board as a place-making project, with residents from public housing and migrant dormitories in the neighbourhood. A member of the Collective sits in a Youth Circle led by MEWR and NYC for youth co-deliberation of legislation with policy makers, with food waste and the Good Samaritan Law being key points of interest. Some efforts in community composting are underway through early groundwork with communities with eventual aims to compile a tool-kit for further community dissemination and use.

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Section F: Green growth opportunities

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Summary for policymakers

Policy recommendations

- EDB to commission a report to identify the short and long term economic risk impacts of late vs early adoption of progressive climate mitigation given the global and long term trends presented in this section

- EDB to develop partnerships internationally to identify high potential direct foreign investment channels for green industries and jobs growth, and to identify export markets for new green technology IP

- EDB to research the new jobs creation potential in at a minimum each of the green sectors presented in this section

- MOM to map the skills requirements for each shortlisted industry and create the necessary education programs through partnerships with polytechnics and universities

Economic case for progressive decarbonization policies

New sea routes in the Arctic means Singapore needs to have an alternative source of competitiveness than its role as a geographic trading route hub

It is in Singapore's best interest to transition sooner rather than later to a new economic role as a regional low carbon technology leader that is less dependent on its role as a geographic trading hub for aviation, refining and maritime. Several factors of climate change suggest that the Arctic ring could become a new geographic center of trade. As early as 2030 (American Geophysical Union, 2019) the Arctic could be completely ice free in the summer freeing up direct connections between North America, China, Japan and Europe. The countries with borders to the Arctic are preparing their strategies to ensure they are able to stake as large of a claim as they can (News Corp Australia, 2018). Also, pressure to reduce emissions in transport and China's Belt and Road infrastructure boost favor overland electrified rail routes with a short ocean leg across the Arctic. A route through the Straits of Malacca in the coming years may be limited only to connect Australia and Indonesia and otherwise an unnecessary detour for all other trading routes.

Maturity and normalization of international carbon market

In response to news of ever increasing intensity of climate impact, the global political pressure for carbon emissions reduction can only intensify with time and create the political context environment for mature carbon markets that financially incentivise emissions reductions. Political changes are happening across the globe from pressure driven by a diverse group of student movements, religious institutions, progressive businesses and environmental activists to increase ambition for meeting Paris Agreement targets. Early leaders will have the largest influence of which technologies are promoted, receive privileges and listed as approved for meet new international regulatory requirements. Late adopters may be left with the requirement to purchase and license these IP in order to meet new regulatory compliance. Being an early adopter ahead of the major economies like US means improving the likelihood of being a seller, rather than a buyer of low carbon IP. Development of the IP means first having at scale demonstration using your city as a test bed.

The changes may not happen simultaneously across the globe but rather some countries are likely to be early adopters and others late adopters. The United States and China in particular are key developments that could become large markets for state of the art carbon emissions reduction technology. Global investment in renewables is forecasted to be USD 13.3 trillion over the next 30 years (Ausick, 2019). In the car industry, while 85% of vehicles are currently forecasted to use internal-combustion engines, companies are ramping up electric vehicle models being launched. So, too, ethical investing is gaining popularity.

A cultural shift is occurring in business that is placing more emphasis on the impact of the business and less primacy on maximizing profits. The B Corp certificate promoted by an influential group of US fortune 500 companies, “The BusinessRoundtable” is a new certification programme that recognizes companies that adopt a shareholder philosophy that places the return of capital to shareholders as just one part of a more general responsibility of investing in the lives of the workers, the community and care for the environment (Business Roundtable, 2019). Funds with USD32trn of assets have joined to put pressure on the world’s biggest emitters. Fund managers, facing a collapse in their traditional business, are glad to sell green products which, helpfully, come with higher fees. In the case of Solar, the case for investing has matured to the point that in countries like China, feed-in tariffs are not required to sustain capacity investments from the private sector. Lessons from China could also apply for Singapore in how to use Government stimulus and subsidies to pave the way for private section opportunities to later reap the benefits (Zhai, 2019).

Building manufacturing capacity for renewables infrastructure

The speed and scale of the infrastructure investments will require a ramp up in the manufacturing capacity for the capital equipment in a range of sections - solar PV, electrical grid storage monitoring and distribution, turbines, carbon capture catalysts, nuclear power plant and rail. There is opportunity to shift Singapore’s manufacturing base towards these industries and selectively phase out manufacturing for FMCG and non-essential lifestyle based products. In some cases the decision to promote the growth of a particular industry considers for international competition, however in the environment of a state-sponsored stimulus programme with a strong domestic market, the new nascent industry has a safe space to grow and build capacity with less exposure to international competition. Infrastructure investment coupled with a strong domestic capacity for renewables equipment manufacturing also helps to minimize the country-level expenditures in the stimulus phase to the lower value raw materials and input commodities instead of higher value added capital products and consulting services.

Urbanization trends away from materials and towards people

The global trends of urbanization set the focus for predicting economic development phases. Historical examples of development have evidence of three distinct phases - energy intensive development in basic materials and heavy industry, followed by advanced manufacturing, assembly and then mature phase rise of services.

In parallel to these developments is the context of deleterious urban side effects of poor health habits, and the impersonal social distancing amplified by AI and automation. Recent trends in high-end consumer preferences are reacting by shifting away from material consumption (Marie Kondo) and towards experience, information, personal enrichment and human contact. The combined effect of maturation of cities into late-phase services economy, coupled with consumer preferences away from material based products both predict a shrinking demand for material-intensive manufacturing industry and increasing demand for knowledge and human contact services.

Relying on market alone risks not achieving the speed required to respond to the warming crisis and take advantage of the green growth opportunities - bold governmental action and directed economic stimulus is necessary

Despite growing concerns for action on global warming, energy firms are still increasing fossil fuel production - demand for oil is still rising and the energy industry is planning multi-trillion-dollar investments to satisfy it eg. Exxon plans to pump 25% more oil and gas in 2025 than in 2017 (D'Urbino, The Economist 2019). Governments are responsible for regulating industry and controlling polluters, and there is no difference in the moral responsibility of leadership in managing the public spaces for carbon pollution than there is for control of CFCs, sulfur emissions. The transition into new industries should consider for the workers affected from current manufacturing, luxury goods and services and petrochemical industries. Responsible steps include identification of key target industries, skills mapping for just transition and retraining programmes and safety nets for transitioning workers.

Growth industries

Green growth industries

1. Carbon capture utilization and storage
2. Solar, PV and wind
3. Circular manufacturing
4. Dynamic, intelligent electricity grid
5. Net positive buildings
6. Sustainable, walkable urban design
7. Vertical farming
8. Plant based protein
9. Soil carbon sequestration

10. Next generation nuclear
11. Coastal protection

Carbon capture utilization and storage

Nearly all of the RCP emissions reduction pathways to 1.5C and 2.0C include substantial rates of negative emissions in excess of what can be generated from plants through land use. The estimated cost of direct air capture is estimated at USD100/ton of carbon dioxide and is currently demonstrated in pilot facilities. The open unmet technology areas are catalytic pre-combustion capture of CO_2 and sequestration. Together these two technology areas have established theoretical foundations and the catalytic conversion is demonstrated at pilot scale. Both require investment in technology prove-out to be ready to scale them up to be market-ready.

Solar PV and Wind

Around the world countries have demonstrated a head start in the race for solar PV and wind technology. Given that these two technologies are now cost competitive with coal, it is advantageous to have some intelligence capabilities in these industries even in a fast follower capacity. Opportunities exist to extend the technology with novel extensions and adaptations such as energy scavenging at micro and nano scale and PV integration into composite materials and architecture.

Circular manufacturing

The single-pass manufacturing model will continue to face pressure both political and economic as input commodities become more difficult and unpredictable to source and incentives for waste-takers become more attractive. Shifting to circular present new design challenges to be able to adapt and characterize a wide range of feedstock conditions, separation, sorting into pure components and detect, isolate, inoculate impurities.

Dynamic, intelligent electricity grid

A challenging complexity of working with renewable energy sources is the dynamic nature of the supply with natural cycles of day, night and weather. In contrast chemical energy in petroleum can be stored and readily utilized on-demand to adapt to the dynamics of electricity consumers. Dynamic supply and demand present new challenges - intelligent information signaling to minimize peaks of over and under-supply, distributed vs centralized grid models and energy storage devices. Lithium-ion present material availability challenges at large scale implementations, and motivate the search for alternative energy storage such as hydrodynamic or molten liquid salts.

Net positive buildings

Architecture is a natural fit for a city with many examples of world class buildings showcasing both beauty and sustainable themes. Net positive buildings go beyond Green Marks to be net producers of primary resources of food and energy for the surrounding area by utilizing the resources of sunlight, rainwater and diurnal cycles from the natural environment.

Sustainable, walkable urban design

Urbanization in the developing world - India, Southeast Asia, Africa creates the opportunity to get urban design right from the start. For optimal psychology and health humans need between 30-60 minutes per day of motion, and walkable pedestrian cities have a range of benefits both from a carbon footprint and well being perspective. By applying the latest knowledge about behaviour, people and resource transport networks and metabolisms of cities, the resulting cities have the opportunity to achieve better overall outcomes for well-being and productivity. Institutes such as Singapore ETH-Zurich and Future Cities Laboratory are already getting a head start in this growth industry.

Vertical Farming

Vertical farming is a solution to concentrate agriculture in highly industrialized controlled environments near or inside cities. Shifting agriculture closer to cities in controlled environments has the dual benefit of reducing the stressor of agriculture on land and opening up opportunities for land-based carbon sequestration solutions, and simultaneously relieving the anxiety of food security for cities in a world of uncertain and unreliable climate conditions. Singapore's unique vulnerability as a city state without a secure hinterland inside its territorial boundaries is also an opportunity to pioneer the expertise of applying high tech Agriculture seamlessly into the urban environment. The Netherlands model of greenhouses and supplemental LEDs has proven that technological expertise is a better predictor of agricultural exports vs land area. Climate change reports by the IPCC predict food security pressures will occur in tropical and subtropical regions like Africa, India and Southeast Asia, so Singapore's unique tropical climate abundant with rainfall and sunlight is a unique opportunity to become a leader to meet a critical need for these emerging economies.

Plant based protein

As the awareness of the harmful effects of livestock agriculture on global warming and personal health continues to diffuse into mainstream, the demand for plant based proteins is forecasted to grow. Success stories of rapid growth of meat substitute startups such as Impossible Burger and Beyond Meat are testimony to the market potential in this industry. The diversity of human taste and plant genetics offers a wide range of permutations and variations on this theme. Similar opportunities for food and nutrition technology are cereal alternatives with low glycemic index and sourced from crops with high yield, drought and heat stress tolerance.

Soil carbon sequestration

The two trends of stresses on agricultural yields from soil loss and the demand for carbon sequestration are pressures for increasing biological carbon sequestration on the land. Other need areas are reforestation of deserts and bioremediation solutions to slow the emissions release from thawing permafrost. Technology needs areas are in the development of ecological models as well as treatment and intervention methods. Establishment as a center of excellence in land based solutions creates opportunity for symbiotic trade relations with food exporters where agriculture outputs of food, timber and carbon credits are exchanged with consulting and precision engineering services.

Next Generation Nuclear

While environmentally conscientious and less cost competitive, as pressure increases for rapid reduction of emissions and switch to renewables there are few technology opportunities available to deliver the speed and scale as nuclear. One of the main technology challenges is demonstrating high reliability and low safety risks that is acceptable to the public. Recent advances in third generation nuclear technology may be able to meet the requirements to reduce the perceived risk down to a benign level commensurate to other industries. Singapore's unique land scarce circumstances and track record of sustaining high safety and reliability performance in industry may be an ideal match for pioneering this open opportunity.

Coastal protection

Rising sea levels presents new challenges and new opportunities for coastal cities. The first lines of defense are physical barriers. A number of architecture firms are emerging to provide solutions for cities that balance the needs of aesthetics, performance as a tidal barrier and utility for community, industry and wildlife conservation. A complimentary development theme is adapting city architecture and infrastructure at higher elevations. Unfortunately these incremental adaptation responses can only provide short term relief and may prove ineffective if and when sea level rises breach beyond the design points. To meet the needs for 2100 and beyond, alternative concepts currently in early concept phase are exploring ways of extending the urban landscape onto ocean surface on floating structures that seamlessly integrate with existing land-based cities. The advantage of floating urban spaces are resilience to rising sea levels and opportunity to sustainably harvest sources of energy and nutrients from the sun and water resources.

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Section G: Maritime, Logistics and Aviation

Authors: Shao Hung Goh, Taylor Hickem, Sylvester Siew

Summary for policymakers

Singapore is in a unique position to take the lead in playing a much more proactive role in shaping the direction for emissions by the logistics and transportation sector in the ASEAN region, if not globally. Some examples of action plans that could be incorporated within Singapore's emissions strategy include:

- Developing a stewardship framework (with both voluntary and co-regulatory components) for the shipping and warehousing sectors, under which the industry takes ownership for its own emissions and recommends specific incentives or guidelines for emissions abatements. This could begin with Singapore-based firms, and other regional countries can be invited to take part.
- Taking the lead in funding research and designing incentives to encourage firms towards adopting low-carbon technologies in the logistics and transport sector.
- Developing a set of national/regional standards for emissions from logistics activities such as warehousing and shipping feeder services.
- Working with international and regional organisations such as the IMO, Global Maritime Forum and ASEAN on shaping the long-term direction for any a cap-and-trade regime for the logistics and transport sectors such as the Getting to Zero Coalition initiative (Global Maritime Forum, accessed Sep 2019) which aims to introduce zero emissions vehicles into operation by 2030.
- Adopting a national governance framework for emissions from maritime terminals (encompassing the container, bulk, oil and cruise terminals).
- Inclusion of Maritime and Aviation carbon emissions in national greenhouse gas inventory accounting reporting.
- Shift consumers and businesses travel behaviour to limit air travel only for essential and emergency purposes through a variety of incentives and policy actions such as surcharges on all flights such as proposed in the EU (Sustainable business, accessed Sep 2019) or for multiple trips in a year.
- Voluntary participation in ICAO carbon emissions reporting and reduction scheme CORSIA.

Singapore may have a small domestic market, but could play an out-sized role in the logistics and transport sector beyond its borders, by virtue of its position as a key node in global supply chains. Singapore therefore has an opportunity to demonstrate leadership not just in reducing emissions domestically but also in driving advocacy for low-carbon shipping and warehousing within the Asia-Pacific region.

Background

In 2018, the transport and storage sector generates 6.7% of Singapore’s Gross Domestic Product (GDP) and employs 9% of residents (Department of Statistics Singapore, 2019). It is therefore an important contributor to Singapore’s economy, as well as a large producer of greenhouse gas (GHG) emissions.

Globally, storage, movement and handling activities for freight are also a significant source of carbon emissions. According to a report from the World Economic Forum (2009), the logistics and transport sector accounts for 5.5% of global emissions. Of these, 57% is attributable to road freight, 17% to ocean freight and 13% to “logistics buildings”, with air and rail freight accounting for the rest. From a product perspective, logistics and transport emissions are 5% to 15% of product lifecycle emissions.

Although road freight (i.e. delivery trucks) emits the lion’s share of global emissions from logistics, Singapore has a very small domestic road freight industry. The sector is also relatively more mature in terms of its efforts to tackle the problem, such as the advent of electric/hybrid vehicle technologies and the Euro VI standard for diesel engines. On the other hand, progress on reducing emissions from ocean freight and logistics buildings has been generally lacking, not just in Singapore but also globally. The former is generally outside of the remit of national governments while the latter has often fallen under the radar of policy makers since warehouses are classified generally as industrial buildings.

The issue of ocean freight emissions is especially pressing. A study by the International Maritime Organisation (2014) suggests that under a business-as-usual scenario, emissions from shipping could rise by as much as 250% from 2012 to 2050, in line with growth in international trade. Yet, if global warming is to be kept within 2°C, the shipping industry would need to play its part and cut emissions to no more than 80% of the 1990 baseline by 2050 (Bows-Larkin et al., 2014).

As a standalone market, domestic actions adopted in Singapore may appear to have limited impact on logistics and maritime industry emissions. However, as a regional logistics, shipping and trading hub, Singapore has a vested interest in (and an indirect responsibility for) much of these emissions in the overseas markets that we serve. The main challenge however is the transnational nature of emissions from shipping. Likewise, a significant portion of emissions from warehouses in Singapore is also be due to the regional function that our distribution centres plays in fulfilment demand for products (such as spare parts) around the Asia-Pacific.

Maritime

Despite the stark warnings on the effect of climate change, sustainable initiatives in shipping (and to a lesser extent logistics) have been slow to gain traction. This is complicated by the fact that the pertinent issues in shipping emissions are not limited to GHG, but also pollutants, which tend to receive greater regulatory scrutiny due to their more obvious adverse effects on air quality and human health.

To address the problem of GHG emissions, the IMO has recently set a target to reduce total GHG emissions from international shipping by at least 50% (International Maritime Organization, 2018) in 2050, compared to 2008 levels. The industry has scored some early gains (Bows-Larkin, et al., 2015), primarily from the slow steaming of ships (Lindstad, Asbjørnslett, and Strømman, 2011) and the move towards larger ships that tend to be more fuel efficient on a per unit carried basis. Other initiatives that have had some impact include the adoption of "cold ironing" (Zis et al., 2014), in which ships shift to the use of more efficient shore-based electrical power when they berth at ports, as well as the switch from diesel to electric rubber-tyred cranes (RTG) in container port terminals, There have otherwise not been major technical breakthroughs in reductions of carbon emissions from the shipping industry, notwithstanding the pledge by the IMO and increasing attention from the international community.

Nonetheless, several emerging technologies (Bows-Larkin et al., 2014) have been proposed for shipping, namely: improved vessel hull designs, energy efficient engines, solar sails, wind-assisted propulsion and foldable containers. For maritime terminals, promising emissions-reduction technologies include rail-mounted gantry cranes (RMGs), regenerative systems in RTGs/RMGs and air-slide conveyors for bulk cargo (DHL-SMU Green Transformation Lab, 2015). However, many of these technologies are unproven and/or involve large capital expenditures. For example, while the foldable shipping container appears to have some potential to reduce carbon footprint for the shipping industry, it has faced scepticism in its viability, as shown in Exhibit G.1.

Exhibit G.1: Foldable containers as instruments to reduce shipping's carbon footprint

Foldable containers have been the subject of numerous studies in the past few decades, as a means to reducing the cost and energy in repositioning empty containers globally. It was only in the past few years however, that the first operationally-viable foldable containers started to be commercialised. A recent study (Goh, 2019b) explored the potential of foldable containers as an instrument of carbon offsetting. It quantified their carbon abatement potential at about 0.4 ton per foldable container per year mainly during landside repositioning, but such containers can cost twice as much as a conventional shipping container (or at least USD1,000 per unit more). Hence, foldable containers are currently uneconomical, due to the high cost of the technology and the limitations of current designs. Yet, with the "social costs of carbon" at between USD40 and USD100 per ton (Howard and Sylvan, 2015), the adoption of such a container could bring about a social benefit of as high as USD400 per unit, based on the GHG abated per year over a 10-year equipment lifespan. Shipping carriers and operators could therefore be incentivised to adopt these containers, via outright grants, carbon tax rebates or the sale of carbon credits. The foldable container is but just one example of the maritime industry's continuous search for technologies that can mitigate both the monetary and environmental costs of empty container repositioning.

Logistics

On the warehousing front, the prospect and suite of energy efficient solutions are more promising. They include new refrigeration/heating technologies, lighting technologies and electric material-handling equipment, as shown in Table G.1.

Table G.1: Technologies and Payback Periods for Warehouse Carbon Efficiency (Goh, 2019a)

Technology	**Description**	**Payback**
Use of energy-saving lighting	Implementation of highly efficient energy-saving bulbs (e.g. T5, LED)	1.5–5 years
Installation of motion sensors for lighting	Motion sensors, dimming sensors and timer switch allow on-demand illumination	2–5 years
Application of new heating/ cooling technologies	Install innovative heating and cooling technology (e.g. Solar heat, block heating works)	7–15 years
Modernization of heating controls	Install heating control of boilers	1–2 years
Use of innovative power generation	Own decentralized generation of electrical power, Installation of photovoltaic panels or wind turbines	10–20 years
Introduction of electric powered equipment	Replace fuel-powered warehousing equipment (e.g. fork lift, tow trucks) by electric-driven vehicles	NA

From the policy perspective, challenges persist due to more fragmented nature of the industry. Both the United States and the European Union have developed standards and/or studies to benchmark the emissions of warehouses, but there is no single standard for regulating or measuring emissions from logistics buildings in the Asia Pacific region. Yet, as shown in the following Exhibit 2, the lack of effort by governments is probably the biggest barrier through which real and meaningful abatement in emissions in the logistics sector can be affected.

Exhibit G.2: The carbon footprint of warehouses

Warehouses are large consumers of energy. They are getting larger, are increasingly being run 24 hours a day to meet near real-time fulfilment requirements and have more power needs from greater utilization of information/automation technologies. For example, a single mid-sized refrigerated warehouse of 50,000 square metres can consume about 30million kWh of electric power annually. Based on a grid emission factor of 0.42 kg CO_2/kWh (Energy Market Authority, 2018), such a facility would generate about 12,500 tons of GHG per year, which is equivalent to the emissions from more than 2,500 passenger vehicles. The contract logistics industry In the Asia Pacific is rapidly growing, outpacing the GDP growth rate of the region, due to the rise in consumption and modern retail formats. A study (Goh, 2019a) recently investigated the barriers that inhibit the adoption of low-carbon warehousing in Asia-Pacific and their links to carbon abatement performance based on actual emissions data. Findings show that “government” and “technology” are the most important barriers that logistics companies face in efforts to reduce carbon emissions from warehouses in Asia. In addition, the results suggest that the purchasers of warehousing services are driven by local government regulations and as such abatement in carbon emissions are difficult to be achieved, without government intervention in the form of incentives, emissions standards or regulations. Furthermore, the study found that the prohibitive cost of energy-efficient warehousing technologies also ranks very highly as an obstacle in the Singapore context. The study quoted an example of 15 operating sites located in Asia that upgraded from fluorescent to T5 lighting, resulting in yearly carbon emissions reduction of 2,850kg. There was a large upfront capital expenditure and government incentives played a large part in the case company in obtaining internal approvals for the investment.

Aviation

total passenger volume	65600000	passengers
total tonnage	2150000	tons
tons per passenger	0.065	tons/passenger
resident population	5.6	mil
passenger + tonnage	98676923	passenger eqv
emissions per passenger	335	kg / passenger
total emissions per year	33.0	MT CO2e/yr
emissions per capita	5.90	tons CO2e/capita

Assumptions
1. origin = inbound traffic patterns
2. 1 passenger = 0.065 of tonnage

sources
1 Changi Airport group statistics
2 ICAO emissions calculator

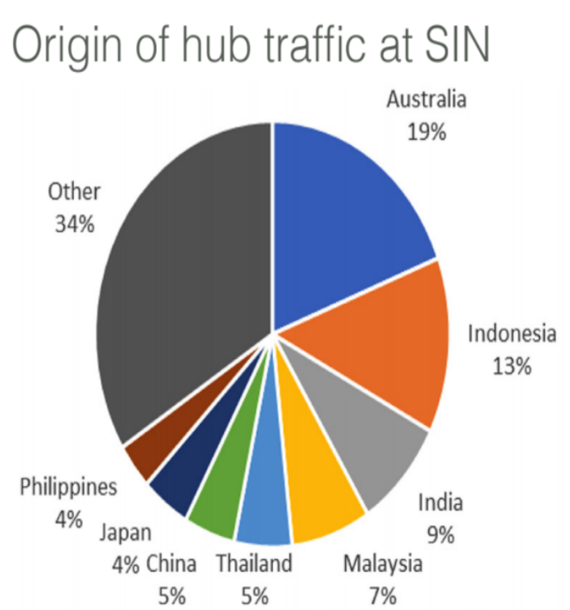


Figure (OAG - Asia's biggest airport hubs)

Up until the 1950's it was unusual and rare for humans to fly like birds in the air. Since that time the global economy has taken for granted this intrinsically high carbon footprint transportation mode. Aviation accounts for 3% of global greenhouse gas emissions and has unique challenges for emissions reduction due to the limited 100% renewable alternatives for engines and forecasted growth. Singapore in particular benefits from air traffic of international holiday and business travelers both inbound for Singapore and connecting flights. Using data from Singapore's Changi airport, traffic patterns published by OAG and ICAO emission calculator, the total passenger and tonnage traffic through Changi represents 33 MT CO_2e/year or 1.8 times Singapore's total greenhouse gas emissions inventory. Given the limits on efficiency and emissions intensity per passenger km, the first measure for control of emissions in aviation is reduction is to avoid flights and reduce km by encouraging individuals and businesses to limit flying only for essential and emergency purposes.

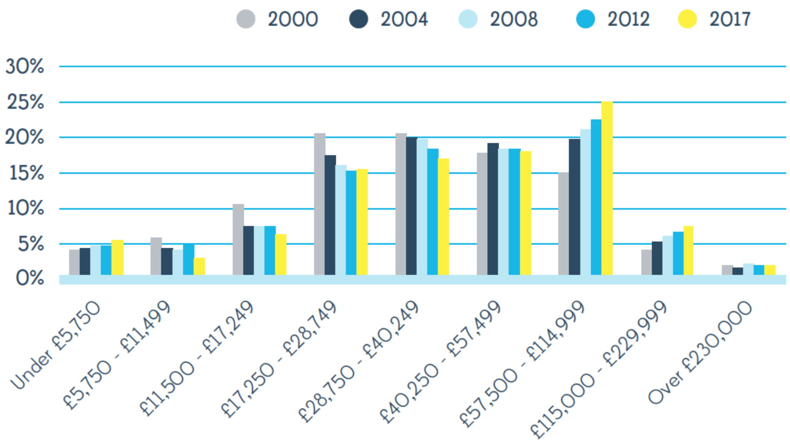
Like Maritime, Aviation is excluded from the Paris Agreement however member states are expected to manage their emissions through other UN frameworks. The UN framework for carbon emissions reduction from aviation is ICAO CORSIA agreement (CORSIA 2019). Under the agreement, states are expected to report their emissions from aviation using a custom calculation that considers for the industry performance as well as individual performance. The goal of the CORSIA agreement is to cap emissions at 2020 levels and to reduce emissions by 50% by 2050. While Singapore is a member of the excluded island states SIDS, the state is encouraged to participate voluntarily in the reduction scheme.

Four focus areas for reduction proposed by the International Air Transport Association (IATA, Accessed 2019)

1. 1.5% per year improvement in energy efficiency
2. Cap total industry emissions starting from 2020

3. 50% reduction in total emissions by 2050

A study of passenger traffic at London Airports revealed not surprisingly that households with higher incomes have a disproportionate representation of total passenger km[2]. The study finds that leisure travel as opposed to business is the majority of total passenger volume and furthermore that passengers with foreign properties traveled on average 2x as much annual mileage as those that did not own a foreign property. If a similar study to be performed at Singapore Changi it may likely reveal similar trends based on evidence from the Singapore Household Expenditures Survey in 2010.



Distribution of total passenger volume with income

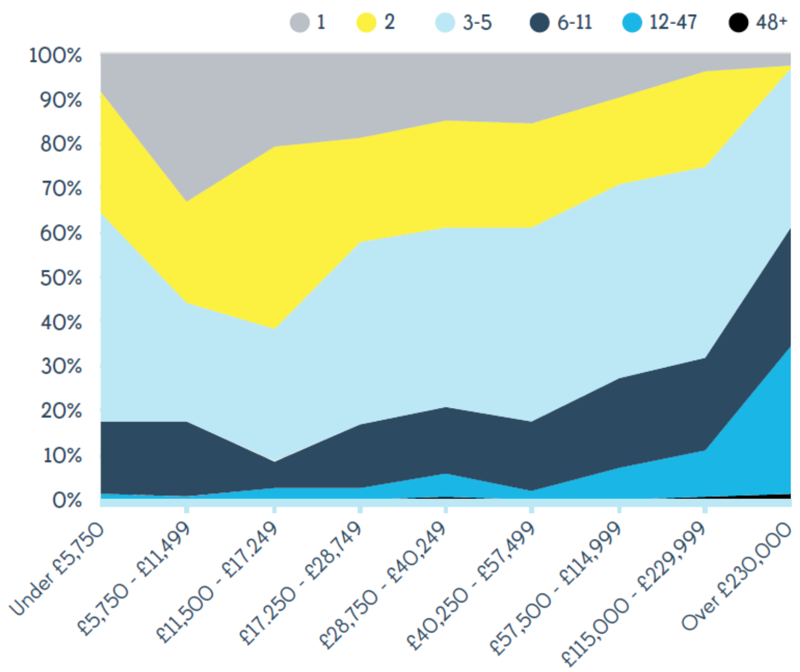


Figure (Green Gumption, Accessed 2019) “Runway for the few” - Distribution of trip frequency vs income - normalized to 100% for each income band

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Section H: Land use and food production

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Maps: Erwan Xiao, Khoo Zi-Yu

Building food security and regional resilience through land use

Singapore is often described as an island with a net food imports of more than 90%, highly food secure through its diversified food imports. Another view of Singapore considers it as part of an "*agri-pelago* of cities linked through food trans-boundaries" (Diehl, Sia, and Chandra 2019). This section looks at the implications of the alternative view, for climate policy and practice relating to adaptation, mitigation, and hybrid response options, particularly in the context of Southeast Asia.

In 2010, in the wake of the 2008 financial crisis, McKinsey released a revised version 2.1 of their Global GHG Abatement Cost Curve (McKinsey 2010). This identified energy, forestry, and agriculture respectively as the top three sectors with GHG abatement potential. Agriculture, in particular, was estimated to cost the least amount per year to transform the industry, making it the most cost-effective transformation sector.

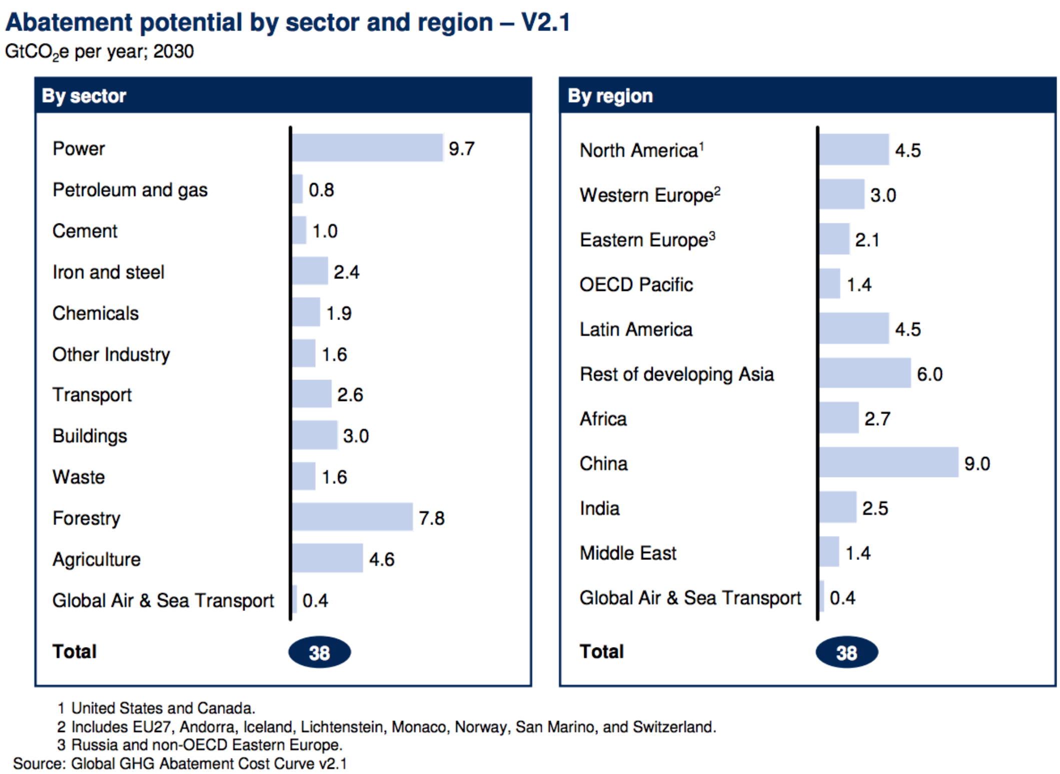


Figure H1. Global GHG Abatement Cost Curve 2.1 (McKinsey 2010)

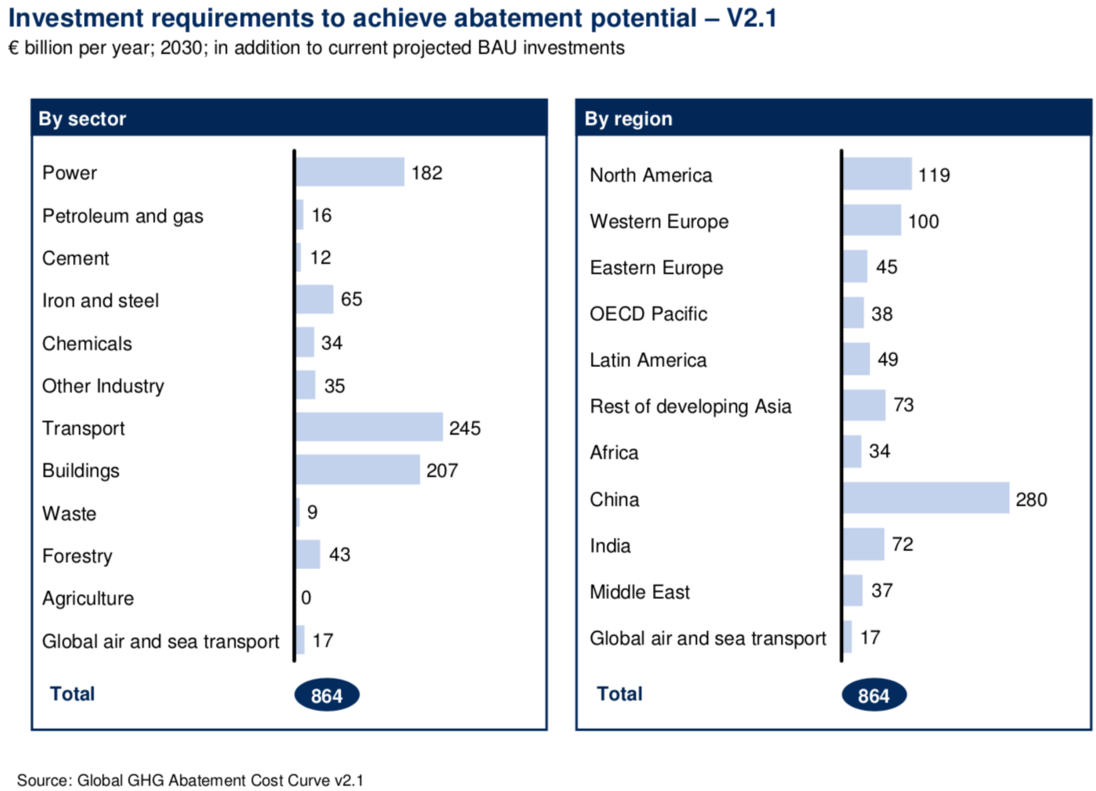


Figure H2. Global GHG Abatement Cost Curve 2.1 (McKinsey 2010)

The IPCC's 2019 Land Use report supports this finding. While land-related response options have certain limits to their contribution to global mitigation, the IPCC report notes specifically that land's relation to socio-cultural and liveability factors in urban planning, means that land use holds multi-value benefits that should be weighed together with their environmental impact (IPCC 2019a, B1-B3). Importantly, it noted that response options can be deployed and scaled up to advance adaptation and mitigation (B6), and policies that reduce food loss and influence dietary choices, *when paired with* more sustainable land-use management, will enhance food security and low emissions trajectories (C6). This aligns significantly with local policy directions in Singapore and is an area of strength that can be further developed.

First, **local food production** has gained ground again in Singapore's planning strategies, with the release of the *Edible Horticulture Masterplan* (National Parks Board 2019), and **is a blue ocean industry--a key sector for green growth opportunities**. Second, as the Zero Waste Masterplan points out, **local agricultural and carbon technology R&D** has much to offer to potential climate mitigation benefits to Singapore, and market value of carbon abatement approaches and technologies internationally and in the Southeast Asian region.

There is much opportunity for local food production, liveability, public and private homes, food waste and collective action to come together around land uses that support climate mitigation and adaptation strategies. We have outlined scenarios for this in Section 1, Table 1.2: *Towards a Singapore Zero-Carbon Stimulus Package*

These suggestions extend big-picture policy suggestions from a letter co-written by a group of individuals, and sent by Foodscape Collective to Minister Masagos Zulkifli and officers in NEA, AVA, and NParks on 28 May 2018.

With energy, agriculture and forestry as potential sectors for large-scale GHG abatement, land use becomes a prime sector to align multiple innovation pathways. Redeploying Singapore's capital investments on its land investments beyond Singapore to invest in long-term sustainable agriculture will support the current re-alignment of domestic policy. While Singapore is a city, the FAO's City-Region Food System policy toolkit provides a clear, constructive, and replicable model of city-region food system planning, with clear indicators and guidelines for policy-making and governance. There are a few strengths with considering the city-region for Singapore's food security, with Singapore as part of Southeast Asia.

- **The city-region food system supports and refines the "30 by 30" food policy plan** by defining the regional foodspace as essential to city-region food systems.
- **The city-region food system model prioritises the long-term sustainability of food systems in the region**. The capacity for neighbouring countries to provide a safety net to their urban, peri-urban and rural populations in times of social, environmental and political crisis has been discussed as being tenuous (Diehl et al 2019).*Thinking beyond Singapore's immediate food needs would mean to direct trade and policy strategies to orient towards averting long-term degradation of land, and working with neighbours to push for long-term regenerative land practices, including accelerated soil restoration practices and technologies to mobilise knowledge and societal resources and regional leadership.*
- **The city-region food system highlights a key edge Singapore has for urban farming**: i) championing, 'pioneering', and developing knowledge for urban food production in the tropics, and ii) expanding the potential market for agri-technologies (already underway in the agricultural roadmap) and carbon technologies, as outlined in our section on CSUS technologies.
- **The city-region food system highlights the importance of a new set of metrics, transparency and traceability measures** to guide Singapore supermarkets and food importers to seek out regional producers with chemical-free, organic, or regenerative farming practices that rebuild soil health. These will ensure a long-term partnership for the consumer market and producers' livelihoods.

Case study: ASEAN Regional Interfaces

At present, Singapore is primarily attempting to mitigate the impact of climate change on food production through advancements in high-tech vertical farming; however these technologies are often associated with high energy input and input costs. Since there is such a strong regional linkage between Singapore's efforts to combat climate change and its food security and land use, it is worth exploring collaboration with climate-vulnerable countries in the region that exports local food production to Singapore.

Malaysia: Opportunities for collaboration with Singapore's closest neighbor

1. Increasing agricultural productivity and crop climate resilience

2. large-scale deployment of climate mitigation technologies such as carbon capture utilization and storage (CCUS).

For example, Malaysia's large rice agriculture industry exports to Singapore, but is also climate vulnerable as an industry in the region. Rice paddy production is vulnerable to extreme weather events, such as drought and flooding. Malaysia's large land area and geological rock formations make it a possible candidate for CCUS. CCUS requires large upfront investments and has relatively high operating costs, however it is already cost-competitive with clean energy solutions such as wind and solar, and its potential in terms of long-term emissions reductions is substantial (Groff 2016). Investments in CCUS by Singapore have the potential to benefit the region as a whole, in exchange for securing Singapore's food supply. It is likely to be a key tool in terms of curbing the regions GHG emissions. Under this sort of regional cooperation, and as a financial and innovative regional leader, Singapore could ensure its food security risk is mitigated with no expense to its limited land supply.

As an additional benefit to regional collaboration on climate change and food security, rice emissions are responsible for approximately 24% of agricultural methane emissions globally, and 89% of these emissions come from Asia (IPCC 2019). As a hub of finance, Singapore could lead the region in terms of research and innovation on water-efficient, drought-resistant rice farming paired with ecological land techniques, which is seen widely as one of the key R&D needs for agricultural innovation with climate change, and mobilizing sustainable finance to deploy new technologies in sustainable agriculture. Current trials are ongoing to reduce methane emissions from enteric fermentation such as bovine diet supplements (Mernit 2018). Such partnerships could not only lead to a reduction in agricultural GHG emissions in the region, but also could help secure rice production in the region as a sustainable food source for export.

Enhancing the long-term value of Singapore's land portfolio

The agri-food system plays a role in meeting and going beyond emissions reduction targets. Expanding and growing the long-term fertility of Singapore's land portfolio also improves nutritional security and adaptive capacities amongst its regional partners. ***Below, we summarise findings from three reports: the IPCC Land Use Report Summary for Policymakers (2019) the EAT-Lancet Report (2019), and the HLPE Report on Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition (2019), prioritising them in order of relevance to Singapore's spatial considerations.***

Big picture policy considerations

Highest priority: make the food value chain (e.g. food waste and diets) an area for technical expansion *and* education about emissions reductions. Food is a persuasive teacher about our interdependence with the environment. While policy focuses on reducing food waste at the earliest point, providing opportunities for adult and school-based learning about food production and distribution helps to ease the transition.

Food production and ecological cycles are complex, and public education will change consumer behaviour and allow new solutions to scale. This has to be considered in light of the social and environmental impacts of the food production systems, and foodspaces, that will sustain these diets. As the Food and Agriculture Organisation's (FAO) High Level Panel of Experts (HLPE) Report (2019) notes, sustainable food production through agroecological and other innovative practices hail new sectors for substantial R&D and industry expansion.

Production (2050)	Waste (2050)	Diet (2050)	Greenhouse-gas emissions (Gt CO_2-eq/yr)	Cropland use (M km²)	Water use (M km³)	Nitrogen application (Tg)	Phosphorus application (Tg)	OPTM biodiversity loss (E/MSY)	MAN biodiversity loss (E/MSY)	OPTN biodiversity loss (E/MSY)	NAT biodiversity loss (E/MSY)
Food production boundary			5·0 (4·7–5·4)	13 (11·0–15·0)	2·5 (1·0–4·0)	90 (65·0–140·0)	8 (6·0–16·0)	10 (1–80)	10 (1–80)	10 (1–80)	10 (1–80)
Baseline in 2010			5·2	12·6	1·8	131·8	17·9	100	100	100	100
			–	–	–	–	–	–	–	–	–
(1)											
BAU	full waste	BAU	9·8	21·1	3·0	199·5	27·5	2	36	153	1067
BAU	full waste	reference	5·0	21·1	3·0	191·4	25·5	2	45	120	1309
BAU	full waste	pescatarian	3·2	20·6	3·0	189·7	25·3	2	46	118	1313
BAU	full waste	vegetarian	3·2	20·8	3·1	186·9	24·7	2	48	122	1374
BAU	full waste	vegan	2·1	20·7	3·3	184·1	24·4	2	50	128	1431
(2)											
BAU	halve waste	BAU	9·2	18·2	2·6	171·0	23·2	1	24	105	716
BAU	halve waste	reference	4·5	18·1	2·6	162·6	21·2	2	32	81	940
BAU	halve waste	pescatarian	2·7	17·6	2·6	160·0	20·8	2	33	78	940
BAU	halve waste	vegetarian	2·7	17·8	2·7	158·5	20·5	2	35	83	1000
BAU	halve waste	vegan	1·7	17·7	2·8	155·0	20·0	2	36	90	1051
(3)											
PROD	full waste	BAU	8·9	14·8	2·2	187·3	25·5	1	7	68	237
PROD	full waste	reference	4·5	14·8	2·2	179·5	24·1	1	14	54	414
PROD	full waste	pescatarian	2·9	14·6	2·2	178·2	24·0	1	15	54	426
PROD	full waste	vegetarian	2·9	14·6	2·2	175·5	23·6	1	15	56	462
PROD	full waste	vegan	2·0	14·4	2·3	172·8	23·4	1	17	59	507
(4)											
PROD	halve waste	BAU	8·3	12·7	1·9	160·1	21·5	0	3	41	103
PROD	halve waste	reference	4·1	12·7	1·9	151·7	20·0	1	9	33	270
PROD	halve waste	pescatarian	2·5	12·4	1·9	149·3	19·8	1	9	34	281
PROD	halve waste	vegetarian	2·5	12·5	1·9	148·0	19·5	1	10	36	317
PROD	halve waste	vegan	1·6	12·3	2·0	144·6	19·2	1	12	40	358
(5)											
PROD+	full waste	BAU	8·7	13·1	2·2	147·6	16·5	1	10	61	292
PROD+	full waste	reference	4·4	12·8	2·1	140·8	15·4	1	14	47	414
PROD+	full waste	pescatarian	2·8	12·4	2·2	139·3	15·3	1	15	46	424
PROD+	full waste	vegetarian	2·8	12·5	2·2	136·6	14·8	1	16	47	455
PROD+	full waste	vegan	1·9	12·3	2·3	133·5	14·4	1	17	49	494
(6)											
PROD+	halve waste	BAU	8·1	11·3	1·9	128·2	14·2	0	7	38	196
PROD+	halve waste	reference	4·0	11·0	1·9	121·3	13·1	0	10	28	290
PROD+	halve waste	pescatarian	2·4	10·6	1·9	118·8	12·9	0	10	27	298
PROD+	halve waste	vegetarian	2·4	10·7	1·9	117·6	12·6	0	11	29	330
PROD+	halve waste	vegan	1·5	10·5	2·0	113·9	12·1	0	12	33	366

Figure H3. Global predicted abilities to meet the food production boundary, given a range of dietary, waste, and emissions scenarios. (EAT-Lancet 2019)

Directing diets to reduce meat consumption and expand vegetarian and vegan options, *when aligned with best practices for land use* (ecological and regenerative land practices), will deliver big impacts in emissions reduction.

In other words, technologies and sectors that increase consumer exposure to sustainable land management practices in different locations, working with the local knowledge of smallholders, will expand the market for consumer support for food traceability and transparency, and help to pair conscious consumption with regional land practices which include a range of practices involving animal husbandry, aquaculture, insects and regenerative plant-soil interactions.

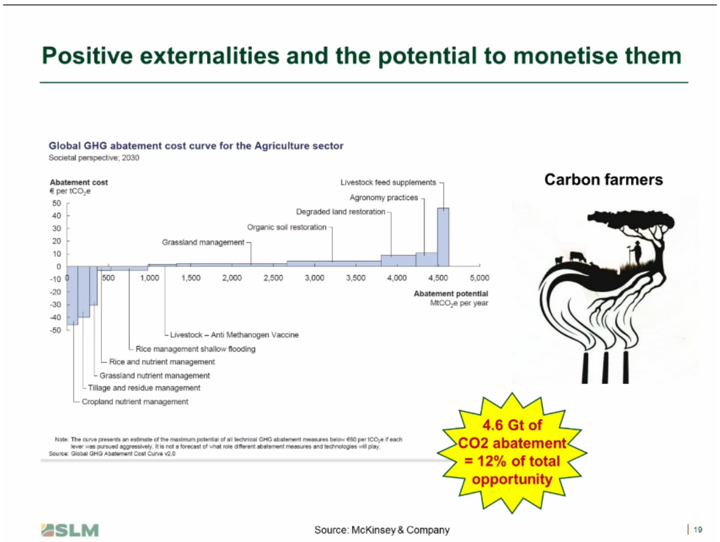


Figure H4. Global GHG Abatement cost curve for the Agriculture sector (McMahon 2016)

Second priority: achieving land degradation neutrality through integration of multiple responses across local, regional and national scales. A number of land management options, such as improved management of cropland and grazing lands, improved and sustainable forest management, and increased soil organic carbon content, do not require land use change and do not create demand for more land conversion (high confidence). Further, a number of response options such as increased food productivity, dietary choices and food losses and waste reduction, can reduce demand for land conversion, thereby potentially freeing land and creating opportunities for enhanced implementation of other response options (high confidence). Response options that reduce competition for land are possible and are applicable at different scales, from farm to regional (high confidence).

A range of flexible farming arrangements within the city provides a way of achieving eco-efficiency, carbon-neutrality and a range of SDGs including access to food growing and environmental education, across demographics and needs--for awareness of our interdependence with the environment for pleasure, food supplementation and food security.

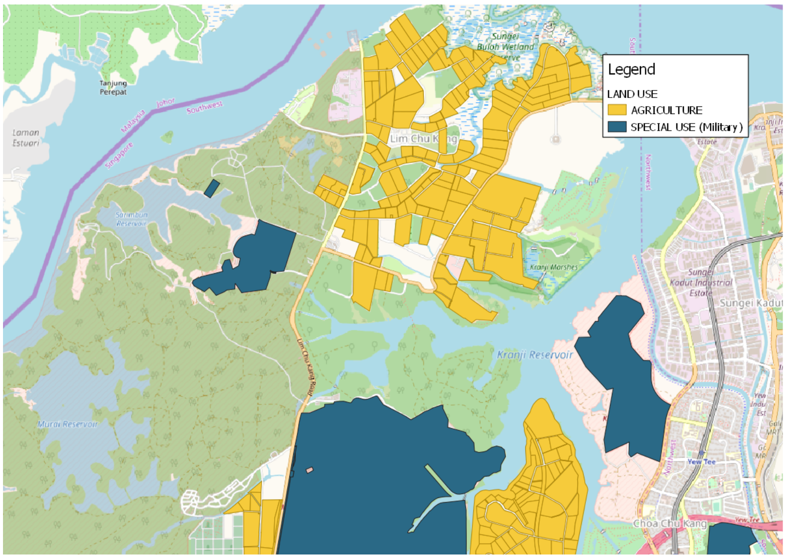
Case study: Coastal mangrove reforestation

For many coastal communities, mangrove forests are intimately linked to food security, even in urban or peri-urban areas (Satyanarayana et al. 2012). Mangroves directly provision a variety of edible marine species and also support offshore fisheries by functioning as key fish nurseries (Rönnbäck 1999). While these features may be less critical in the food supply of modern Singapore, our remaining mangroves are also estimated to sequester over 450,000 tonnes of carbon (Friess et al. 2016). This makes their survival (and recovery) crucially important to Singapore's climate change mitigation strategy.

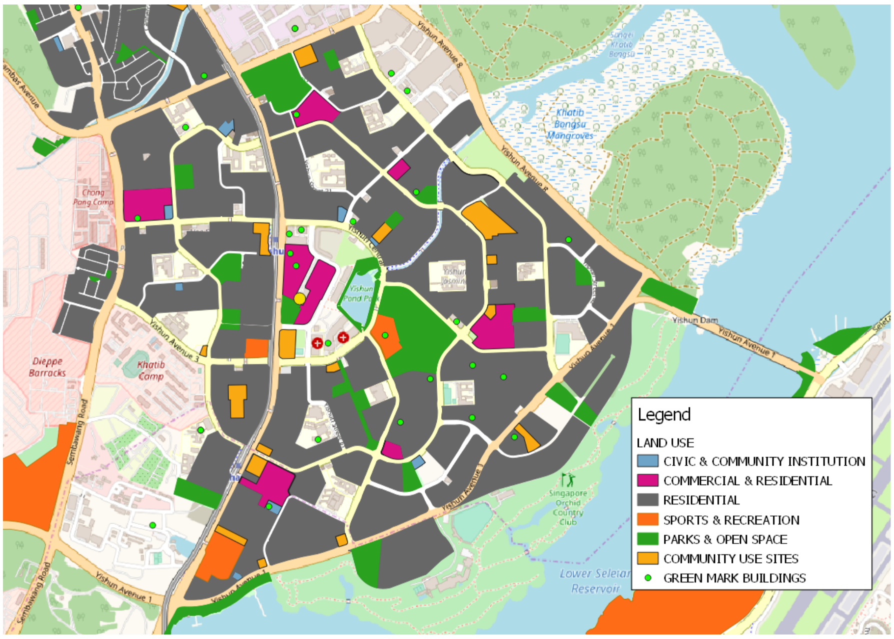
Singapore's mangroves now occupy just 5-10% of their original extent (Lai et al. 2015), but there are plans to restore these coastal forests to degraded areas. The Restore Ubin

Mangroves (RUM) initiative, a volunteer-led partnership between NParks, NUS, and several local non-profits, is an ambitious collaboration to restore mangroves to abandoned aquaculture ponds on Pulau Ubin (RUM 2017). The 8.8 ha restoration site has undergone topographic assessment to determine requirements for mangrove regrowth. Relatively minor coastal reengineering will make elevation corrections, ensuring natural forest reestablishment with no replanting required. Mangrove rehabilitation will bring a suite of ecosystem services ranging from recreation and education to biofiltration and shoreline protection. The program has enthusiastic support in particular from Ubin fishermen, who recognize the impact of mangroves on local fisheries and water quality.

Convivial green space offers substantial design opportunities to interweave food production and consumption space, spaces for connection and meeting diverse others, including the creation of productive urban landscapes with an unbroken chain of open, edible food growing spaces across the city (Parham 2015).

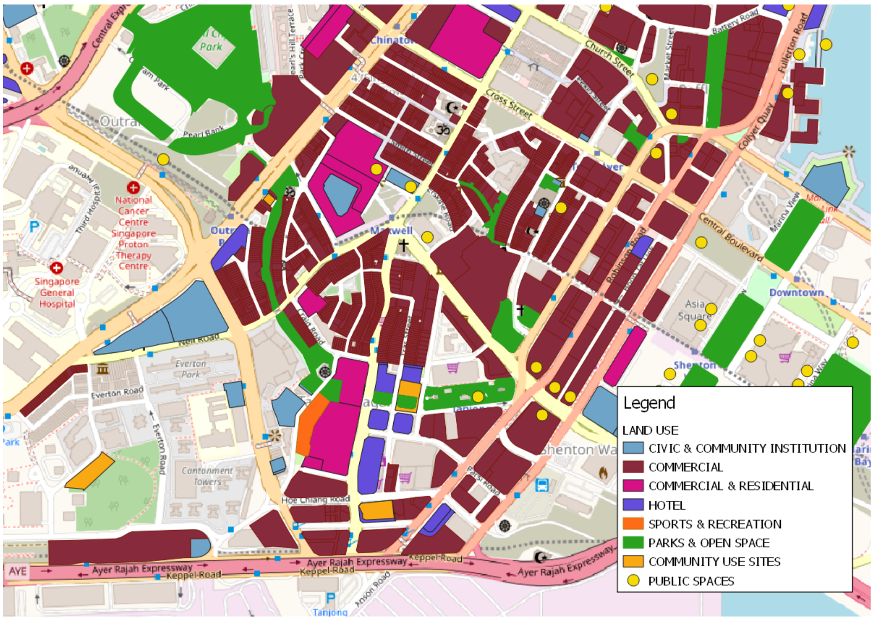


Map H1: Lim Chu Kang area. Suitable sites for agroforestry within existing farm areas can be identified.
Layers: special use including military use, and industry (farmland)
Data Source: URA Masterplan (2019)
They also become a space for national service to teach edible forest product identification, searching and identifying sources for clean water--skills for long-term survival and civilian care.



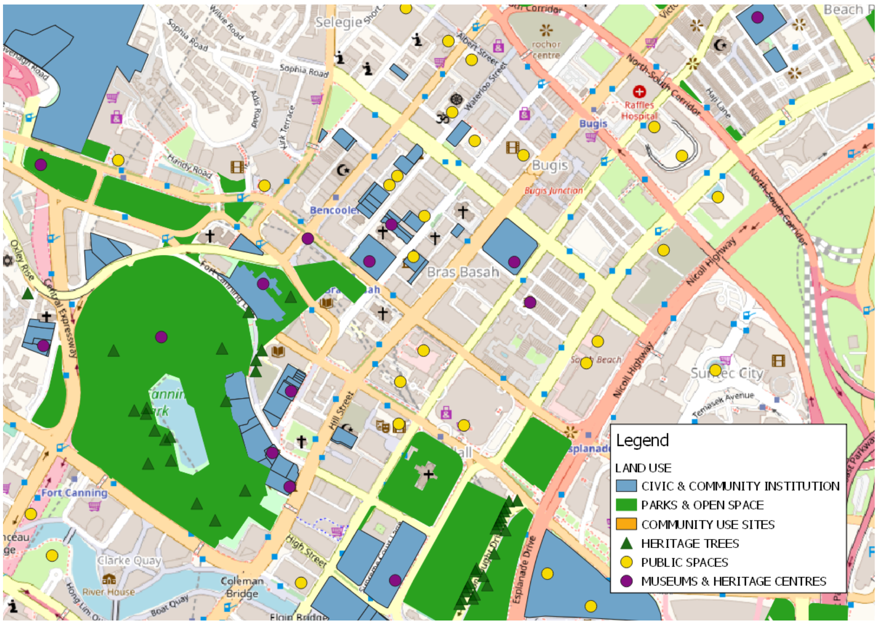
Map H2: Yishun area: areas for intergenerational community farming.
Land uses: residential areas, parks, community use sites, greenmark buildings
Data Source: URA Masterplan (2019)

Heartland areas (including young estates like Punggol) where intergenerational community farming in a closed loop system (as HDB's Tengah Forest Town will illustrate) can take place along sidewalks and in public housing estates



Map H3: Downtown core (Telok Ayer, Duxton, Keong Siak): Workplace vitality
Land uses: office property, parks, community use sites, public spaces

Urban farming in the city, where office-goers, with the new work rhythms of flexible work arrangements and co-working spaces, can tend to an allotment or rooftop space in the city, drop off food waste, collect compost, or access resources for everyday sustainable living



Map H4: Bras Basah Bugis, Jalan Besar area: Living heritage stretch
Land uses: heritage trees, public spaces, parks, community use sites; museums and Heritage Centres

This stretch has a mix of heritage trees, resident and commercial spaces, resident and visitor demographics, and green space where multiple uses of green space can be folded together to increase resident engagement, intercultural exposure.

Third priority: application of biochars: The application of certain biochars can sequester carbon (high confidence), and improve soil conditions in some soil types/climates (medium confidence); in tropical climates biochar application increases yields by 25% while its effectiveness in temperate climates is reduced. A path for this has been laid out in the industry roadmap outlined by the Zero Waste Masterplan.

Fourth priority: encouragement of low-input agroecology in Singapore's land investments in agricultural R&D, food production for domestic imports and technology and urban planning knowledge exports.
While Singapore has small land size, its status as a city laboratory for sustainable urban design makes it a good place to model how agroforestry, which can substantially reduce erosion and nutrient leaching while building soil carbon (high confidence), can be used even within Singapore. Management options that reduce vulnerability to soil erosion and nutrient loss include growing crops that serve as mulch (green manure crops) and cover crops, crop residue retention, reduced/zero tillage, and maintenance of ground cover.

Inter-regional cooperation in environment, technology, urbanisation sectors are also key to safeguarding our future. Sustainable land management, including sustainable forest management, can prevent and reduce land degradation, maintain land productivity, and sometimes reverse the adverse impacts of climate change on land degradation (very high confidence). It can also contribute to mitigation and adaptation (high confidence). Reducing and reversing land degradation, at scales from individual farms to entire watersheds, can provide cost-effective, immediate, and long-term benefits to communities and support several Sustainable Development Goals (SDGs) with co-benefits for adaptation (very high confidence) and mitigation (high confidence). Limits to adaptation can be exceeded in some situations (medium confidence). (IPCC 2019, B5)

Case study: ASEAN Regional Interfaces

The IPCC observes that there is currently an 'outmigration' of those employed in agriculture on the basis of climate change and warming temperatures (IPCC 2019). This is an important consideration for Singapore, considering the level of food imports it receives from the region. A potential climate migration crisis near its borders could only exacerbate the challenges that exist in terms of food security and land use.

Vietnam, Myanmar, the Philippines and Thailand are among the top 10 climate-affected countries over the past 20 years, and Vietnam is among the top 5 most likely to be affected by climate change in the future (Prakash 2018). The Asian Development Bank estimates that the region could lose 11 percent in GDP by the end of the century, with agriculture, tourism and fishing being the sectors with the most to lose. Risks to these industries could see an increase of regional migration as those traditionally employed in agriculture and fishing looking towards employment in urban centres such as Singapore.

Increased climate migration from across the region to Singapore will put pressure on the city-state economically, however there may be environmental and economic opportunities to explore in this space. One of the key areas that the National Climate Change Secretariat has set out in its low carbon emissions strategy consultation paper is the deployment of low carbon technologies. While Singapore already leads the region in terms of technological innovation, in order to effectively deploy low carbon technology on a large-scale, specialized employment will be required. In fact, the ILO predicts that globally, a lack of skills relevant to a low carbon economy may 'bottleneck the greening of economies' (ILO 2011). The ILO argues that skill shortages are already hampering the transition to greener economies. There is an opportunity to invest in upskilling migrants, in particular climate migrants, in the skills necessary to deploy renewable power, energy efficiency and sustainable infrastructure, and Singapore is well placed to lead the low carbon skills transition.

As part of its green growth and innovation focuses, Singapore should consider creating a training hub that focuses on the skills needed for the deployment of the innovation and technology it is exploring today – before new innovations come 'online'. For example, throughout the 1980s and 1990s, Navarre, Spain introduced an industrial policy aimed at retraining workers to staff a quickly expanding renewable energy industry. Working with local trade associations, the regional government identified the primary skills shortages, and on this basis set up a public training centre specifically focused on skills development in renewable energy deployment. As a result, Navarre now derives two-thirds of its electricity production renewably, and has seen unemployment rates drop (Poschen and Torres, n. d.) Implementing a programme like this now would not only does this shoulder Singapore from the economic burden of an emerging low carbon skills gap, but it would also mitigate the economic burden of a potential climate migrant crisis where migrants do not possess skills that are applicable within the Singaporean economy.

Our concrete suggestions based on our experience with community groups and independent work include:

Using urban farming to bring together societal connection/cohesion between diverse demographic groups in convivial green space, and to build adaptive capacities for food security.

We suggest the following policy improvement areas for urban farming:

1. A single, streamlined set of procedures, or a single legal license, for grassroots farmers to sell their produce. Such a license would set standards for food production, and allow people to earn from it so that the local food economy can grow.

   Current barriers to selling include: SFA requires certain food quality standards. With URA, the sale of vegetables on rooftops is a grey area because rooftops are not agriculture zoning. NParks encourages individuals to grow food, but not on a large scale, otherwise there are legal implications. There needs to be a consolidated effort to gather all agencies and consider shaping a policy package/standard that will apply to urban farming companies and communities.

2. For local food branding / certification to support a range of grades of "ugly" local produce

3. Working through the success of the popular NParks allotment programme to increase the physical accessibility of land and space allotments for entrepreneurs and small-holders who may desire to use SLA community use sites for community farming leases.

4. Incentivise agricultural businesses and newly leased farm tenants to meet two objectives for the food and farming sector: enable a people-centred approach to a just and inclusive circular food system in Singapore, and to contribute new value to the food system through regenerative and resource-smart means. Alternative KPIs can support this: such as nutrition per land unit (sqm2), the use of indigenous crops, and initiatives to work with independent groups or other farms to circulate reusable materials.

The following may come under inter-agency regulatory sandboxes, similar to the NEA Regulatory Sandbox outlined in the NEA's Zero Waste Masterplan (2019):

1. Enabling a rainwater collection licensing scheme--we see this occurring at a pilot level at HDB's Tengah Forest Town project. Other proposed projects in schools also offer good case studies for future green infrastructure development.
2. More flexible zoning classifications (industrial, agriculture, residential) that welcome agriculture in a wide range of technology and methods
3. Encouraging horticultural landscaping companies that service schools and residences to work with select biodiverse edible gardens, to coordinate enabling efforts, including: 1) halting mosquito fogging in a small buffer area around the site to

allow biodiversity on-site to develop, ii) and to set aside dead leaves for these gardens for on-site educational composting.

On a big-picture scale, expand national security beyond military service to include more-than-military security: environmental education, skills for agroforestry, regional peatland reforestation, and knowledge exchange networks, and to open this to recruits of all genders.

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Section I: Emissions reduction for manufacturing

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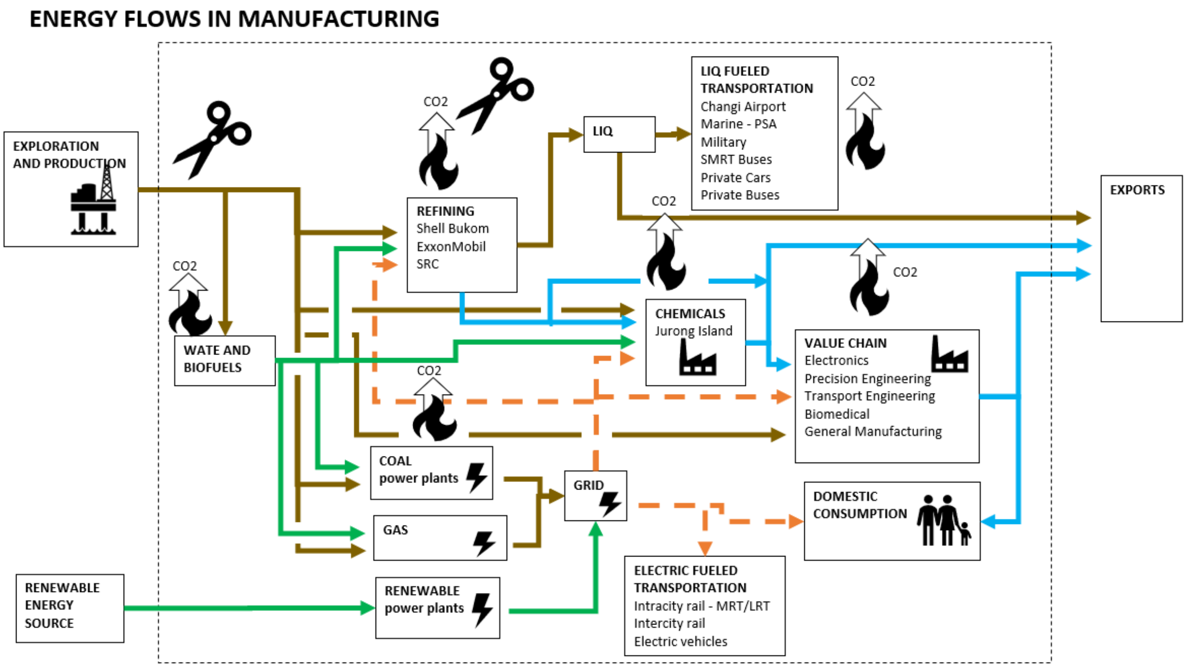

Summary for policymakers

Policy recommendations

- Systematic identification and classification of manufacturing processes ranked by emissions intensity to the individual business and sub-process level
- Empower the Ministries to translate the NDC commitments into emissions reduction targets for individual sectors and business entities
- Set legal barriers for entry of new carbon pollutive business entities and processes
- Create legal responsibility for the highest carbon polluters to producer to develop decarbonization plans
- Setup transition fund to provide financial support for industries that chose to voluntarily decommission and transition out of certain sectors via M&A, spin-off, write-off via a state facilitated buy-out program
- Promote transition to alternative low carbon intensity methods of production such as hydrogen, electrical/mechanical, biochemical, general energy efficiency improvement via a range of incentives and regulations
- Set up industry education programs for decarbonization led by local universities

Manufacturing contributes the largest source of Scope 1 direct emissions in Singapore. The top contributors to Singapore's emissions are the power plants (40.5%) and chemical process and manufacturing (44.0%) with a smaller contribution from domestic transportation (14.3%) and commercial/institutional and residential (1.2%). Reduction of carbon emissions can be achieved through four system level changes

This submission addresses the following specific focus areas that provide alternative low-carbon intensity methods of production for the manufacturing sector.

1. Switch to hydrogen fuel as a combustion source
2. Switching from thermal to electrical energy operating modes in manufacturing
3. Switch from abiotic to biological
4. Waste heat integration
5. Energy efficiency upgrades

1. Hydrogen as combustion fuel

Figure: Stock image of industrial burner

Hydrogen is a colorless, odorless gas and is the lightest element in the periodic table. The gas can be burned using the same burner equipment as natural gas, and produces negligible pollutants - only water vapor. Hydrogen can be produced from hydrocarbons either biological or fossil fuels via several chemical routes. Hydrogen is also a strong reducing agent, and can be used in steel-making and a number of basic chemical synthesis pathways including ammonia and methanol. The gas can also be produced from electricity via electrolysis, and newer generation nuclear plants can also produce hydrogen (MIT, 2018). An example of a carbon free hydrogen production method using a modified steam methane reforming process is presented in Appendix E.

In the short term the most practical production of hydrogen would be existing infrastructure from natural gas, however long term renewable based hydrogen is an area for research. Land intensive renewables sources such as solar, wind are not available in Singapore in sufficient quantities, which leaves Nuclear as the only option for local hydrogen production. If due to public perception concerns or other risks concentrations of placing the nuclear facility close to a populated area, the nuclear plant may be developed in a remote area such as the deserts of Australia and imported to Singapore. In such a scenario, Singapore may diversify its energy sources by cooperation with multiple participating countries. Transport of hydrogen has technical limits due to hydrogen embrittlement, and that it is a gas in most temperature and pressure conditions. Conversion of the hydrogen into other forms such as methanol may be a more practical alternative for the case of imported energy.

2. Electrical vs thermal conversion process

Thermal processes rely on combustion and for the moment fossil fuels are the only scalable and affordable sources for combustion. Since most of the pathways of energy conversion from renewable sources are direct into electricity, one way of decarbonizing chemical process is by switching from using thermal work, to compressive work via electricity.

The basic principles of thermodynamics set the parameters of what is possible for industry decarbonization. Electrical energy is more readily converted into work, but in nature there are no direct forms of electrical energy so it must first be generated by conversion with a conversion loss penalty. Thermal energy is abundant and available in many forms, but the laws of thermodynamics set limits on how thermal energy can be applied usefully to perform work. Specifically in chemical process manufacturing, the thermal energy demand for some processes can be reduced by operation at higher pressures and visa versa. Higher pressures are achieved with the expenditure of electrical energy through mechanical compression work. This is an example where lowered thermal energy demand is achieved from raising the electrical energy demand. A few select examples from industry.

Membrane separation

Traditional separation in chemical process industry is to apply thermal energy in distillation, stripping, absorber towers. These separation techniques are ubiquitous in integrated petrochemical complexes partially due to the availability of a low value refinery gas (REFGAS) that is generated and recycled as a waste byproduct from many of the conversion steps. The separation driving force is the relative vapor-phase fugacity and tendency to vaporize between the different components in the mixture. Alternatives exist for separation that utilize mechanically applied pressure gradients instead of vapor pressure differences, and rely on selective diffusivities, which are often related to but not the same as relative fugacities (Perry's 2018). Here, the mechanical compression work can be supplied by electricity.

Process specific trade-offs

Example: Coil outlet pressure for steam cracker ethylene (plastic pre-cursor) production

In the steam cracker, due to Le Chatelier's principle, the thermal energy required to produce a given amount of ethylene in the furnace is minimized with lower coil outlet pressure.Thus, higher mechanical work at the downstream compressor reduces the amount of thermal energy required.

Desiccant-evaporative cooling (DEP)

The main utility advantage of carbon fuels is easy creation of thermal energy at very high temperatures > 1000 C through combustion. The waste heat generated at that temperature is useful for co-generation of power. Such an optimisation might be lost when transiting away from the use of fossil fuel. However, the lower waste heat temperatures of < 100 C can still be used in DEP.

DEP processes take advantage of the trade-off of thermal and compressive energy transformations by utilizing large, free waste heat sources at >80 C to drive off (de-sorb) adsorbed water from the desiccant, thereby regenerating the desiccant and making it available for dehumidification of a moist air stream. The hot, dry air after heat removal can then be humidified to create evaporative cooling as replacement for compressor based refrigeration. This technique is effective when the cooling temperatures are moderate > 20 C and there is an abundant source of waste heat > 80 C.

The technology has been available for decades for solid desiccant with a COP (coefficient of performance = heat duty / work input) of 0.7 to 1.0 (Barlow, 1982). Even though this might compare poorly to typical refrigerant based cooling system's COP of up to 3.5, more recent advances in liquid desiccant processes claim to achieve improved COP of > 3.0 and are able to utilize waste heat sources as low as 50C.

3. Biological vs abiotic processing

Nearly all industrial synthesis pathways have a biological equivalent and for those products that existed prior to 20th century were exclusively sourced from biological origins. Petroleum is fossilized form of decayed organic matter, and has the same elemental composition as its source biological origin. The energy storage properties of long chain saturated fats that are used by plants and animals are the same chemical properties that are useful in combustion engines. Similarly the chemically reactive unsaturated bonds are exploited both in industrial processes and in biological pathways. Both industrial catalysts and biological enzymes utilize heavy metals active sites to reduce the activation energy for a particular chemical reaction.

Using biological processes results in a reduction in carbon emission as those processes are often carbon neutral. The growing of the biological feedstock (algae for example) sequester carbon as it takes in carbon dioxide to increase its biomass (largely photosynthesis). This carbon is then emitted when oxidised or combusted.

However, it should be noted that the performance characteristics of industrial vs biological processes are different. Selectivity, kinetic speed of reaction and thermal efficiency in some cases the biological process outperforms and in other cases under-performs.

Biofuels

Land based agriculture biofuels such as corn ethanol have been reported as not an attractive alternative to fossil fuels from a carbon emissions perspective due to the release of CO_2 from deforestation and fossil fuel energy inputs in the pre-harvest production. Aquatic based biofuels however from kelp or algae may have the potential to be more attractive in overall net emissions reduction per BTU of chemical energy. The oceans are also larger surface areas with less competition for alternative uses. Of Singapore's 1,400 km^2 nearly 50% is ocean.

Conversion process at lower temperatures

One common limitations of biological processes is their inflexibility in utilizing higher rates of reaction from Arrhenius law by increasing temperatures because most proteins start to denature at moderate temperatures > 50 C. In general, biological processes are slower than the industrial high temperature counterpart but often out-perform in selectivity and overall thermal efficiency. Operation at lower temperature however has the additional advantage of reducing dependency on thermal based energy inputs and opens opportunity for utilizing low temperature waste-heat streams for other industrial processes.

4. Heat and material integration

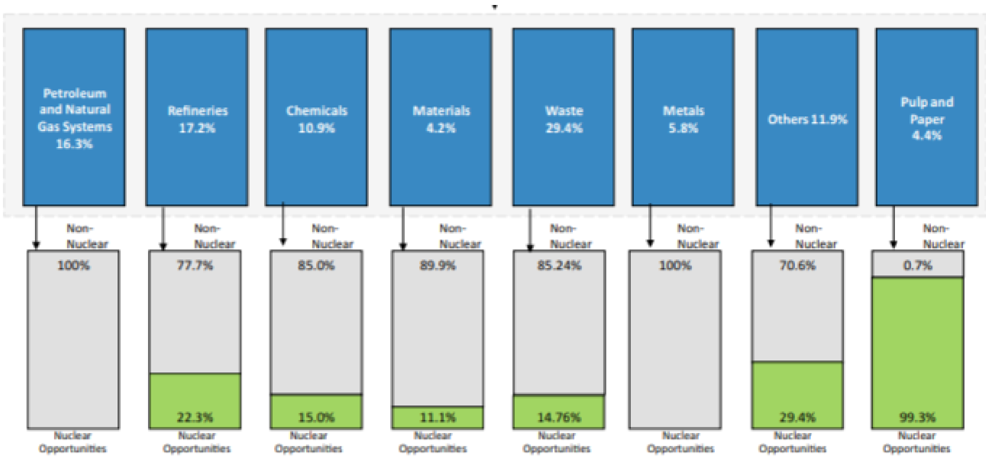

Figure: Share opportunities for waste heat integration by industry from nuclear power plant. The green area represents low temperature heat sink opportunity, and by corollary the grey represents a potential heat sources.

Due to the nature of the thermal and energy intensity of manufacturing, there is often a large volume of waste heat generated at medium 80-150 C and high temperatures > 150 C. Two ways of integration is material integration (circular economy), and heat integration. Heat integration use the surface area of heat exchangers to move energy from a waste stream to cool or heat a process stream that otherwise would have used fossil fuel energy input for the same purpose. The energy inputs to maintaining Heat Exchangers in operation is minimal limited to control valves and instruments.

Within industry integration

The Jurong Island complex similar to other complexes around the world shares many material and energy stream connections between operators. The island has pipeline networks of electricity, steam, natural gas and hydrogen, and some operators have special case pipeline links for chemical intermediates such as offgas, naphtha and syngas. Without interconnecting networks, operators would otherwise have to import petroleum origin feedstocks and export or burn waste byproducts, further increasing carbon emissions.

Circular economy - organic waste

In addition to biological processes, biological feedstocks can also be considered as an alternative to fossil fuels. Carbon waste streams have both energy value and unique organic compounds which can either be purified or processed into high value products. Caloric value for food waste and municipal sewage are around 4-6 kcal/g and used cooking oil 9 kcal/g. Not all of the energy value can be recovered as fuel. State of the art anaerobic process can achieve up to 40% recovery of the energy as biogas fuel. If the fuel is then converted into electricity via turbines with 28% conversion efficiency it is possible to produce 279 MW for a city the size of Singapore based on 1.5 kg/person/day of municipal waste solids (MSW). Singapore has several WTE (waste-to-energy) incineration plants that achieve close to full utilization of this potential.

Circular economy - material waste

For many materials, the overall life cycle unit energy input is lower for recycling than for virgin material. Less virgin material is also a way of conserving the environment from damaging extraction process. A term for this new phase of manufacturing is the “circular economy”. Large scale centralized waste reprocessing is a key part of a circular manufacturing model. Plastics, heavy metals, glass from urban waste streams all have recycling and reprocessing potential, and the economic opportunities improve when the long-term cost of carbon emissions is incorporated. The state of the industry is at early stages and processing models in operation are specific to the materials and at small pilot experimental scales. Reprocessing may require higher precision workforce and more advanced technological sophistication of instruments and machinery, but has the attractive benefits of better long term economic sustainability and resilience to instability in global commodities markets.

Mixed development clusters - industrial, commercial, residential and agriculture

Further opportunities for efficiency gains from interconnections within the manufacturing complex are limited because for many of the operators there are few ways of economically utilizing warm streams < 100 C. By contrast, there are numerous opportunities to utilize these low temperature streams in commercial, residential and agriculture. One of the largest energy demands in residential and commercial in a tropical city like Singapore is cooling and heat for cooking. By utilizing desiccant cooling together with district cooling to gain economies of scale it is possible to simultaneously reduce the energy demand for cooling of industrial waste heat and also reduce the demand for grid electricity for building cooling systems. At the same time, such clusters would have multiple overlapping heating (heated showers, industrial use of hot water) and cooling (coolers, or cooling of heated processes) requirements. Here the use of a heat pump can easily produce a hot water and cool water stream concurrently from the industrial process (similar to how the outside of an air conditioning vent is hot). Here, both requirements can be met in a cost and energy efficient way.

Moving towards mixed use clusters has the added benefits of shortening transit commute distances and promoting walkable city design. To realize this potential, manufacturers must meet high emissions and noise standards, which is a realistic goal for Singapore which has already demonstrated high compliance in the industrial zones where conditions at the fence are very close to conditions in the city. Such mixed use urban designs can also incorporate green buffer corridor zones or green facades of manufacturing complexes to improve aesthetics.

5. Energy Efficiency

At the initial startup of a new process, energy efficiency often takes second priority to meeting purity and capacity targets. Even after startup during periods of low energy prices, efficiency projects often get pushed out and shelved indefinitely. Every manufacturer is aware of their energy efficiency improvement opportunities and often organizational knowledge and psychology are the main barriers to achieving best in class operational efficiencies.

Precision control and intelligence

A wide trend across industries is the trade-off between reliability and safety risks and energy and material efficiency. For every safe operating limit window there is a safety margin buffer to account for uncertainty, which includes both knowledge gap and stochastic sources of uncertainty -- both of which can be improved with AI and automation. The benefits of implementing intelligence into manufacturing is the ability to run closer to the true operating limits constraints, and hence higher operational efficiencies.

Reliability

Reliability incidents result in downtime losses and major energy efficiency penalties during start-up. An indirect benefit of improved track record of good reliability performance that is related to precision intelligence is that it builds confidence to operate closer to true constraints boundary.

Material efficiency

For a constant ratio of energy inputs for a single pass of a process, any improvement in material yield of product/inputs will also result in an increase in energy efficiency of energy inputs/product output. There are some processes where energy efficiency and conversion trade-off but generally material efficiency have a direct positive impact on energy efficiency.

Overdesign - conservative forecasting and modular capacity expansion model

With few exceptions, overdesign for new plants it usually associated with lower operating efficiencies. Usually efficiency reaches an optimum near the design point, with dropping efficiency at lower load and also dropping efficiency at pushing capacity constraints beyond the design point. Operation at under-design is not only a problem for energy and material efficiency, but for prolonged periods can be a real threat to the financial viability of the business. Overdesign is often a strategic “eyes-wide-open” business decision and is the result of combination of large project scales and uncertain forecasts. Adopting smaller modularized designs can help to create a scalable capacity expansion that retains efficiency across a wide range of capacity scales. Additionally, more conservative forecasting models that penalize over-optimism can help to safeguard against overdesign risk.

Best practices and benchmarking audits

Operating units quickly habituate to local norms and experience ranges, and it takes an extra effort to compile the data into meaningful metrics that can be compared to a representative peer group. Benchmarking audits help to anchor performance to an absolute reference to sustain the local drive and motivation for improvement. Benchmarking alone may not be enough, and is best when the solutions for achieving the benchmark - best practices are available and translatable to the local operation.

Combined heat and power

For facilities that have combustion driven mechanical energy, the waste heat from this process can be utilized for heat integration. By utilizing the heat energy in another process the energy efficiency of the overall system is maximized.

Fouling management

Every manufacturing process has some form of performance fouling that affects material and/or energy efficiency. Heat Exchangers, Catalytic Converters and Mechanical Lubrication systems are typical examples. Fouling monitoring and prediction programmes help to ensure these systems are always operating at an optimal operating conditions and thus, optimal overall energy efficiency.

Furnace excess O_2

Every furnace operator knows the importance of stack excess O_2 for overall plant energy efficiency. Best practices recommend 10-20% excess air for optimal thermal efficiency of 85-95%. Push-pull forced draft and air pre-heaters can also help to boost furnace energy efficiency. Many plants operate continuously with over-conservatism in excess air >>20% due to concern of the risk of firebox explosions. This comes with an energy penalty. . Contributing factors to these risk perceptions are out-of-date air register controls and instrumentation, poor burner management, out-of-date burner technology and inadequate operator training. These can all undermine the operator confidence that is necessary for sustained operation in the optimal excess air range.

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Section J: Transport

Author: Bertrand Seah

Recommendation 1: Enhance existing plans for a “car-lite” society to a “post-car” society

Recommendation 2: Redirect infrastructure development from roads and highways to further enhancing the MRT rail network

Recommendation 3: Expand pathways and infrastructure for walking, cycling, and PMDs

Under Singapore’s latest BUR, transport takes up a combined 16% of primary and secondary emissions from Singapore’s 2014 greenhouse gas emissions profile. Compared to other urbanised cities, Singapore’s approach to transport deserves credit for its general effectiveness at alleviating the traditional issues with personal motorised transport. By severely restricting the supply of cars through the VQS/COE policy, Singapore suffers far less from the dual issues of pollution and traffic congestion that have plagued many cities. It is also commendable that the government has announced that its fleet of public transport vehicles will progressively be shifted towards electric vehicles, a change that will bring further benefits the more quickly the electricity grid can be shifted towards renewable sources.

However, there is still scope for further reducing this 16% of emissions from the transport sector, while also helping to create a more equitable society. A main pillar of transport policy is the move towards a “car-lite” society. This move away from cars is commendable given the numerous studies that show the many disadvantages of cars compared to alternative forms of transport (Achakulwisut et al, 2019; Shaw et al, 2015). A further stretch goal for this car-lite ambition would be a post-car future, which should aim to make the public transport network a faster and more efficient form of transport than the personal automobile. This brings the potential for significant reductions in emissions.

The existing LTA Master Plan for 2040 is aiming for a 20 minute town, 45 minute city vision. This planned around the Walk-Cycle-Ride modes of transport, indicating strong existing efforts at working towards such a vision of interconnected, efficient and accessible public transport that is free of dependence on the personal motorcar. Given that the first two are generally used for shorter distances, the accomplishment of this vision will depend to a significant extent on the Ride component, defined in the plan as public transport such as buses and trains and point-to-point transport defined as taxis, private hire cars and shared cars. How much this vision can lead to a reduction in emissions will likely come down to how transport infrastructure be developed to favour cleaner types of public transport. As already stated, the public transport network should aim to make trains a faster, more efficient and desirable means of commuting than cars – be it personal cars, private hire cars, and taxis – in the majority of travelling contexts.

This can be illustrated by an approximate ranking of the estimated emissions per person that might come from each type of transport, which should follow roughly, in descending order: personal cars => private hire cars/taxis => buses => MRT trains => PMDs => walking

To put simply, the aim of the transport plan should be to shift commuting practices to the right of this axis as much as possible, but centred around the MRT network as the predominant mode of transport across the city. This is important because the propagation of ostensibly greener forms of transport might ultimately lead to even more energy consumption.

As an example of this, the rise in private hire ride-sharing firms such as Grab and Go-Jek are often seen as cleaner forms of transport, primarily because their fleet of vehicles contain a much higher proportion of hybrid or electric vehicles than the car population. As such, they would lead to lower petrol consumption if motorists decide to use such services rather than buying and driving their own personal automobiles. Conversely, if public transport modes cannot be competitive enough, based on cost and travel time, with private hire options and taxies, enough people might move away from travelling by bus or train that emissions will be increased.

This trend could be seen at a wider societal level around 2016-2017. In spite of the trend of decreases in car population (approximately 2% from 2013-2017) and decreases in the average mileage per motorist (16,700km, a fall of 21% from 2006), petrol consumption still rose approximately 3% to a record 6,453,600 barrels of petrol in 2017 (Tan, 2017). Notably, this was the period in which there was intense competition between Uber and Grab, leading to a proliferation of discounts which dramatically lowered prices for commuters. What seems to have happened here is thus a typical example of the phenomenon known as the Jevons paradox, where increased efficiencies or lower prices drive increased consumption, negative efficiency increases and surpassing the original consumption levels (McDonald, 2011). Singapore is not alone in experiencing this; while the initial presumed effect of shared transportation (Uber/Grab) was a reduction in the car population, the Uber and Grab phenomenon has been shown to have demonstrably increased car populations as well as predictions of new vehicle purchases (Hughes 2017). This has induced regulator action, such as the New York City mayor's recent restriction of Uber and Lyft fleets to reduce cruising, reduce peak hour traffic and maintain a reasonable worker pay (Reichert 2019).

To be clear, this is not to say that lowering the costs for transport is necessarily a bad thing, but that ramifications on emissions should always be taken into consideration. Promoting ride hailing services is desirable if it replaces more polluting private car ownership, but not if it shifts commuter choice away from cleaner forms of public transport. In view of this, the development of MRT rail networks should be strongly prioritised over the building of more roads and highways in Singapore's urban planning. In addition to making public transport more viable relative to personalised and individualised forms of commuting, there are other reasons why this would be desirable. Firstly, expanding road networks brings questionable benefits, as studies have shown that increasing the road space typically leads to more car traffic to fill that increased space – another example of the Jevons paradox (Schneider, 2018). Secondly, because the car population, by virtue of the high price of COEs, is made up of a relatively higher income demographic, using government funds to expand the road network would be a more regressive measure. Using government funds to expand the MRT rail network, on the other hand, would lead to benefits that can be enjoyed by a much larger cross-section of the Singapore population. Lastly, it would be a much more efficient use of land in terms of the number of commuters it can ferry within a given space.

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Section K: Financial risk and financial transformation

Author: Bertrand Seah

Recommendation 1: That the sovereign wealth funds take the lead in financing low carbon investment and infrastructure development

Recommendation 2: Set standards for risk analysis that factors in long-term climate risks, and ensure that all institutional investors follow these standards

Recommendation 3: Revise monetary policy to dis-incentivise brown investments and incentivise green investments through adjustments in capital requirements

Recommendation 4: Divest all public institutions from fossil fuel-related assets

Recommendation 5: Create a Green Investment Bank of Singapore to provide low-interest loans for green projects

Singapore is widely acknowledged as a financial hub within the region. Given this privileged status, there needs to be a greater scrutiny on the ways in which financial markets help or inhibit decarbonisation, the risks that climate change brings to financial markets, and how the financial industry can be reformed to be a driver of decarbonisation.

The importance of financial markets in view of the climate crisis cannot be understated. Numerous studies have pointed out how financial markets today fail to adequately account for climate risks. Frequently cited is that the analysis horizons of market actors are far too short to take note of longer term climate. Mark Carney, Governor of the Bank of England and Chair of the Financial Stability Board, suggests that this brings forth a “Tragedy of the Horizon”, whereby “the horizon for monetary policy extends out to two to three years. For financial stability it is typically a bit longer, but typically only to the outer boundaries of the credit cycle - about a decade. In other words, once climate change becomes a defining issue for financial stability, it may already be too late." (“Tragedy of the Horizon”, 2019)

The risks of climate-induced financial shocks include market risks, insurance risks, and liability risks. Market risks involve mainly the possibility that fossil fuel assets become stranded (Tooze, 2019). A key reason for this is that market valuations of fossil fuel companies are based on their proven fossil fuel reserves, which presumes that those reserves will be tapped on and extracted in the future. At the same time, it is projected that approximately 80% of this fossil fuel stock must be kept in the ground in order to keep to the targets of the Paris Agreement (“Unburnable Carbon”, 2014).Put simply, fossil fuel companies are aiming to extract fossil fuels at a level about five times the permissible amount to avert climate catastrophe, meaning that these fossil fuel assets are likely to be overvalued. As a study by the 2°C Investing Initiative has found, compared with a pathway that would limit warming to a 2°C level, global market capitalisation under-weights renewable power generation by 19-36%, electric car production by 66-96%, and over-weights coal-fired power generation by 7-16%, oil and gas production by 12-14%, and coal production by 0-31% (Monnin, 2018).

This means there is a substantial risk that these assets will ultimately become stranded, subjected to premature write-downs, or subjected to massive climate-induced shocks. It could certainly be the case that what we are seeing is a carbon bubble that could lead to a financial collapse in the future.

Today, it is estimated that approximately one-third of equity and fixed-income assets globally belong to sectors related to natural resources, extraction, carbon-intensive power utilities, chemicals, construction, and industrial goods, meaning that the risks of stranded assets amount to USD1-4 trillion, rising to USD20 trillion in the broader industrial sector. By comparison, this far dwarfs the financial crisis of 2008, where the subprime mortgage crisis worth about USD1 trillion ran into losses worth several hundred billion dollars.

Furthermore, if climate catastrophe is to lead to widespread damage in society, it might well overwhelm the ability of the insurance industry to act as a shock absorber for society, both in terms of physical damages as well as losses to assets. For example, average annual losses from wildfires have drastically risen in recent years, from below USD5 billion since the turn of the millennium to over USD20 billion in 2017 and 2018, which might lead to insurance premiums rising beyond what many people can afford (Neslen, 2019). As a result, executives from insurance giants such as AXA and IAG have suggested that a four degree world almost certainly be uninsurable (Holder, 2017).

Finally, fossil fuel assets run liability risks. These are the risks that enormous costs are imposed on fossil fuel companies who are judged to be legally responsible for climate damages and losses, and are forced to financially compensate other parties. While most of these lawsuits have originated in the US, lawsuits aimed at reducing greenhouse gas emissions have arisen in an increasing number of jurisdictions, including Australia, the EU, the United Kingdom, New Zealand, Canada, Spain, Pakistan, India, Indonesia, South Africa, Colombia and Brazil (Urevig, 2019). Even though these are not directly happening in Singapore, it is still important to note that many of the fossil fuel corporations that Singapore is heavily invested in are common targets of such climate-related lawsuits.

Given that the climate catastrophe is already likely to lead to widespread dislocations and social ruptures, the possibility that collapses in the financial or insurance industries might happen simultaneously is unconscionable and must be averted. In view of this, economists at the Bank of England have suggested two possible scenarios: either 1) the existing status quo in financial systems is preserved, fossil fuel industries continue to receive widespread subsidies from state actors around the globe, and investment in renewable alternatives remains insufficient to displace fossil fuels, leading not just to widespread environmental collapse, but enormous shocks to the financial system, or 2) governments commit to full-scale decarbonisation, and produce comprehensive plans that allow financial markets to clearly identify fossil fuel losses and efficiently phase them out with minimised shocks to the system.

The choices facing policymakers here are stark. As François Villeroy de Galhau, governor of the Banque de France, puts it: “it is delusional to think that when risks become perceptible, everyone will be able to cut their exposures at the same time and in an orderly fashion.” (“Green Finance – A New Frontier for the 21st Century”, 2018)

This would require substantive reform to the financial industry, and a redefining of fiduciary duties that incorporates longer term accounting of climate risks and commits financial actors to environmental objectives.

One measure currently in place to promote green finance has been green bonds, which are earmarked for projects that have positive environmental benefits. These green bonds thus help to channel financial capital towards projects and innovation that achieve green objectives. Because sustainability-minded investors will have a higher demand for green bonds, the cost of capital for green projects will be lowered, driving further adoption and innovation.

However, in the absence of a more rigorous supporting policy environment, its positive effects are still limited. This is because of a lack of enforceable standards on what constitutes green projects – most issuers use ICMA Green Bond Principles, which define broad eligible categories but not in any strict technical detail. As a result, certain questionable projects have been financed by green bonds. Chinese banks, for example, have included “clean coal” projects under their green bond use of proceeds (Brightwell, 2016). More pertinently, there are little concrete financial incentives for these green bonds relative to conventional bonds, and no means of dis-incentivising dirtier assets, which means that in many cases green bonds do not directly replace investments in fossil fuel assets.

Indeed, global renewable energy investment has been on the decline in recent years (Zhai and Lee, 2019), while investments into oil and gas rebounded in 2018, rising for the first time since 2015 (Hill, 2018). As the International Energy Agency notes, “there are few signs of the substantial reallocation of capital towards energy efficiency and cleaner supply sources that is needed to bring investments in line with the Paris Agreement and other sustainable development goals.” More broadly, the IMF estimates that global fossil fuel subsidies totals USD5.2 trillion, or approximately USD10 million a minute (Carrington, 2015). The proliferation of such subsidies constitute major barriers to the development and adoption of renewable energy technologies.

As a result, many of such green projects, particularly those pertaining to new technologies, do not have favourable risk/return profiles, which means that the development of such technologies should not be left to financial markets alone.

Singapore, as an important financial hub for the region, has the means for using this power to take the lead in transitioning to a low carbon future. This can be done through Singapore’s sovereign wealth funds, and through the role of central banks and monetary policy.

While the ostensive aim is to ensure that healthy returns on investments can be generated, they have also been involved in building up infrastructure in developing areas around the region. The flipside of this is that the accounts of various institutional actors reveal exposure to many dirty and carbon-intensive assets. Most notably, the major banks have been involved in major coal financing projects around the region, which has received major scrutiny from civil society groups (Daubach, 2018). As Market Forces has revealed, this includes 13 deals for coal-fired power stations worth USD1,409 million, five coal port deals worth USD630 million, and four focused on coal mining worth USD372 million (“Singapore Banks – Market Forces”, 2018). While public pressure has forced these banks to announce a stop to financing new coal plants, this has not been extended to projects it is already financing, including the Vung Ang 2 and Van Phong 1 power stations in Vietnam, and Java 9 and 10 in Indonesia. This is extremely problematic given that coal is by far the dirtiest fossil fuel in terms of emissions, and Southeast Asia is still increasing its coal demand at a time when the rest of the world has already made moves to curb, if not eliminate the use of coal to serve energy demands (Taylor, 2019). Similarly, public universities here have come under increasing pressure to divest their endowment funds from fossil fuel assets (Zhuo, 2019). While public pressure has played a key role in pressuring banks to move away from coal financing, the most effective way of bringing about change should definitely start from state policy, which can then shape the investment decisions of banks and other institutional actors.

Financial reform that places decarbonisation on its agenda should start from the sovereign wealth funds. An article by Robinson and Fabian in the Straits Times suggests four steps in which this can be done: 1) the funds themselves become world leaders in financing low-carbon infrastructure, capturing the incentives that governments are directing towards a green economy, 2) the aforementioned longer term risk assessments are incorporated into investment decisions, 3) the funds use their institutional might to lobby the boards of companies to identify, report and manage the transition to a low-carbon economy, and 4) the funds collaborate closely with policymakers to factor in the real costs of carbon-intensive assets, and drive the change locally and regionally towards low-carbon infrastructure (Robinson and Fabian, 2015).

MAS can also play a crucial role by making reforms to its monetary policy. This is important as financial markets play a key role in influencing investment costs and serve as a reference point for investment decisions. This can be done through the development of appropriate environmental risk measures, and the integration of such measures into asset purchase strategies and collateral frameworks. One promising proposal would be too increase capital requirements for capital-intensive lending (Van Lerven and Ryan-Collins, 2018). For such loans that are heavily reliant on fossil fuels, or carry a higher carbon risk, an increased capital requirement would help to reflect the actual, growing systemic risk that comes with investing in carbon intensive activities. This would bring two main benefits: carbon-intensive investments would be dis-incentivised relative to low-carbon investments, and the increased capital requirements would add a greater buffer to increase resilience against the losses that are expected from a carbon bubble.

On top of that, a possible measure would be the creation an entirely new development bank that is explicitly focused on providing low interest loans for green projects. A Green Investment Bank of Singapore would have the institutional mandate to take the lead in financing green innovation in Singapore and around the region. A recent report by the WWF suggests that banks around the Southeast Asia are still lagging behind in addressing the risks posed by climate change, with only 9% having no-deforestation policies, while 91% continue to finance coal plants (Daubach, 2019). The report indicates that Singaporean banks are by no means the worst in the region, but as a financial hub, Singapore could certainly be playing a more proactive role in filling the massive need for sustainable infrastructural development in the region. Another report jointly conducted by the United Nation Environment Programme and DSB estimates that the amount of additional investment needed in Southeast Asia until 2030 totalling USD3 trillion, including USD1.8 trillion in infrastructure, and USD400 billion each in energy efficiency, renewable energy and food, agricultural and land use ("Green Finance Opportunities in ASEAN", 2017).

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APPENDIXES

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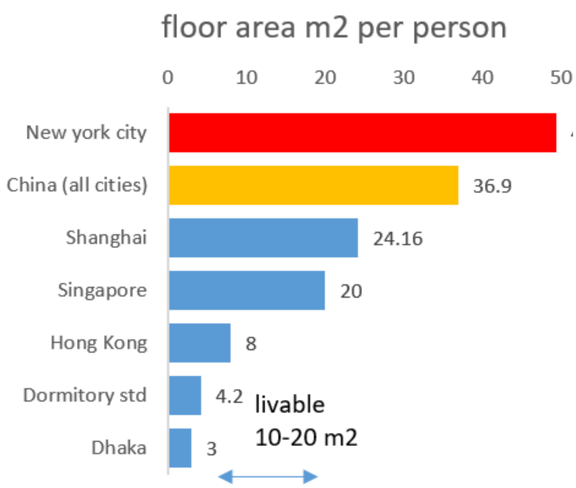
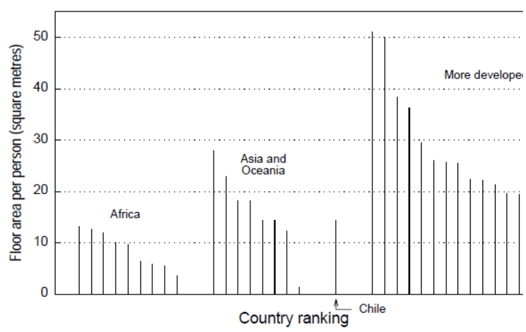
Appendix A: Residential floor area per person

The energy usage intensity of buildings is based on the floor area, and floor area varies widely as a preference across cultures and income groups, therefore the floor area should be included in the consideration for energy reduction opportunities. The essential floor area unit for urban planning traces to the residential unit. A standard Double to Queen bed in Asia ranges from 2.8 to 3 m^2 (Simmons.com, 2019) and minimum standard for dormitories is 4.2 m^2 per person (UK DOH, 2012) to accommodate access walkways 30-90 cm and space for storage and working. Typical toilet sizes are in similar range as bed sizes 2-3 m^2.

Kitchens by comparison can vary over a much wider range, from, on the low end as small as toilets, 2.5 m^2, up to 20 m^2. The practice of individual kitchen spaces, while common in many cities, is not a strict requirement as evident in the use of shared dining facilities in space-constrained submarine and dormitory designs. Common dining facilities design recommend 1 m^2 per person (Central Restaurant Products) for comfortable spacing and a 40/60 ratio of kitchen to dining area layouts. At a turnover rate of 4 = 3 hr serving period and 45 minutes per table this corresponds to a total kitchen footprint of 0.4 m^2 per person. High-space-efficient military dining designs can achieve a dining footprint as low as 0.1 m^2 per person (Zanteson, 2011).

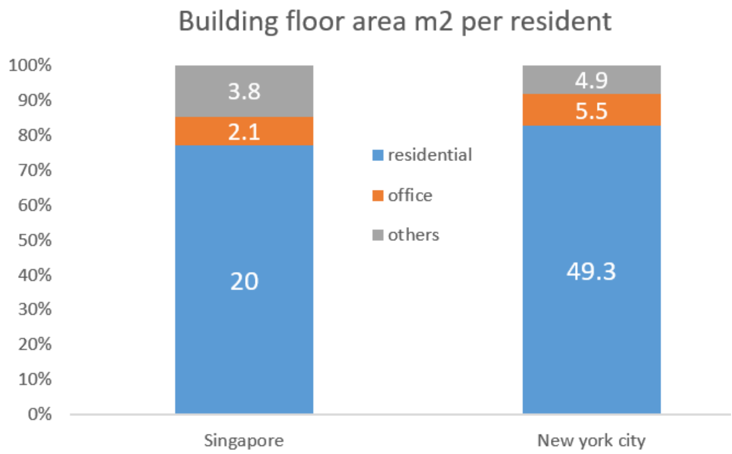
By applying these minimum requirements for bed, toilet and kitchen, a standard livable area requirement, with extra allowance for comfort, is estimated in the range of 8-20 m^2 per person. Worldwide this represents the typical range for highly dense urban centers such as Hong Kong, Dhaka and Chinese cities. The Singapore average is moderate in the middle of these cities at 20 m^2, where newer HDB flats have a smaller floor area per person than the older ones.





Source (UNCHS, 1997)

The ratios of floor area for non-residential spaces in Singapore are close to other similar cities, for example New York City. A typical value is > 80% of building floor area as residential.



Appendix B: Cooling requirements and thermal comfort standards from ASHRAE

Thermal comfort is a psychological experience and varies from person to person. However, it does fall within a predictable range and can be explained by physical process and heat transfer. The standard comfort range is 23 - 29 °C and varies with air speed and relative humidity. Typical air speed is around 0.3 m/s. Two different theories are used to design cooling systems - predicted mean vote (PMV) and adaptive. PMV is based on a survey of respondents who vote comfort or discomfort, and adaptive is based on a moving scale range which assumes that the person adapts their subjective comfort level to the outdoor climate. For tropical climates, a comfortable range can be achieved at 25 - 29 °C and relative humidity below 70%.

metabolic rate 1.0 = 105 W for standard person. (26, 13, 7) W/m^2 based on office spacing of (4, 8, 16) m^2/person which represent the range from most dense to least dense office designs (ASHRAE, 2019).

Appendix C: Next Generation Nuclear Gen III / IV

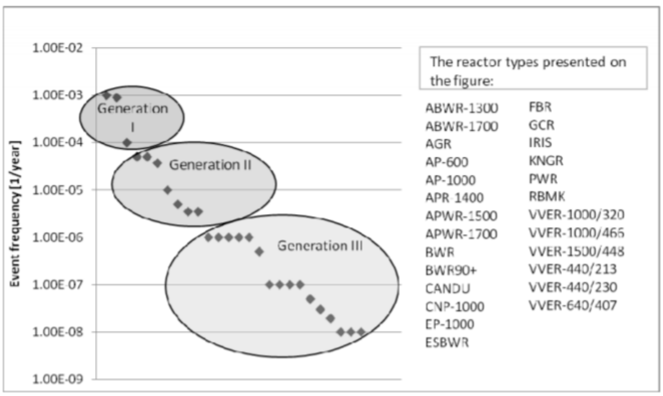
If implemented with the best practices and Gen III or IV, nuclear could deliver reliable, 24/7, safe, low carbon emission electricity at competitive market rates. Demonstration plants typically are in range of 50-300 MWp and the largest sized nuclear plants can be as large as 2000 MWp with a total installation cost of USD 11 billion based on USD 5,500/MWp. 3-4 plants of this size could sufficiently power 100% of Singapore’s electricity needs for the foreseeable future and the costs would be similar to the cost of solar panel installation to meet the same demand. Compared to Solar, nuclear provides a steady 24/7 supply, does not require additional capital investment in grid upgrades to manage the dynamic nature of the supply and is concentrated in a smaller footprint <10% of the solar panel area. Models of electricity grids that use significant nuclear range in 0.05-0.08 for China and 0.08 - 0.12 USD /kWh in US. Furthermore some of the Gen IV designs are capable of generating hydrogen fuel as a replacement for natural gas for thermally intensive processes on Jurong Island.

Generation IV Nuclear reactor types (MIT, 2018)

- Gas cooled fast reactor (GFR)
- Lead cooled fast reactor (LFR)
- Sodium cooled fast reactor (SFR)
- Molten salt reactor (MSR)
- Supercritical water cooled reactor (SCWR)
- Very high temperature reactor (VHTR)

Much progress has been made in Nuclear energy technology in safety, waste generation and non-proliferation safeguards (OECD NEA, 2010). The major implementation barrier and area of active research is construction costs. The causes of construction cost escalation have been attributed to mostly avoidable causes of poor project planning and execution and problems with permitting approvals between project approval and commissioning. The newer designs incorporate new materials that slow down the neutron speeds which act as an inherent passive safety feature, safeguard against weapons proliferation concerns and also help to minimize waste generation. The safety accident rates of nuclear are known to be of the lowest within the power generation industry.

Figure 6: Reduction in design estimates of the large release frequency between reactor generations over the past five decades



Source: IAEA (2004).

Accident and fatality risk for Nuclear plants

Table 2: Summary of severe (≥ 5 fatalities) accidents that occurred in fossil, hydro and nuclear energy chains in the period 1969-2000

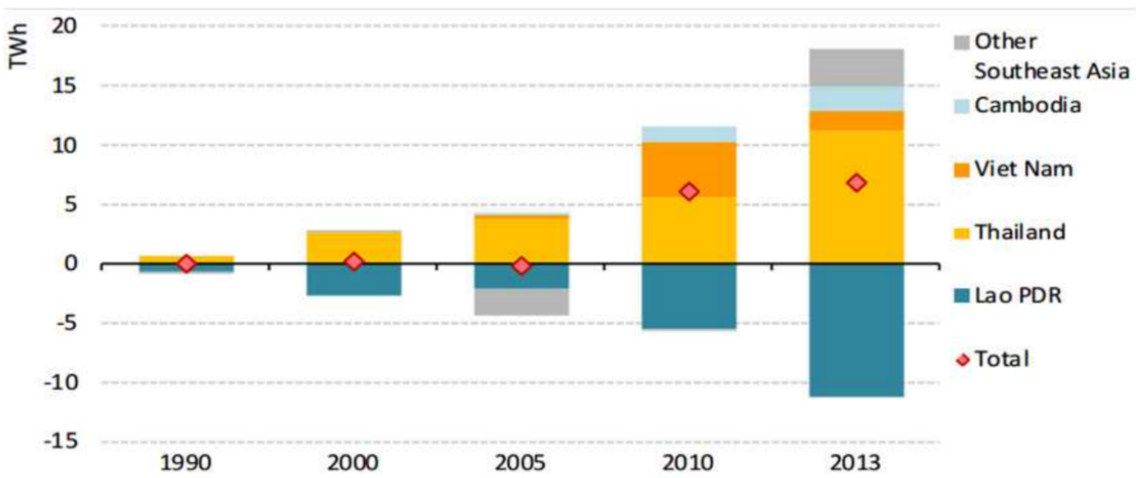
	OECD			Non-OECD		
Energy chain	Accidents	Fatalities	Fatalities/ GWey	Accidents	Fatalities	Fatalities/ GWey
Coal	75	2 259	0.157	1 044	18 017	0.597
Coal (data for China 1994-1999)				819	11 334	6.169
Coal (without China)				102	4831	0.597
Oil	165	3 713	0.132	232	16 505	0.897
Natural Gas	90	1 043	0.085	45	1 000	0.111
LPG	59	1 905	1.957	46	2 016	14.896
Hydro	1	14	0.003	10	29 924	10.285
Nuclear	0	0	–	1	31*	0.048
Total	**390**	**8 934**		**1 480**	**72 324**	

Note: * These are immediate fatalities only.

Source: Data provided to NEA by PSI.

Source: OECD NEA, 2010 - Comparing Nuclear Accident Risks with those from other energy industries - NEA

Appendix D: ASEAN power supply tables and figures



Thailand's consumption was 165 TWh in 2010

IEA (2015)

Figure: Growth of APG supply and demand vs time, Source: Finenko

Renewable Source Country	Hydroelectric	Geothermal	Solar	Wind (Limited)
Indonesia	Y	Y	Y	Y
Malaysia	Y	N	Y	Y
Thailand	N	N	Y	Y
Laos	Y	N	Y	Y
Philippines	Y	Y	Y	Y
Vietnam	Y	N	Y	Y
Cambodia	Y	N	Y	Y
Myanmar	Y	N	Y	Y

Figure: Sources of renewables by country and type, Source: Finenko

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Appendix E: Hydrogen fuel and CO_2 capture from steam methane reforming with amine unit

Hydrogen as a fuel source can be a direct replacement to natural gas burners with minimal retrofit costs at an additional 30-50% price premium vs natural gas. Hydrogen can either be generated from renewable sources via electrolysis or other means, or by conversion from natural gas + CCS. Singapore's Jurong Industrial District including Jurong Island and Tuas already have installed capacity for hydrogen generation from steam methane reforming (SMR) as well as a pipeline network for distribution. This section introduces the retrofit modifications required to capture the carbon in the reforming process. A large surplus of cheap hydrogen could be beneficial for the value chain since hydrogen is a better reducing chemical compared in reaction processes compared to natural gas

Figure: Stock image of industrial burner

Low carbon emission hydrogen fuel from steam reforming + carbon capture

The overall SMR process converts a carbon based fuel source into syngas - hydrogen and CO. Modern high efficiency SMRs recycle the purge gas as fuel for the conversion and utilize the export steam either with a co-facility or using a steam turbine to generate electricity power. At high loads the overall process is a net exporter of electricity, and the electricity/steam generation may be further increased by increasing the molar ratio of steam to carbon (SC Ratio) (Peng, 2012). The purge gas stream is rich in CO_2 which could improve the potential efficiency of separation compared to typical flue gas stream.

$CH_4 + H_2O \rightarrow H_2 + CO / CO_2$ Steam reforming chemical reaction

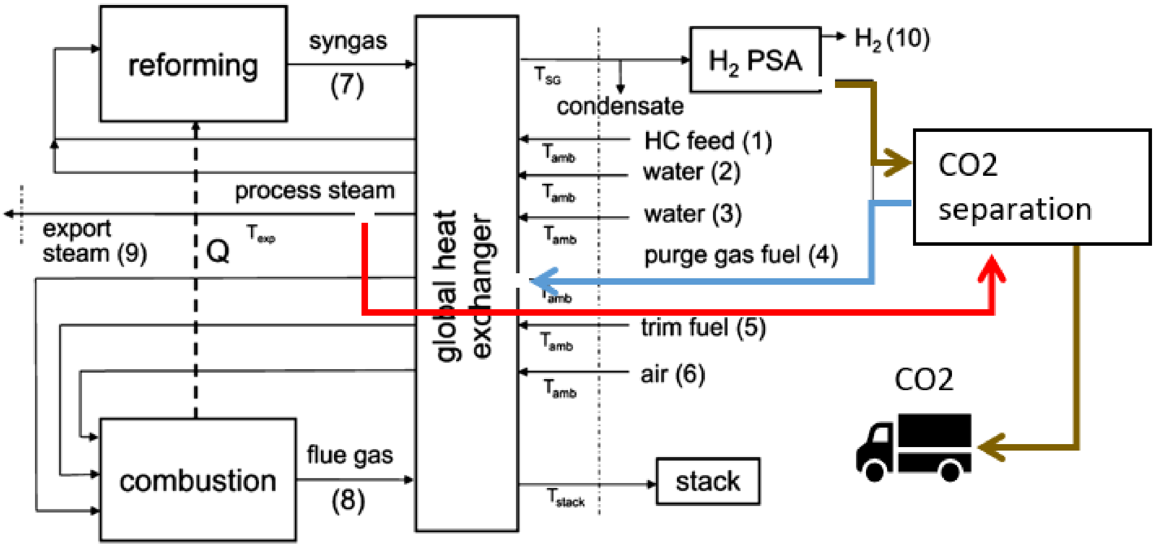

Figure: Modified process flow diagram from (Peng, 2012) for steam reformer with added purge gas CO_2 separation facility

The main reforming reaction is conversion of methane to syngas in the presence of steam and nickel catalyst at high temperature. The main reactions are steam reforming + water gas shift. A typical SMR without CO_2 capture can achieve 90% total thermal efficiency if the export steam thermal value is fully utilized.

Thermal efficiency = HHV syngas / (fuel - export steam) SMR only
Thermal efficiency = HHV syngas / (fuel + separation - export steam) SMR + CO_2 capture

A challenge for the SMR is to utilize value from the export steam. The CO_2 separation process requires thermal and electrical energy demands, without going into the details of the split between these two sources the two extreme cases are presented in this section. The expected additional energy costs assuming either electrical energy or thermal energy used in the separation process at 4,700 kJ/kg CO_2 (Zhang, 2012). In the case of electrical energy, the steam is first converted to electricity using a turbine with 35% conversion efficiency.

	Thermal efficiency	Thermal cost vs Natural gas
SMR base case	90%	+11%
+ CO_2 steam as thermal energy	75%	+34%
+ CO_2 steam cvt to electricity	65%	+55%

Appendix F: Comparison of carbon sequestration methods

1. Underground storage - Terrestrial
2. Mineralization
3. Deep ocean
4. Bio-assisted terrestrial
5. Bio-assisted open ocean

Underground storage

Singapore generates in the range of 40 GTon/year of carbon dioxide emissions. While a wide range of options are available for sequestering small volumes of CO_2 few have the potential to be deployed at the scale required. Underground geological structures meet the criteria of having both the physical volumes and a process of delivering them at industrial rates. Underground storage in porous and permeable reservoir rocks is technically feasible and all the necessary steps are commercially proven and in use today (Holloway, 2001). A case study, the Sleipner West Gas field (MIT) is a large scale operation started in 1996 with a capacity of 0.9 Mt/yr at a cost of USD 17 / ton. The types of storage locations are grouped into caverns (natural and human-made), unused porous/permeable rock formations, and depleted oil and gas fields. Porous rock formations are geological feature exploited in oil and gas fields. The formations are typically occupied with a brine water solution and trace amounts of oil/gas. The process begins by injection of CO_2 using a well into the porous rock at 90% of the fracture pressure to avoid over-pressuring the structure. The CO_2 then displaces the existing fluid, and eventually migrates to form an underground bubble underneath a trap formation. Traps can be either aquicludes salt formations (impermeable), or aquitards shale, mudstone (slowly permeable). The exit/extinction of the CO_2 reservoir over time is by a combination of reaction/dissolution into the brine, mineralization reaction with the trap, diffusion through the trap and diffusion through cracks and faults in the trap. The measure of the reservoir's atmospheric sequestration performance is assessed based on level of leak rate to the surface and the entire system can be rated in terms of ton-years of storage capacity. Estimates of total storage capacity globally vary from 400-10,000 Gt (10 to 250 years at current rates) (Holloway, 2001). The technology and skills required to implement the solutions has a large overlap with the fossil fuel exploration and production industry.

Mineralization

$Ca^{2+} + CO_2 + H_2O \rightarrow CaCO_3 + 2H^+$ Mineralization to calcium carbonate (Oelkers, 2008)

CO_2 reacts readily with calcium in oxidized state to form calcium carbonate. One benefit of mineralization is that the product could potentially have some practical use such as construction material. Two drawbacks of mineralization are the slow speed of reaction and the tonnage of reactant input materials / reaction products generated and the scale of the reaction volume needed. Using a reference mineralization rate of 2.0 mM h^{-1} (Yildirim, 2009) at ideal laboratory conditions would implies 52 km^3 of required reaction volume for sequestration of 40 MT/yr of emissions. While mineralization may be an appealing solution for specific localized context where reactant minerals and reaction volume are readily available, it is a less attractive option as a large scale strategy for industrial emissions.

Deep ocean

CO_2 is soluble in water, and its solubility increases with lower temperatures and higher pressures. Deep oceans are high pressure, low temperature and a very large volume. At a depth of > 3000 m, carbon dioxide is more dense than water and expected to sink to the ocean floor (IPCC, 2010). The total amount of carbon (as C) stored in the ocean is estimated to be 52x above what is stored in the atmosphere (Rackley, 2010) and the deep oceans have a larger capacity for storage compared to the shallow zones 0-1000 m. Use of the deep ocean as a sink must ensure that the gas stays in the ocean for sufficiently long period of time and not re-released back into the atmosphere. To achieve this is through some combination of increasing the density of the CO_2 carrier form, and by injecting at sufficient depth. Methods for increasing density are formation of hydrates and formation of a saturated solution with water. At sufficient depths >3,000m, CO_2 is expected to be in liquid form more dense than water and form an underwater lake. Over time the lake would break-up and eventually be recycled back into the atmosphere over a long time cycle (millennia), allowing time for other more long- term solutions to be implemented (IPCC, 2010). The environmental impact assessment of deep ocean methods is an area of open research and to date such methods have only been developed in laboratory settings and not demonstrated at scale. The nearest depths of 3,000 m are in the South China Sea offshore Brunei in the Palawan Trough and just off the southern shores of Sumatra.

Bio-assisted terrestrial

New growing forests naturally sequester carbon into the soil and bark as the ecosystem builds up a carbon inventory. In the long run the forest eventually reaches carbon balance and is not a net gain or loss of carbon from the atmosphere, although this process takes decades. Typical sequestration rates for forests range depending on the forest type from 4 to 10 ton CO_2/ha/yr (Nabuurs, 2001). Doubling the CO_2 atmospheric concentration by injection of CO_2 into the forest was shown to increase assimilation rates in pine forests by +10-25% (DeLucia, 2008). Applying 4 tons/ha/yr and a +25% increase assimilation rate would require 400,000 km^2 forest area to sequester 40 MT/yr, or approximately an area the size of Sumatra, Indonesia. Furthermore, a large portion of the injected CO_2 will diffuse back into the atmosphere so that to sequester 40 MT/yr a much larger volume must be injected, reducing the overall efficiency. Application to enclosed space greenhouses or bio-based farms such as algae tubes however may be more attractive so that the CO_2 is utilized more efficiently. In such cases the resulting biomass must have a final end-of-life that is not released to the atmosphere to have the sequestration impact. If the biomass is sent to the food industry either for direct human consumption or for animal feed, there is no net gain in sequestration since the digestion process will ultimately re-release the CO_2 into the atmosphere.

Bio-assisted open ocean

A combined strategy of bioremediated ocean solution is to use the upper trophic ocean zone to create biomass from plankton or kelp using sunlight, harvest the salable biomass for economic value and allow the unusable biomass to sink to the ocean floor (Hawken, 2014). The solution combines the economic value add of bio-based solution with the gravity and large size advantage of open ocean. One of the main challenges anticipated for the bio-assisted open-ocean remediation are achieving the required scale (possibly thousands of km^2) of technology deployment in open oceans.

Sample calculation volume requirement for mineralization

mineralization rate	2	mM/h
mineralization rate	88	ton/km3/h
mineralization rate	0.77	MT/km3/yr
MW CO2	44	g/mol
emissions rate	40	MT/yr
volume required	51.9	km3

Mineralization for a given production rate requires some volume in order to carry out the reaction. The volume is estimated as V (km3) = Q / r where "Q" is the emissions rate in MT/yr and "r" is the mineralization rate in MT/km3/yr. Based on this quick assessment and standard mineralization rates at room temperature, very large volumes would be required to mineralize all of Singapore's emissions.

Sample calculation land area for forest sequestration enhancement

	value	units
sequestration rate	4	ton/ha/yr
enhancement	25%	
sequestration rate	100	tons/km2/yr
emissions rate	40	MT/yr
land area reqd	400	thousand km2

A similar sample calculation is performed to determine the land area required to sequester carbon from forests. Forests sequester carbon over 50-100 year periods and varies significantly with the type of ecosystem and annual sunlight. The highest sequestration rates are in new growth and flat to neutral sequestration rates for very old forests > 100 years with a typical sequestration rate of 4 ton/ha/yr. Mangroves are reported to have one of the highest sequestration rates. A median range for temperate forests is presented here. Under certain conditions the carbon sequestration may be enhanced with more intensive planning and land care. In this sample estimate the land area required is A = Q / r where A is the land area in km2, and r is the sequestration rate in ton/km2/yr. To balance Singapore's emissions 400,000 km^2 of land area of forest is required, on the scale of the size of the island of Sumatra.

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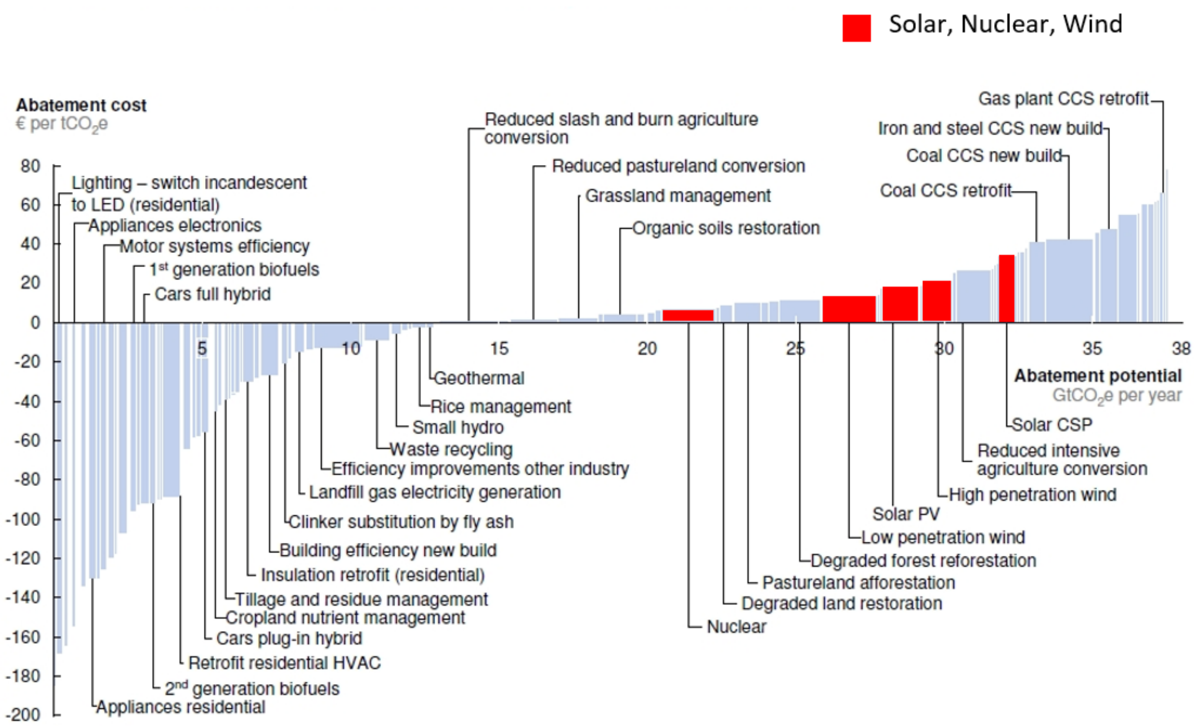
Appendix G: Estimate solar cost and land area

The land area A in km2 of PV cells for a solar farm is based on the annual unit power output C in kWh/m2/yr and the electricity demand D in GWh/hr. A = D / C. There are two methods for assessing demand, one is on peak basis and one on daily average. Solar has better peak capacity than overall demand since it is only generating power in the daytime. Peak hours demand however may not be in the middle of the day so the peak capacity can only be approximated using this naive method. MWp is the units for peak capacity. The annual unit power output is determined by the peak irradiance, I in W/m2 multiplied by the solar efficiency, the performance ratio and the number of peak daylight hour equivalents in a year, which is specific to the latitude and here estimated at 1,920 hrs/yr.

Peak irradiance	625	W/m2
solar efficiency	14%	
performance ratio	85%	
annual power output	143	kWh/m2/yr
solar panel cost	4.05	SGD/kWp
electricity demand 2020	55000	GWh/yr
peak electricity demand 2020	7500	MWp
installed solar capacity	350	MWp
new land area to reach 100%	379	km2
cost of new solar panels	207.0	SGD bil

Appendix H: McKinsey emissions abatement cost curve



Source: Mckinsey greenhouse gas abatement cost curve, 2019