CLIMATE CHANGE AND RISING SEA LEVELS:

MITIGATING AND ADAPTING TO THE LOOMING THREATS

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KEY TAKEAWAYS ON

SEA LEVEL RISE

Even though sea levels have been higher in the past, the rate of increase has been higher over the last three decades than any other comparable period.

Under a high carbon emissions scenario, the rate of sea level rise could overwhelm our capacity to adapt and respond.

The global costs associated with flooding from rising sea levels could reach US$27 trillion annually by 2100.

Loss of land value from floods due to sea level rise in Singapore is estimated at US$2 billion by 2100.

Sea level does not rise or fall uniformly around the globe.

The equatorial pacific region, including countries like Singapore and Indonesia, are likely to experience the highest sea level rise from melting ice sheets.

The equatorial pacific region, consisting of more than 20 countries (more than 50 percent of which are lower middle-income) with a cumulative population of 700 million, is not well equipped to cope with an increase in sea levels.

Given the equatorial pacific region is particularly exposed to the impacts to rising sea levels, it is crucial that this region is also at the forefront of related science. But at present, most of the education and research institutions focused on sea level rise are in Europe and the United States.

The risk of climate-related mass migration is increasing, and will pose serious transnational immigration challenges.

Global business opportunities and policies will be focused around climate mitigation and adaptation efforts.

Opportunities linked to building resilience of cities could be worth US$90-155 billion annually by 2030.

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MITIGATING AND ADAPTING TO THE LOOMING THREATS

On 28 November 2018, Temasek organised a discussion by Professor Benjamin Horton (Chair, Asian School of the Environment, Nanyang Technological University), as part of the Ecosperity Conversations series.

Professor Horton is a global leading expert on the impact of climate change on rising sea levels, and has published over 180 articles in peer-reviewed journals, including Science, Nature, Proceedings of the National Academy of Sciences, and Geology. Professor Horton was an author of the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5), and his research was cited by President Obama in his 2015 State of the Union Address at the United States Capitol on 20 January 2015.

The session discussed the drivers of sea level change, the impact of carbon emissions and climate change on sea levels, and the potentially devastating effects of this globally and particularly here in Southeast Asia. This summary report covers the key topics discussed during the session and includes additional insights to complement the discussion on the potential implications for businesses and policymaking.

Sea levels are rising faster than ever

Rising temperatures due to the greenhouse effect has accelerated the rate of increase in global mean sea levels (GMSL)[1]. Between 1901 and 2010, GMSL rose by up to 190 millimetres in total.[2] While the absolute rise in GMSL is worrying, it is the rate of increase in the last few decades that has alarmed scientists and policymakers. Even though sea levels have been higher in the past, the rate of increase has been higher over the last three decades than any other comparable period.[3] This trend has become even more pertinent in the last few years. Between 2008 and 2017, GMSL rose more than 50 percent faster than the annual increase between 1993 and 2005 (i.e. 2.5 to 3.0 millimetres per year).[4] In comparison, global sea levels rose by 0.5 millimetres per year from the 11th century to the 15th century, remained stable until the late 19th century,[5] and then rose by 1.7 to 1.9 millimetres per year in the 20th century.[6]

Although sea level rises are a global occurrence, the level and rate of increase varies by geography, which can be explained by both global and local/regional drivers. The three global drivers influencing the GMSL are:

1. **Increase in global ocean volume.** This relates to thermal expansion where the increase in sea water temperature leads to a decline in water density, such that the water expands and increases in volume to raise sea levels. Estimates show that global ocean volume increase contributed to 35 percent of the global mean sea level increase between 1993 and 2008.[7]

2. **Ocean mass additions.** Glacial ice melts as global temperatures rise, increasing global sea levels as the melted ice is drained into the sea. In particular, the melting of major ice sheets in Greenland and Antarctica has contributed to around 70 percent of the total sea level rise between 1993 and 2008.[8] Greenland and Antarctica ice sheets store the equivalent of 7 metres and 60 metres of sea level

[1] Global mean sea level change is explained as changes in sea surface height averaged across the whole ocean.
[2] Intergovernmental Panel on Climate Change [IPCC] (2014), *Fifth Assessment Report.* Available at: https://archive.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter13_FINAL.pdf
[3] National Oceanic and Atmospheric Administration [NOAA] (2017), "Global and regional sea level rise scenarios for the United States". Available at: https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf and In the last interglacial period (i.e. 129,000 to 116,000 years ago), the GMSL was at least 5 metres higher and 2 degrees Celsius warmer than the 1950 levels. See Intergovernmental Panel on Climate change [IPCC] (2014), *Fifth Assessment Report*. Available at: https://archive.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter13_FINAL.pdf
[4] World Climate Research Programme [WCRP] (2018), "Global sea-level budget 1993–present". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/essd-10-1551-2018-1.pdf
[5] Treehugger (2011), "Sea Level Rise Since 19th Century Greater Than Any Time In Past 2,100 Years". Available at: https://www.treehugger.com/climate-change/sea-level-rise-since-19th-century-greater-than-any-time-in-past-2100-years.html
[6] Intergovernmental Panel on Climate Change [IPCC] (2014), *Fifth Assessment Report*. Available at: https://archive.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter13_FINAL.pdf
[7] The National Academies of Sciences, Engineering, Medicine (2012), "Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future". Available at: https://www.nap.edu/read/13389/chapter/5
[8] The National Academies of Sciences, Engineering, Medicine (2012), "Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future". Available at: https://www.nap.edu/read/13389/chapter/5

respectively. In particular, the Antarctica is identified as the biggest threat to rising sea levels given that it is nearly twice the size of the United States and contains 90 percent of the earth's ice.[9] West Antarctica (Larsen C ice shelf) is deemed especially unstable – underlined by the event in 2017 where part of its ice shelf (iceberg A-68), eight times the size of Singapore's in terms of land mass, broke off.[10] This raised concerns on further disintegration of Larsen C due to collision with the broken iceberg, the potential for accelerated melting if the iceberg moves towards warmer waters, as well as the potential hazards for commercial vessels sailing around the region.[11]

3. **Land water storage.** This relates to the climatic occurrences that alter the water cycle, such as variation in rainfall and evaporation. Higher rainfall and snowfall between 2002 and 2014 increased the amount of water stored on land, slowing the sea level rise by around 0.7 millimetres per year.[12] For example, from 2002 to 2009 the Amazon basin contributed the most to land water storage, followed by the Lena and Yenisey basins in Siberia, primarily due to increased rainfall.[13] Historically, increase in land water storage from 1993 to 2008 contributed to an overall decline in sea level by 3 percent.[14]

Regional and local deviations from GMSL change can be attributed to both natural climatic and anthropogenic (linked to human activity) climatic factors. On the natural climatic front, five key drivers are identified.

1. **Tectonic movements.** Land movements arising from tectonic motion can cause the land to either sink or rise, leading to corresponding shifts in sea level.[15] For example, after the 1995 earthquake in Antofagasta, Chile, neighbouring areas experienced land uplifts. The south and west of Antofagasta bay, and the southwestern tip of the peninsula of Mejillones were lifted 25 centimetres, 40 centimetres and 80 centimetres respectively leading to a relative decline in sea levels.[16]

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[9] SeaLevelRise.org. Available at: https://sealevelrise.org/causes/

[10] Iceberg A-68, measures 5,800 square kilometres. See Dailymail.com (2017), "Earth's newest iceberg up close: NASA reveals incredible new images of trillion ton A-68 which is the size of DELAWARE". Available at: https://www.dailymail.co.uk/sciencetech/article-5082241/Earth-s-newest-iceberg-close-NASA-reveals-68-iceberg.html and Singapore's area is 721.5 square kilometres. Hence, A-68 is about 8 times the size of Singapore. Taken from the Singapore government database. Available at: https://data.gov.sg/dataset/total-land-area-of-singapore

[11] Boy Genius Report [BGR] (2018), "Colossal iceberg finally breaks free in Antarctica, and now the real crisis begins". Available at: https://bgr.com/2017/07/12/antarctica-iceberg-larsen-c-shelf/

[12] J.T. Reager, A.S. Gardner, J.S. Famiglietti, D. N. Wiese, A. Eicker and M.-H. Lo (2016), "A decade of sea level rise slowed by climate-driven hydrology", The Science Mag. Available at: http://science.sciencemag.org/content/351/6274/699

[13] W. Llovel, M. Becker, A. Cazenave, J.F. Cretaux and G. Ramillien (2010), "Global land water storage change from GRACE over 2002–2009; Inference on sea level", Institut de France. Available at: https://pdfs.semanticscholar.org/42f8/6b7e9d404cc2ca05e2f30276e60973a988c8.pdf

[14] The National Academies of Sciences, Engineering, Medicine(2012), *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. Available at: https://www.nap.edu/read/13389/chapter/5

[15] SeaLevelRise.org. Available at: https://sealevelrise.org/causes/

[16] Luc Ortlieb and Sergio Eduardo Barrientos (1996), "Coseismic coastal uplift and coralline algae record in Northern Chile: The 1995 Antofagasta earthquake case*",* Quaternary Science Reviews. Available at: https://www.researchgate.net/publication/229418087_Coseismic_coastal_uplift_and_coralline_algae_record_in_Northern_Chile_The_1995_Antofagasta_earthquake_case

2. **Atmosphere and ocean interaction.** The dynamics between the atmosphere and oceans cause changes in surface winds, ocean currents, temperature and salinity leading to distinct differences in rates of sea level change across different locations. For example, the strength of the surface wind is inversely linked to sea levels, where strong surface winds with high pressure create a downward force that reduces sea levels.[17] Between 1993 and 2010, the increase in strength of surface winds in the central and eastern tropical Pacific led to two distinct scenarios, where sea level fell in the eastern Pacific due to cooling from the strong surface winds[18], but rose in the western tropical Pacific due to easterly wind-driven convergence of surface water that propagated westwards.[19]

3. **Gravitational and elastic deformational effects.** The self-gravitation exerted by melting ice sheets can lead to an instantaneous elastic response of the earth's crust.[20] This results in sea levels being reshaped almost immediately at the earth's surface. Sea levels fall near shrinking ice sheets and increase more than the GMSL unevenly elsewhere. Ice sheets attract water due to gravity and hence, as they melt the sea level falls[21]. For example, sea level rises in California and Florida – located in middle to low latitude regions – due to melting of the Antarctic sheet is more than 50 percent greater than the rest of the world.[22] However, melting of ice sheets will have the most prominent rise in sea level in the equatorial pacific region[23], especially the low-lying coastal zones, while European regions will experience less than the global mean sea level rise.[24]

Equatorial pacific regions are likely to experience the highest sea level rise from melting ice sheets

4. **Glacial isostatic adjustment.** Glacial isostatic adjustment refers to the rise and decline of land in order to return the earth to a state of equilibrium due to the pressures created by mass redistribution during a glacial cycle.[25] Even though the last glacial cycle was about 16,000 years ago, there is ongoing movement of land as a reaction to the ice-age burden.[26] For example, Sweden's sea level

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[17] The Weather Window, "Tide Height and Air Pressure". Available at: http://weather.mailasail.com/Franks-Weather/Pressure-And-Tides
[18] Science Daily (2014), "Atlantic warming turbocharges Pacific trade winds". Available at: https://www.sciencedaily.com/releases/2014/08/140803193642.htm
[19] Intergovernmental Panel on Climate Change [IPCC] (2014), *Fifth Assessment Report.* Available at:https://archive.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter13_FINAL.pdf; Advancing Earth and Space Science (2011), "Regional sea level trends due to a Pacific trade wind intensification". Available at: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2011GL049576
[20] B. Horton, R. Kopp, A. Garner, C. Hay, N. Khan, K. Roy and T. Shaw (2018), "Mapping Sea-Level Change in Time, Space, and Probability", The Annual Review of Environment and Resources. Available at: https://www.annualreviews.org/doi/pdf/10.1146/annurev-environ-102017-025826
[21] Guardian (2018), "The strange science of melting ice sheets: three things you didn't know". Available at: https://www.theguardian.com/environment/ng-interactive/2018/sep/12/greenland-antarctic-ice-sheet-sea-level-rise-science-climate
[22] The National Aeronautics and Space Administration [NASA] (2017), "NASA/UCI Find Evidence of Sea Level 'Fingerprints'". Available at: https://www.nasa.gov/feature/jpl/nasauci-find-evidence-of-sea-level-fingerprints
[23] AlphaBeta defines this region as countries bordered by the Pacific Ocean and within 15 degrees north and south of the equator
[24] Ice2Sea (2013), "From Ice to High Seas". Available at: https://www.ice2sea.eu/wp-content/uploads/sites/27/2013/05/From_Ice_to_High_Seas.pdf
[25] B. Horton, R. Kopp, A. Garner, C. Hay, N. Khan, K. Roy and T. Shaw (2018), "Mapping Sea-Level Change in Time, Space, and Probability", The Annual Review of Environment and Resources. Available at: https://www.annualreviews.org/doi/pdf/10.1146/annurev-environ-102017-025826
[26] National Oceanic and Atmospheric Administration [NOAA], "What is glacial isostatic adjustment?" Available at: https://oceanservice.noaa.gov/facts/glacial-adjustment.html

has fallen 40 centimetres over the last 110 years, due to the glaciers that were formed across Scandinavia in the last ice age.[27]

5. **Sediment deposition and compaction.** Sediment deposition is the process by which sediments and soil are added to land masses. Deposition impacts the sea level by increasing the elevation of the sea floor which reduces sea levels.[28] On the contrary, compaction is the loss of volume of sediment deposits. As the layers of sediments build up, the pressure on the lower layer increases, reducing porosity such that the layers are squeezed together, and water stored in the sediments is forced out. This leads to land subsidence and relatively higher sea levels. The level of compaction is determined by the prevalent sediment type (fine-grained soil such as peat and clay are more susceptible to compacting) in the area as well as the depositional history.[29] The land subsidence due to compaction is further escalated by human-linked activities such as ground water pumping.[30] For example, in the Mekong Delta of Vietnam, sea level rises in 2006 to 2010 correlated well with calculations of land subsidence due to natural compaction resulting from delta evolution as well as presence of fine-grained soil.[31] [32]

On the anthropogenic climatic front, the extraction of underground resources is a major driver of land subsidence.[33] Human activities such as the building of dams and reservoirs, and the withdrawal of groundwater, can impact the amount of land water storage which disturb the hydrological cycle and cause sea level changes. The deviations from GMSL in Manila in the Philippines are primarily driven by land subsidence caused by intensive groundwater pumping for domestic use, agriculture and other industries.[34] In Indonesia, parts of Jakarta are sinking by up to 15 centimetres each year partly because of groundwater withdrawal for drinking water, bathing and other everyday purposes – the most drastic being north Jakarta which has sunk 2.5 metres in 10 years.[35]

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[27] Greening Earth Society, "Testing the waters". Available at: https://www.john-daly.com/ges/msl-rept.htm
[28] K.Ferrier, J. Austermann, J. Mitrovica and T. Pico (2017), "Incorporating sediment compaction into a gravitationally self-consistent model for ice age sea-level change", Geophysical Journal International. Available at: https://academic.oup.com/gji/article-abstract/211/1/663/4004749
[29] C. Zoccarato, P. Minderhound and P. Teatini (2018), "The role of sedimentation and natural compaction in a prograding delta: insights from the mega Mekong delta, Vietnam", Scientific reports. Available at: https://www.nature.com/articles/s41598-018-29734-7
[30] B. Horton, R. Kopp, A. Garner, C. Hay, N. Khan, K. Roy and T. Shaw (2018), "Mapping Sea-Level Change in Time, Space, and Probability", The Annual Review of Environment and Resources. Available at: https://www.annualreviews.org/doi/pdf/10.1146/annurev-environ-102017-025826
[31] M. Brain (2016), "Past, Present and Future Perspectives of Sediment Compaction as a Driver of Relative Sea Level and Coastal Change", Current Climate Change Report. Available at: https://link.springer.com/content/pdf/10.1007%2Fs40641-016-0038-6.pdf
[32] C. Zoccarato, P. Minderhound and P. Teatini (2018), "The role of sedimentation and natural compaction in a prograding delta: insights from the mega Mekong delta, Vietnam", Scientific reports. Available at: https://www.nature.com/articles/s41598-018-29734-7
[33] World Climate Research Program [WRCP], "Regional Sea-level Change and Coastal Impacts". Available at: https://www.wcrp-climate.org/gc-sea-level
[34] World Environment Partnership in Asia [WEPA], Available at: http://www.wepa-db.net/policies/state/philippines/groundwater.htm
[35] BBC News (2018), "Jakarta, the fastest-sinking city in the world". Available at: https://www.bbc.com/news/world-asia-44636934

The business-as-usual trajectory on carbon emissions could significantly increase sea levels and have devastating impacts

Climate change is the key driver behind sea level rise. A recent report by the Intergovernmental Panel on Climate Change (IPCC) warns of the catastrophic impact that climate change could have on the world's ecosystems, economies, and society.[36] This includes increased risk of sea level rise, flooding, droughts, tropical cyclones, ocean acidity, threats to food security and water supply, and decline in economic growth. A study found that flooding from rising sea levels could cost US$14 trillion to US$27 trillion worldwide annually by 2100, if the target of holding global temperatures below 2 degrees Celsius above pre-industrial levels is missed.[37] More than 80 percent of the world's fastest growing cities are facing extreme climate change risks – with 95 percent of those in Asia or Africa. The ten cities rated 'extreme risk' in terms of highest economic exposure to climate change in 2023 include key emerging markets such as Jakarta, Manila, Lagos and Baghdad.[38]

> The world needs to reach **net zero carbon emissions** within the next 25 years to limit temperature increase to no more than 2 degrees Celsius (over the course of this century)

The Paris Climate Change Agreement is a global pact where countries agreed to put forward their best efforts to mitigate global warming to keep global temperature rise this century well below 2 degrees Celsius (compared to pre-industrial levels), and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.[39] However, the current emissions trajectory is far in excess of this.[40] Human induced rise in temperature has already reached 1 degree Celsius in 2017 and is estimated to increase at 0.2 degrees Celsius per year.[41] Furthermore, only 49 countries representing almost 40 percent of total global emissions had reached their national CO2 emission target.[42] In particular, many developed regions including Australia, South Korea, European Union (EU) and the United States (US) are falling short of achieving their national

[36] This special report has received extensive coverage in the press. See Intergovernmental Panel on Climate change [IPCC] (2018), *Global Warming of 1.5 ºC – Summary for Policymakers*. Available at: http://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf
[37] S. Jevrejeva, A. Grinsted and J.C. Moore (2018), "Flood damage costs under the sea level rise with warming of 1.5 °C and 2 °C", Environment Research Letters. Available at: http://iopscience.iop.org/article/10.1088/1748-9326/aacc76/pdf
[38] As per the Climate Change Vulnerability Index as calculated by Maplecroft. See Verisk Maplecroft (2018), "84% of world's fastest growing cities face 'extreme' climate change risks*"*. Available at: https://www.maplecroft.com/portfolio/new-analysis/2018/11/14/84-worlds-fastest-growing-cities-face-extreme-climate-change-risks/
[39] United Nations Framework Convention on Climate Change [UNFCCC] (2018), *The Paris Agreement.* Available at: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
[40] United Nations Environment Programmme [UNEP] (2018), *Emissions Gap Report 2018.* Available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/26895/EGR2018_FullReport_EN.pdf?isAllowed=y&sequence=1
[41] Intergovernmental Panel on Climate Change [IPCC] (2018), *Global Warming of 1.5 ºC – Summary for Policymakers*. Available at: http://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf
[42] https://www.carbonbrief.org/analysis-wri-data-suggests-emissions-have-already-peaked-49-countries

targets for 2030.[43] In order to keep the warming under 2 degrees Celsius, countries are required to raise their ambitions fivefold,[44] and reach net zero carbon emissions within the next 25 years.[45]

Exhibit 1 summarises estimates of changes to global mean surface temperature and global sea level under different Representative Concentration Pathways (RCPs) across two time periods: 2045-2065 and 2081-2100.[46] These projections are conditioned on four RCPs which represent a set of climate change scenarios to guide climate modelling.[47] The four RCPs, from worst-case scenario to best case-scenario, are: i) RCP8.5 represents a high-emission pathway with continued growth of CO2 emissions; ii) RCP 6.0 represents the upper bound of a moderate-emission pathways with stabilised emissions; iii) RCP 4.5 represents the lower bound of a moderate-emission pathways with stabilised emissions; and iv) RCP2.6 represents a low-emission pathway consistent with the Paris Agreement's goal of net-zero CO2 emissions.[48]

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[43] United Nations Environment Programmme [UNEP] (2018), *Emissions Gap Report 2018.* Available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/26895/EGR2018_FullReport_EN.pdf

[44] Independent (2018), "Countries must raise emissions targets fivefold to stop disastrous global warming, UN warns". Available at: https://www.independent.co.uk/environment/climate-change-carbon-emissions-un-report-environment-global-warming-a8654186.html

[45] K. Tanaka and B. O'Niel, "The Paris Agreement zero-emissions goal is not always consistent with the 1.5 °C and 2 °C temperature targets*",* Nature climate change. Available at: https://www.cfa.harvard.edu/~wsoon/myownPapers-d/Ronan-2018withBob-d/TanakaONeill18-March26-ParisAgreementZeroEmissionGoalIsNotConsistentwithTempTargetsof1.5-2C.pdf

[46] Intergovernmental Panel on Climate Change [IPCC] (2014), *Fifth Assessment Synthesis Report*. Available at: https://www.ipcc.ch/pdf/assessment-report/ar5/syr/drafts/SYR_FOD_Topic2.pdf

[47] "They represent a range of possible future climate forcing pathways, which are time and space dependant that could be potentially achieved with more than one underlying socioeconomic scenario, containing elements of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use. They are identified by the approximate value of the radiative forcing (RF) (expressed in Watt per meter square or W/m2) at 2100, relative to pre-industrial values"; See Intergovernmental Panel on Climate change [IPCC] (2014), *Fifth Assessment Report - Working group 1, Chapter 12 (Long-term Climate Change: Projections, Commitments and Irreversibility)*. Available at: http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter12_FINAL.pdf

"Radiative forcing is defined as the additional energy take up by the Earth system due to the enhanced greenhouse effect. More precisely, it can be defined as the difference in the balance of energy that enters the atmosphere and the amount that is returned to space compared to the pre-industrial situation". See Center for International Climate Research (CICERO), "A guide to Representative Concentration Pathways*".* Available at: .https://www.mpimet.mpg.de/fileadmin/communication/Im_Fokus/IPCC_2013/uk_ipcc_A_guide_to_RCPs.pdf

[48] B. Horton, R. Kopp, A. Garner, C. Hay, N. Khan, K. Roy and T. Shaw (2018), "Mapping Sea-Level Change in Time, Space, and Probability*"*, The Annual Review of Environment and Resources. Available at: https://www.annualreviews.org/doi/pdf/10.1146/annurev-environ-102017-025826

EXHIBIT 1

Projection of global mean sea level rise per year under the four different RCPs					
		2045-2065		2081-2100	
	Scenario	**Mean**	**Likely range**	**Mean**	**Likely range**
Global mean surface temperature change (°C)	**RCP8.5**	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
Global mean sea level rise (m)	**RCP8.5**	0.30	0.22 to 0.38	0.63	0.45 to 0.82
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55

Source: Intergovernmental Panel on Climate change (IPCC)

From Exhibit 1, the best-case scenario (RCP2.6) will see global mean surface temperature increase by up to 1.6 and 1.7 degrees Celsius over the two time periods respectively compared to the temperature in 1980 to 2005. Correspondingly, this would result in a GMSL increase of up to 0.32 and 0.55 metres annually. RCP8.5 depicts a high emission business-as-usual scenario, characterised by high population growth, modest improvements in technology and relatively slow income growth.[49] Under this worst-case scenario, the global mean surface temperature increase could reach a maximum of 4.8 degrees Celsius (between 2081 and 2100), almost 3.2 times higher than the 1.5 degree Celsius target outlined in the Paris agreement.

[49] Riahi et al (2011), "RCP 8.5—A scenario of comparatively high greenhouse gas emission". Available at: https://link.springer.com/content/pdf/10.1007%2Fs10584-011-0149-y.pdf

Under the RCP8.5 scenario, devastating impacts are expected across physical, biological, and human systems globally:

1. **Physical systems.** Land becomes more susceptible to floods, coastal erosion, and droughts due to a combination of adverse climate change impacts such as increased incidence of extreme weather events and rising sea levels. The increase in moisture content of the atmosphere due to increased evaporation from temperature rise leads to higher rainfall causing flash floods, storms and sea level rise. Heatwaves in Sydney, severe flash floods in Singapore, record low temperatures in Bangladesh are some examples of extreme weather events due to increase in temperature.[50] The equatorial pacific region, consisting of more than 20 countries across Southeast Asia, Latin America and Oceania with a cumulative population of 700 million, is most vulnerable to sea level rises, especially the low-lying coastal areas. More than 50 percent of these countries are classified as lower middle-income[51], and are thus not well equipped to cope with the increase in sea levels. Currently up to 800 million people are living in low lying coastal areas (within and outside the equatorial pacific regions), and this number is expected to rise to 1.4 billion people in 2060 (70 percent of those will be in Asia, of which China, India, Bangladesh, Indonesia and Viet Nam consist the majority).[52] The number of people at risk from flooding due to increasing sea levels is estimated at 411 million (about 50 percent are from Asia).[53] A one-metre increase in sea levels would submerge more than 50 percent of the Marshall Islands (Majuro, the capital city of the Marshall Islands and home to 50 percent of the population, would be expected to be submerged)[54], 30 percent of Bangladesh,[55] and many other islands and coastal areas. 2,000 islands in Indonesia could disappear by 2030 if sea levels continue to rise at present rates.[56] Additionally, if sea levels were to increase by 1.5 metres by 2100, cities such as Amsterdam and New York would be under water.[57]

> More than **50 percent** of countries in the equatorial pacific region are classified as lower middle income, and not well equipped to cope with the increase in sea level

> In 2060, the number of people in low-lying coastal areas will rise to **1.4 billion**

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[50] The Straits Times (2017), Deep freeze, heatwave, flash floods: What on earth is going on with the weather? Available at: https://www.straitstimes.com/world/deep-freeze-heatwave-flash-floods-what-on-earth-is-going-on-with-the-weather
[51] Defined by the world bank as countries with Gross National Income per capita between US$ 1,026 and US$ 4,035
[52] Science Daily (2017), "Rising seas could result in 2 billion refugees by 2100". Available at: https://www.sciencedaily.com/releases/2017/06/170626105746.htm
[53] B. Neumann, A. Vafeidis, J. Zimmermann and R. Nicholls (2015), "Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment", National Center for Biotechnology Information. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4367969/
[54] Climate Home News (2018), "Graphics of Marshall Islands sea level rise 'brought EU ministers to tears'". Available at: http://www.climatechangenews.com/2018/06/22/graphics-marshall-islands-sea-level-rise-brought-eu-ministers-tears/
[55] United Nations Framework Convention on Climate Change [UNFCCC] (2012), Climate Displacement in Bangladesh. Available at: https://unfccc.int/files/adaptation/groups_committees/loss_and_damage_executive_committee/application/pdf/ds_bangladesh_report.pdF
[56] Jakarta Post (2015), "Rising sea levels threaten 2,000 islands in Indonesia". Available at: https://www.thejakartapost.com/news/2015/12/17/rising-sea-levels-threaten-2000-islands-indonesia.html
[57] Independent (2018), "Worst-case climate change scenario could be more extreme than thought, scientists warn". Available at: https://www.independent.co.uk/environment/climate-change-model-scenario-rcp85-global-warming-illinios-study-a8353346.html

2. **Biological systems.** These are alterations to terrestrial and marine ecosystems as well as wildfire. IPCC's AR4 study concluded that up to 30 percent of plant and animal species are at increasing risk of extinction if temperatures were to rise 2 to 3 degrees Celsius higher than pre-industrial levels.[58] On the marine ecosystem, 90 percent of global reefs are expected to experience annual coral bleaching by 2055 under the RCP8.5 scenario.[59] Coral bleaching leads to reduced growth rates, decreased reproductive capacity and higher mortality rates. This in turn negatively impacts the rich biodiversity of the coral reef ecosystem and would result in a decline of wider marine biodiversity that rely on the coral reefs for food or shelter.[60]

3. **Human systems.** This includes impacts to food security, livelihood, health, governance and policy. Rising sea level causes saltwater intrusion into inland freshwater systems. Increased salinity in lakes and streams along coastal areas such as Bangladesh has led to shortage of drinking water. Seawater intrusion into soil may also result in a decline in rice yield by more than 15 percent by 2050.[61] Under the RCP8.5 scenario, vulnerability to food insecurity will rise by around 40 percent in 2050 versus current levels for Bangladesh.[62] On the health front, the IPCC has estimated rising temperatures would increase the habitat range of disease-carrying vectors such as mosquitoes. Consequently, the global population at risk from vector-borne diseases is expected to reach 400 million by 2100, up from 220 million currently.[63] Additionally, displacement of people in high risk areas as a result of sea level rise may pressure nations to re-define refugee policies. For example, New Zealand is the first country to propose a climate refugee scheme offering visas to families in neighbouring pacific countries threatened by the effects of climate change.[64] The risk of climate-related mass migration is increasing, and will pose serious transnational immigration challenges.

Singapore is particularly vulnerable to negative impacts of climate change and rising sea levels

In 2007, Singapore's former Prime Minister Lee Kuan Yew called global warming and climate change the "ultimate threat to human survival."[65] As a low-lying city with at least 30 percent of land area less than 5 metres above sea level, Singapore is prone to flooding from rising seas and vulnerable to the

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[58] Projections are based on medium confidence; see Intergovernmental Panel on Climate Change [IPCC] (2014), *Fifth Assessment Report*. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap4_FINAL.pdf
[59] National Oceanic and Atmosphere Administration, "Warm Forecast for Coral Reefs". Available at: https://sos.noaa.gov/datasets/warm-forecast-for-coral-reefs/
[60] Reef resilience network. Available at: http://www.reefresilience.org/coral-reefs/stressors/bleaching/bleaching-impacts/
[61] Science Daily (2017), "Food security threatened by sea-level rise". Available at: https://www.sciencedaily.com/releases/2017/01/170118082423.htm
[62] World Food Programme (WFP) database. Available at: https://www.metoffice.gov.uk/food-insecurity-index/
[63] L. Mboera, B. Mayala, E. Kweka and H. Mazigo (2011), "Impact of climate change on human health and health systems in Tanzania: a review, Tanzania Journal of Health Research". Available at: http://www.bioline.org.br/pdf?th11055
[64] Triple Pundit (2018), "New Zealand Creates First Climate Change Refugee Visa Program". Available at: https://www.triplepundit.com/2018/01/tiny-new-zealand-creates-first-climate-change-refugee-visa-program/
[65] Forbes (2015), "Thoughts from Lee Kuan Yew in Forbes" Available at: https://www.forbes.com/sites/forbesasia/2015/03/23/thoughts-from-lee-kuan-yew-in-forbes/

consequences of climate change.[66] While it contributes only around 0.1 percent of global emissions, Singapore ranks 26th out of 142 countries in terms of emissions per capita.[67] However, Singapore ranks 123rd out of 142 countries in the index measuring carbon dioxide emissions per dollar of economic output.[68]

Singapore is particularly impacted by rising sea levels due to the gravitational-attraction impact exerted by melting ice sheets. This refers to the effect of higher sea level rise in areas that are located further away from ice sheets due to the reduced gravitational attraction on ocean waters that are in closest proximity to the melting ice sheet. As counterintuitive as it may sound, this makes the Southeast Asian region particularly vulnerable to rising sea levels as compared to countries located closer to the ice sheets.[69] Between 1993 and 2009, the rate of increase of the mean sea level around Singapore was almost 2 times higher than the global sea level (up to 4.6 millimetres per year around Singapore as compared to 2.8 millimetres per year globally for the same period).[70]

Exhibit 2 summarises sea level rise projections compared to the level in 2000 under the two extreme RCP scenarios for Singapore across different probabilities. The "quantile" row represents the certainty of the projection in quartiles, where the 50th quantile is a median estimate, followed by a likely scenario (17th to 83rd quantile) and a very likely scenario (5th to 95th quantile). By 2030, the impacts under the RCP2.6 (low-emissions pathway) and the RCP8.5 (high-emissions pathway) pathways are not alarming, but from 2050 and beyond, the differences between the two pathways becomes increasingly more significant. For example, sea levels are expected to rise by 1.55 metres by 2100 under RCP8.5 (median or 50th quantile case). This is almost three times higher than an expected sea level rise of 0.55 metres under the median/ 50th quantile case under RCP2.6.

[66] National Climate Change Secretariat [NCCS] (2018), *Impact of climate change on Singapore.* Available at: https://www.nccs.gov.sg/climate-change-and-singapore/national-circumstances/impact-of-climate-change-on-singapore
[67] Based on 2015 data from the International Energy Agency (IEA).
[68] National Climate Change Secretariat (2016), *Take action today for a carbon-efficient Singapore*. Available at: https://www.nccs.gov.sg/docs/default-source/publications/take-action-today-for-a-carbon-efficient-singapore.pdf
[69] Earth Observatory of Singapore (2018), "The Science of Sea-Level Rise: How Climate Change Could Hurt Singapore". Available at: https://earthobservatory.sg/blog/science-sea-level-rise-how-climate-change-could-hurt-singapore
[70] P. Tkalich, P. Vethamony, Q.-H. Luu and M. T. Babu (2012), "Sea level trend and variability in the Singapore Strait", Ocean Science. Available at: https://www.ocean-sci.net/9/293/2013/os-9-293-2013.pdf

EXHIBIT 2

Projection of Singapore sea level rise per year under low and high emission scenarios as compared to a year 2000 baseline						
Year	Low emission scenario: RCP2.6 (cm)			High emission scenario:RCP8.5 (cm)		
Quantile	**50%**	**17-83%**	**5-95%**	**50%**	**17-83%**	**5-95%**
2030	10	3-19	(-1)-25	10	4-18	0-25
2050	22	10-36	2-47	30	17-44	0-25
2100	55	26-87	8-112	155	107-228	82-269
2200	105	45-180	10-241	783	635-984	574-1085

Source: Kopp et al., (2017)

Six key impacts of climate change, including sea level rise in Singapore are identified:

1. **Increased flooding.** Climate change has resulted in an increase in the number of occurrences of extreme weather events. The frequency of flash floods, warm periods and droughts have increased over the years in Singapore. In 2017 there were fourteen occurrences of flash floods, as compared to ten and six in 2016 and 2015 respectively.[71] Thirteen out of the past fifteen years have been the warmest years in Singapore's historical record since 1929, with 2017 being the warmest year in the past few decades not influenced by El Nino events.[72] Additionally, December 2016 and January 2017 have witnessed the strongest rate of increase in warm days and decrease in cool days since 1984.[73] Increasing sea levels also makes it challenging to drain surface water due to lack of adequate infrastructure, leading to higher possibility of flash floods. Geographically, 30 percent of Singapore is

[71] Today Online (2017), "S$500 million to be pumped into upgrading drains over the next 3 years: PUB". Available at: https://www.todayonline.com/singapore/s500-million-be-pumped-upgrading-drains-over-next-3-years-pub

[72] The Straits Times (2018), "How vulnerable is Singapore to climate change?". Available at: https://www.straitstimes.com/singapore/how-vulnerable-is-spore-to-climate-change; Today Online (2018), "2017 marks hottest year for Singapore without El Nino's influence". Available at: https://www.todayonline.com/singapore/2017-marks-hottest-year-singapore-without-el-ninos-influence

[73] Channel NewsAsia (2018), "Maximum temperatures in Singapore's cool months rising faster than warmer months: MSS". Available at: https://www.channelnewsasia.com/news/singapore/maximum-temperatures-in-singapore-s-cool-months-rising-faster-10069584

less than 5 metres above sea level, which leads to a high risk of extreme flooding under the RCP8.5 pathway. Singapore's National Water Agency has identified 96 flood prone areas (low-lying with a history of flooding) to date, including high density regions such as Alexandra, Tanjong Katong, Upper East Coast, and Changi.[74] Historically, Singapore has been exposed to extreme flooding due to a combination of low-lying land and heavy rainfall, sometimes coinciding with periods of high tides. For example, the flood in December 1969 (0.4 metres of rainfall in 12 hours) left 75 percent of Singapore submerged and rendered 3,100 people homeless. In December 1978, floodwater reached 2 metres (0.5 metres of rainfall in 24 hours), with major landslides across the country that led to 2 deaths.[75] More recently, increased instances of heavy rainfall have occurred more frequently from 2010 onwards, causing flash floods in Orchard Road, Upper Thomson, Paya Lebar and Tanjong Pagar, with depth of floods reaching up to 0.5 metres.[76]

2. **Decreased food and water security.** Increased incidences of flooding of agricultural land due to increased extreme weather events and inundation of land due to sea level rise could jeopardise agricultural output in low-lying regions (e.g. rice fields in Indonesia and Thailand), potentially leading to an escalation of global food prices. This has a particularly significant impact on Singapore's food security, given that it imports more than 90 percent of its food supply. Singapore obtains water supply from four national taps: i) water from local catchment including collection of rainwater and used water; ii) imported water from Johor; iii) recycled NEWater; iv) desalinated water. The supply of freshwater will be at risk with the increase in surface temperatures and increased variability of rainfall, increasing uncertainty of the long-term resilience of the first and second national taps. Additionally, Singapore's coastal reservoir structures are also at risk from saltwater contamination due to rising sea levels as nine out of the seventeen reservoirs are situated near the sea.[77] However, current technologies to produce NEWater and desalinated water are highly energy intensive and contribute to emissions significantly.[78]

3. **Negative public health impact.** Singapore's average temperatures are projected to rise between 2.9 and 4.6 degrees Celsius by 2100, creating conditions for vector-borne diseases such as dengue fever to thrive. [79] Based on a study conducted on the influence of climate variables on dengue in

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[74] PUB, Singapore's National Water Agency, "Drainage history". Available at: https://www.pub.gov.sg/drainage/history
[75] C. Kennedy, *Flooding in Singapore: An Overview,* AON. Available at: https://cpb-us-w2.wpmucdn.com/blog.nus.edu.sg/dist/3/3344/files/2015/03/FUTURE-FLOODS-NUS-Workshop-Claire-Kennedy-11cg2j1.pdf
[76] The Straits Times (2017), "5 recent cases of flooding in Singapore". Available at: https://www.straitstimes.com/singapore/environment/5-recent-cases-of-flooding-in-singapore
[77] Singapore's National Water Agency (2016), "PUB studies ways to better protect coastal reservoirs against future sea level rise". Available at: https://www.pub.gov.sg/news/pressreleases/20160127
[78] ASEAN Today (2016), "Singapore's biggest threat? The water crisis at its door". Available at: https://www.aseantoday.com/2016/09/singapores-fight-for-survival-prime-minister-lee-warns-of/
[79] Meteorological Service Singapore (2018), *Analysing Climate Change: Projections for Singapore and the Southeast Asia Region*. Available at: http://www.weather.gov.sg/wp-content/uploads/2018/08/SAMCA-Analysing-Climate-Change-CCRS-Final.pdf

Singapore, it was concluded that for every 2 to 10 degrees Celsius increase in temperature, the number of dengue cases are expected to increase by 22 to 185 percent. This is attributed to higher temperatures shortening the pathogen maturation process within the vector.[80]

4. **Decline of biodiversity and greenery.** Singapore is home to 255 species of corals (representing a third of the total global variety of species).[81] Coral bleaching in 1998 and 2010 linked to the El-Niño cycle[82] led to 20 percent and 10 percent mortality of the coral species in Singapore, respectively.[83] A mean temperature increase of 2.9 to 4.6 degrees Celsius by 2100 could lead to further bleaching and increased mortality of Singapore's corals. Additionally, Singapore's mangroves are also at risk of destruction. Mangroves are extremely valuable to Singapore as they act as sediment traps and carbon sinks, and protect biodiversity. Mangroves are also highly vulnerable to the effects of rising sea levels. Besides being forced inland, rapid rise in sea levels have also caused some plants to be submerged for a longer-than-normal duration, leading to drowning.[84] Research has shown that the 13 percent of the mangroves in the Pacific Islands could be lost by 2100 due to rising sea levels. [85]

5. **Increased economic cost.** Sea level rise will entail large economic costs for Singapore. Costs related to constructing and maintaining coastal hard infrastructure such as seawalls are expected to rise from current levels of US$3 million to about US$6 million by 2050 and US$17 million annually by 2100. [86] Additionally, the Singapore government has already invested US$1 billion between 2012 and 2018 to improve the drainage system, and is expected to invest another US$400 million in the next 2 to 3 years.[87] The loss of land value from flooding is large, estimated to be US$2 billion in 2100.[88] Melting ice sheets could also lead to the opening of alternative sea routes. The melting of arctic ice caps could open up the Northern Sea Route (NSR), which could threaten Singapore's competitiveness as a global sea hub. Ships travelling

> Loss of land value in Singapore from flooding is estimated to be **US$2 billion** in 2100

[80] E. Pinto, M. Coelho and E. Massad, "The influence of climate variables on dengue in Singapore", International Journal of Environmental Health Research. Availale at: https://www.researchgate.net/publication/51112265_The_influence_of_climate_variables_on_dengue_in_Singapore

[81] The Straits Times (2016), "Singapore ready to deal with threat to corals". Available at: https://www.straitstimes.com/singapore/singapore-ready-to-deal-with-threat-to-corals

[82] "El Niño is the warm phase of the El Niño Southern Oscillation (commonly called ENSO). The term El Niño refers to the large-scale ocean-atmosphere climate interaction linked to a periodic warming in sea surface temperatures across the central and east-central Equatorial Pacific". See, National Oceanic and Atmospheric Administration. "What are El Niño and La Niña?". Available at: https://oceanservice.noaa.gov/facts/ninonina.html

[83] L.M. Chou, K. Toh, Y. Tay and V.X.H. Phang (2012), "Coral reefs in Singapore: past, present and future", The Asian conference on sustainability, energy and the environment. Available at: https://www.researchgate.net/publication/292018710_Coral_reefs_in_Singapore_past_present_and_future

[84] C.D. Woodroffe, K. Rogers, K.L. McKee, C.E. Lovelock, I.A. Mendelssohn and N. Saintilan (2015), "Mangrove Sedimentation and Response to Relative Sea-Level Rise", The Annual Review. Available at: https://globalchallenges.uow.edu.au/content/groups/public/@web/@gc/documents/doc/uow221315.pdf

[85] United Nations Environment Programme [UNEP] (2006), *Pacific Island Mangroves in a Changing Climate and Rising Sea.* Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/11812/rsrs179.pdf?sequence=1&isAllowed=y

[86] As of the year 2000.

[87] Today Online (2018), "'Not feasible' to build drains for all extreme rainfall scenarios: Masagos". Available at: https://www.todayonline.com/singapore/not-feasible-build-drains-all-extreme-rainfall-scenarios-masagos

[88] W. Ng and R. Mendelsohn, "The impact of Sea level rise on Singapore", Yale School of Forestry and Environmental Studies. Available at: https://pdfs.semanticscholar.org/81da/0f464319dfb1f10e6f96016da88180b31d41.pdf

from Europe to Northeast Asia may be able to skip Singapore and sail directly to Japan, China and South Korea, as the journey would be up to 33 percent shorter.[89] The first container tank already sailed through the NSR in mid-2018, and the route is expected to be commercially viable beyond the 2030s.[90]

6. **Negative social impact.** Sea level rise may have significant impact on multiple social and political factors such as safety and security due to an increase in the number of climate refugees, as well as financial and job security. For example, a sea level rise of 2 metres is expected to increase the number of climate refugees in 2100 almost eight-fold from current levels, up from 24 million people in 2016 to 187 million people in 2100 – a majority of which are from Asia. Malaysia and South Korea are expected to be critical migration corridors within Asia.[91] However, in the near term the impact will most likely be limited to Singapore's stance on refugees. Singapore has been firm about not accepting refugees and asylum seekers, primarily due to its finite landmass.[92] Thus, with the expected spill over of displaced population from neighbouring countries to Singapore, the government may face increased pressure to rethink its policy on accepting refugees.

Business will need to radically change their approaches to deal with this threat, but there could be business opportunities that emerge

Companies are increasingly taking action to combat climate change. Over the last four years, there has been an eight-fold increase in the number of companies factoring an internal carbon price into their business plans. The challenge is that these firms are still a minority worldwide, and still too many firms have no climate action plans. For example, research found that 52 percent of businesses in the Financial Times Stock Exchange (FTSE) 100 index do not have an adequate assessment of climate risks to their businesses.[93]

These companies might be missing out, as there are a range of business opportunities related to tackling carbon emissions. For example, the Business & Sustainable Development Commission (BSDC) identified

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[89] Mothership (2014), "This Russian ship may spell the end of Singapore's prosperity". Available at: https://mothership.sg/2014/02/this-russian-ship-may-spell-the-end-of-singapores-prosperity/

[90] Eco-Business (2018), "How will development in the Arctic affect Asia?" Available at: https://www.eco-business.com/news/how-will-development-in-the-arctic-affect-asia/ and Eco-Business (2011), "Ice melts open arctic trade routes impact on Singapore". Available at: https://www.eco-business.com/news/ice-melt-opens-arctic-trade-routes-impact-on-singapore/ and The Straits Times (2018), Northern Sea (Arctic) Route unlikely to become commercially viable in the foreseeable future: Global maritime expert". Available at: https://www.straitstimes.com/singapore/transport/northern-sea-arctic-route-unlikely-to-become-commercially-viable-in-the

[91] United Nations Economic and Social Council for Asia and the Pacific [UNESCAP] (2017), *Migration and climate change in Asia and the Pacific*. Available at: https://www.unescap.org/sites/default/files/GCMPREP_5E.PDF

[92] Hong Kong Free Press (2018), "Refugees not welcome here': As ASEAN chair, Singapore must take the lead". Available at: https://www.hongkongfp.com/2018/01/07/refugees-not-welcome-asean-chair-singapore-must-take-lead/

[93] Ecoact (2018), *The Sustainability Reporting Performance of the FTSE 100*. Available at: https://eco-act.com/resource/the-2018-sustainability-reporting-performance-of-the-ftse-100/

US$5.7 trillion worth of opportunities that relate directly to climate change by 2030 (Exhibit 3). There are three key areas for opportunities related to climate change.

Under ‘energy and materials’, the main opportunities include applying circular economy concepts and approaches in the automotive sector and the expansion of renewables. Recycling of end-of-life vehicles is an energy intensive process; however, extending the life of vehicles by remanufacturing components that are weak links can increase the efficiency of energy use. For example, rather than purchasing tyres, airlines and trucking companies can be billed for the use of Michelin’s tyres on the basis of number of kilometres travelled or tonnes transported, with the raw materials remaining with Michelin.[94]

Opportunities linked to expansion of renewables total US$605 billion, with studies projecting that renewables’ share of energy generation could increase to 45 percent in 2030 from 23 percent in 2014.

Under ‘cities’, key opportunities include building energy efficiency and electric vehicles. For example, the market for building energy efficiency solutions such as more efficient heating and cooling technologies is projected to be US$770 billion.

Finally, under ‘food and agriculture’, the top opportunity is from reducing food waste. For example, implementing sensors to track food conditions during transit from production to retail can help to reduce food wastage and prolong the use-by date.[95]

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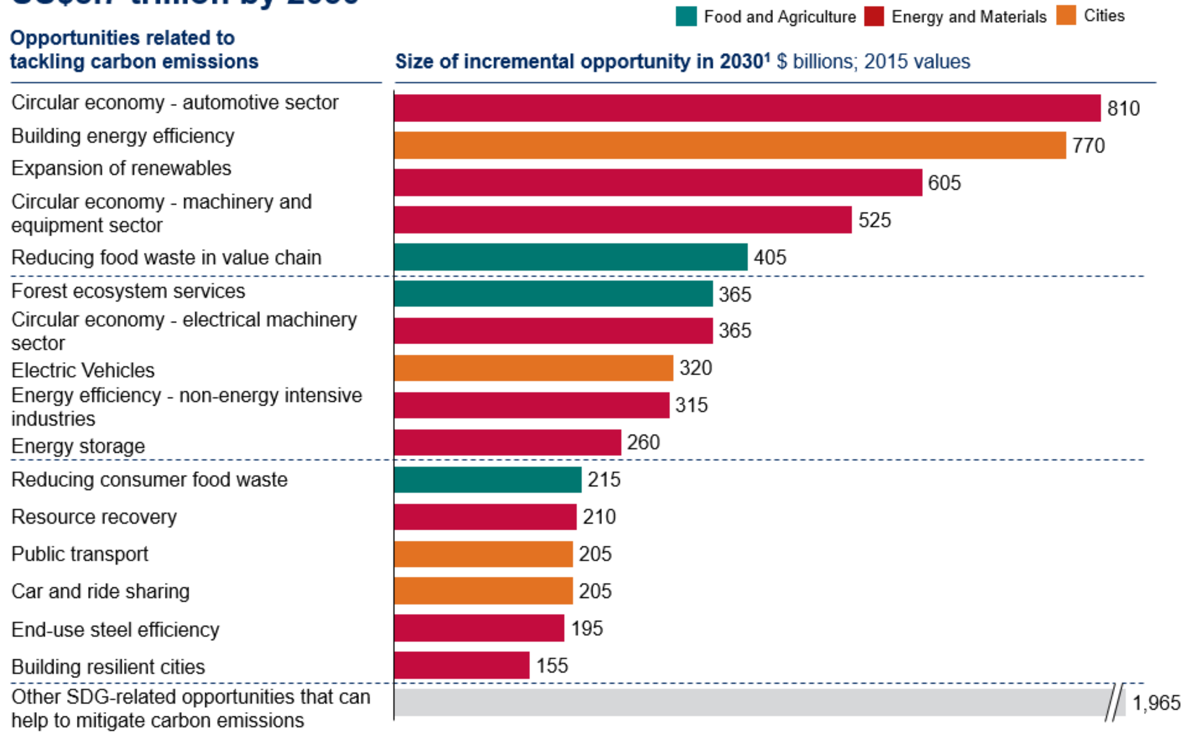
[94] Business and Sustainable Development Commission (2017), *Sustainable Business Opportunities in Asia.* Available at: http://report.businesscommission.org/uploads/Better-Business-Better-World-Asia.pdf

[95] Huffpost (2017), “How Technology Is Reducing Food Waste”. Available at: https://www.huffingtonpost.com/entry/how-technology-is-reducing-food-waste_us_5a2f6bcfe4b012875c465e11

EXHIBIT 3

Opportunities related to tackling climate change could be worth over US$5.7 trillion by 2030



[1]Based on estimated savings or projected market sizings in each area. Only the high case opportunity is shown here. Rounded to nearest US$5 billion.
Source: BSDC; AlphaBeta analysis

These business opportunities in climate change, particularly those directly linked to mitigation and facilitation of transition to renewable sources of energy (i.e. decarbonisation), are widely discussed in a previous report titled "The Great Energy Transition: Challenges and Opportunities for Transformation".[96]

The BSDC research estimated that opportunities in building resilience of cities to rising sea levels and climate change could be worth US$90-155 billion annually by 2030.[97] The United Nations Environment Programme (UNEP) indicates that the annual costs of

> Opportunities in building resilience for cities could reach **US$155 billion** by 2030

[96] Ecosperity (2018). *The Great Energy Transition: Challenges and opportunities for transformation.* Available at: https://www.ecosperity.sg/en/ideas/great-energy-transition-challenges-opportunities-for-transformation.html
[97] Business & Sustainable Development Commission (2017), *Better Business Better World*. Available at: http://businesscommission.org/news/release-sustainable-business-can-unlock-at-least-us-12-trillion-in-new-market-value-and-repair-economic-system

adaptation in developing countries alone could range from US$140 billion to US$300 billion by 2030.[98]

Specific adaptation examples include the following:

Infrastructure and construction-related opportunities. This includes leveraging existing technology and developing new technology to build infrastructure to protect against sea level rises and floods. Examples include:

- Netherlands-based BMK consortium, comprising of BAM, Volker Stevin and Hollandia Kloss, designed and built Rotterdam's floodgate, twice the size of the Eiffel tower, in 1997. The project cost more than US$500 million.[99] Additionally, the Netherlands has also combined disaster management with business opportunity creation and social welfare. Land greater than 20 acres in Rotterdam was reclaimed to act as a pool to store water during flood emergencies, and at other times function as a public social spot. The world rowing championship in 2016 took place in this space. The project was carried out by Dutch companies De Urbanstein and Wallard, costing more than US$5 million.[100]
- Thirty-five MRT stations in Singapore have been equipped with floodgates.[101] The cost of flood-proofing the first seventeen stations was about US$6 million.[102] Part of the contract was awarded to Singapore-based firm, Sigma Builders.[103]
- The concept of floating nations is also being explored. Many islands in French Polynesia are at risk of disappearing due to accelerated sea level rise, and hence the government has contracted San Francisco's Seasteading institute to assess the impact of the world's first floating city off the island of Tahiti. [104]
- A pilot for 3D printing homes in El Salvador is being launched in 2019 to address the high risk of floods and property damage. 3D printing will equip the government to provide homes in a timely and cost-efficient fashion post flooding disasters. The project is being led by a San Francisco based non-profit, New Story, and a construction

3D printing pilot can print homes for flood relief in as little as **24 to 48 hours**

[98] United Nations Environment Programme [UNEP] (2016), *The Adaptation Finance Gap Report*. Available at: http://www.unepdtu.org/newsbase/2016/05/uneps-adaptation-finance-gap-report-released
[99] Deltares, I-Storm and the Dutch Ministry of Infrastructure and Water Management, *Overview storm surge barriers*. Available at: http://www.masterpiece.dk/UploadetFiles/10852/25/Deltares_2018_Overview_storm_surge_barriers_komprimeret.pdf
[100] Public Space, "Water Square in Benthemplein". Available at: https://www.publicspace.org/works/-/project/h034-water-square-in-benthemplein
[101] Today Online (2017), "Bishan, Braddell MRT stations among 35 flood-proofed in recent years." Available at: https://www.todayonline.com/singapore/bishan-braddell-mrt-stations-among-35-flood-proofed-recent-years
[102] SG Car Mart (2013), "Flood barriers will be installed at another 19 MRT stations in an ongoing move by the Land Transport Authority (LTA) to protect stations from flooding". Available at: https://www.sgcarmart.com/news/article.php?AID=9278
[103] https://www.eco-business.com/news/anti-flooding-measures-at-11-more-mrt-stations/
[104] Eco-Business (2012)," Anti-flooding measures at 11 more MRT stations". Available at: https://www.abc.net.au/news/science/2018-06-16/floating-cities-and-seasteading-brilliant-or-bonkers/9851316

technology company, Icon. These 3D printed homes will cost between US$4,000 to US$10,000 and take only 24 to 48 hours to print.[105]

Flood risk monitoring and measurement. This includes opportunities linked to environmental consulting and development of advanced flood forecasting capabilities, using big data tools:

- IBM has multiple big data and artificial intelligence tools to help monitor and measure flood risks accurately. For example, in the Netherlands, IBM prepared a data-driven dashboard to help monitor floods. IBM aggregated, integrated and analysed data on multiple levers such as weather conditions, tides, and water run-off from various organisations to develop the dashboard.[106]
- Bosch has launched a pilot project this year on the Neckar River in Germany, to provide real-time monitoring of water body levels. This solution aims to replace the traditional method of calculating change in sea levels. Ultrasonic sensors, cameras and the Internet of Things (IoT) cloud help to track changing water levels and water velocity, and communicate the information to relevant authorities.[107]
- Mott Macdonald has delivered flood forecasts using mathematical models to simulate different scenarios. For example, they conducted a feasibility study and detailed the design of the Stormwater Management and Road Tunnel (SMART) in Kuala Lumpur. [108]

Policymaking approaches will also need to evolve their approaches, with a twin focus on mitigation and adaptation

Professor Horton stressed that under the current "business-as-usual" carbon pathway (RCP8.5), there are no known engineering solutions to enable cities and countries to adapt to the predicted rate of increase in sea levels. As such, the primary focus must be on mitigating climate emissions to try to reduce the probability of sea level rises.

There is a range of policy measures for tackling climate change, but more action needs to be taken. Singapore has implemented multiple policies in the last few years with regards to rising sea levels, mainly focused on climate mitigation and adaptation efforts.

[105] Business Insider (2018), "These 3D-printed homes can be built for less than $4,000 in just 24 hours". Available at: https://www.businessinsider.sg/3d-homes-that-take-24-hours-and-less-than-4000-to-print-2018-9/?r=US&IR=T
[106] ZD Net (2013), "IBM helps keep the Netherlands above water". Available at: https://www.zdnet.com/article/ibm-helps-keep-the-netherlands-above-water/
[107] Business Wire (2017), "CES 2018: Bosch is showing these smart solutions in Las Vegas". Available at: https://www.businesswire.com/news/home/20171218006182/en/CES-2018-Bosch-showing-smart-solutions-Las
[108] Mott Mac. Available at: https://www.mottmac.com/article/1013/flood-risk

Carbon tax in Singapore may increase to **S$15 per tonne** of GHG emissions by 2030

With regards to climate mitigation, most of Singapore's efforts consist of policies aimed at improving energy efficiency and introduction of suitable renewable energies. Ramping up solar power adoption to greater than one Gigawatt beyond 2020, launching enhanced energy efficiency grants, and achieving green mark standards for 80 percent of building by 2030 are some examples of recent policies in Singapore. The Singapore government has also announced that in 2019, a tax of S$5 per tonne of greenhouse gas (GHG) emissions will be levied on companies that emit 25,000 tonnes or more of GHG annually. This carbon tax rate will be reviewed and could increase to between S$10 and S$15 by 2030.[109]

In general, around 40 countries and more than 20 cities, states and provinces already use carbon pricing mechanisms, with more planning to implement them in the future. Together, the carbon pricing schemes now in place cover about half their emissions, which translates to about 13 percent of annual global GHG emissions.[110] However, this is still a small share of total emissions, and even those pricing mechanisms in place are often too minor to encourage the kind of behavioural shift needed to mitigate carbon emissions and climate change. India has implemented a renewable energy credit trading system and is also piloting carbon pricing instruments in three states.[111] In Thailand, the carbon pricing mechanism is still in the exploratory phase. Thailand Greenhouse Gas Management Organisation, a public organisation, launched a voluntary emissions trading scheme from 2014 to 2017. The next phase from 2018-20 will be the implementation roadmap for the emission trading scheme.[112]

In addition to mitigation, adaption policies and plans are needed to boost the resilience of cities to rising sea levels. Cities are implementing various plans to reduce inundation from flooding. In Singapore, this has taken the shape of policies encouraging infrastructure development to cope with the rise of sea levels. For example, the government plans to build three new desalination plants, to increase the country's total desalination capacity. In 2018, the third Tuas Desalination plant, which can produce 30 million gallons of desalinated water per day, was established.[113] Singapore's National Water Agency raised the minimum land reclamation height from 3 metres to 4 metres in 2011[114] and plans to invest around US$400 million in improving the drainage system over the next 2 to 3 years across 75 ongoing

[109] The Straits Times (2018). "Singapore Budget 2018: Carbon tax of SG$5 per tonne of greenhouse gas emissions to be levied". Available at: https://www.straitstimes.com/singapore/singapore-budget-2018-carbon-tax-of-5-per-tonne-of-greenhouse-gas-emissions-to-be-levied
[110] The World Bank. Available at: http://www.worldbank.org/en/programs/pricing-carbon
[111] Partnership for Market Readiness (2017), "India to Pilot Carbon Pricing Instruments with $8 Million PMR Support". Available at: https://www.thepmr.org/content/india-pilot-carbon-pricing-instruments-8-million-pmr-support
[112] International Carbon Action Partnership. Available at: https://icapcarbonaction.com/en/?option=com_etsmap&task=export&format=pdf&layout=list&systems[]=81
[113] Channel NewsAsia (2018), "Singapore opens its third desalination plant in Tuas". Available at: https://www.channelnewsasia.com/news/singapore/tuas-desalination-plant-water-singapore-pub-10477996
[114] Financial Times (2016), "Singapore airport guards against sea rise". Available at: https://www.ft.com/content/d8c727ee-44e0-11e6-9b66-0712b3873ae1

projects and 16 new locations.[115] The new airport terminal due to open in the 2020s is planned to be built 5.5 metres above mean sea level in order to achieve enhanced resilience to rising sea levels. Additionally, the Singapore-MIT Alliance for Research and Technology's (SMART) water-grid system provides real-time tracking of rising water levels of drains and canals.[116]

Globally, 210 cities already have climate change adaption plans in place, while 111 cities are developing one as of 2016.[117] For example, Netherland's National Water Plan (2016-21) sets new standards for flood risk management, such that the probability of death as a result of a flood would not exceed 0.001 percent per year.[118] The government also launched the "room for river" project from 2006-18 with an investment of more than US$2 billion. The project involved more than 30 measures including relocation and strengthening of dikes, lowering the flood plain by removing accumulated sediments, and changing the focus from higher dikes to wider rivers.[119]

Similarly, governments across other ASEAN countries are putting in place actions to increase resilience to rising sea levels:

- **Ho Chi Minh City's** flood prevention programme, "Moving towards the sea with climate change adaptation", leverages the expertise of the city of Rotterdam to design and invest over US$1 billion in flood prevention infrastructure.[120]
- **Jakarta**. In 2012, Open DRI (a data collection initiative launched by the Global Facility for Disaster Reduction and Recovery) worked with municipal officials to digitally collect data on 29,230 buildings and structures in Jakarta to be used as flood contingency planning analysis. The data was successfully tested during the 2012 flooding season in Jakarta, and has been subsequently used to train local disaster management agencies in other provinces in Indonesia.[121]
- **Manila** plans to plant 1.6 million hectares of bamboo and cultivate 600,000 hectares of mangrove in Laguna de Bay (a freshwater lake to the east of Metro Manila) to enhance the city's freshwater supply and reduce flooding in metropolitan Manila.[122]

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115 The Straits Time (2017), "PUB pumps in $500m more to keep floods at bay". Available at: https://www.straitstimes.com/singapore/pub-pumps-in-500m-more-to-keep-floods-at-bay
116 Financial Times (2016), "Singapore airport guards against sea rise". Available at: https://www.ft.com/content/d8c727ee-44e0-11e6-9b66-0712b3873ae1
117 International Finance Corporation [IFC] (2018), *Climate Investment Opportunities in Cities*. Available at: https://www.ifc.org/wps/wcm/connect/bffd2386-ff4c-454d-8366-8d801bf3b9c5/201811-CIOC-IFC-Analysis.pdf?MOD=AJPERES
118 Government of the Netherlands, *National Water Plan 2016-21.* Available at: https://www.government.nl/documents/policy-notes/2015/12/14/national-water-plan-2016-2021
119 Room for River. Available at: https://www.ruimtevoorderivier.nl/english/
120 Vietnam Climate Adaptation Partnership*, Moving towards the sea with climate change adaptation, May 2013*. Available at: http://www.vcaps.org/en
121 Leveraging partnerships globally, nationally and locally to invest in open tools and open data, Open DRI, 2013.
122 *Flood controls in Southeast Asia*, Eco-Business Research, 2017.

- **Kuala Lumpur's** "river of life" programme focuses on enhancing drainage. The seven-year project will cover eight rivers, with a total length of 110 kilometres, and concentrate on river cleaning, river beautification and commercialisation and tourism.[123]
- **Thailand's** water authority has implemented a state-of-the-art system to monitor and consolidate data across all its regional water systems to track supply, losses, customer use, and water levels during flooding. It relies on IoT to capture real-time data and uses big data analytics to synthesise the information and shape their responses in real-time.[124]

More investment needed to enhance our understanding of rising sea levels

Currently, there is immense opportunity for Singapore to develop local expertise to deal with rising sea levels. Three key areas require effort:

Singapore has limited or no university courses on oceanography and its relevant fields

1. **Deepen the local knowledge base.** Professor Horton emphasised the need for investment to build local expertise on oceanography and other relevant fields. There is also a need for interdisciplinary courses with oceanography, engineering, economics, public policy, and business to build a pool of local experts with strong context-based knowledge. Deepening our knowledge base would also enable Singapore to more accurately understand how climate change and rising sea levels would impact us, instead of having to work with a wide range of scenarios. Currently, there are a limited number of education and research institutions focused on sea level rise in countries most susceptible to the impacts. Most of them are located in Europe and the United States. The Netherlands is widely regarded as a pioneer in sea level rise management.[125] Their education institutions have strong emphasis on oceanography and coastal and marine engineering. For example, the TU Delft University Global initiative uses the expertise of the university's scientists to find solutions to problems around disaster resilience and response, healthcare, water, energy and urbanisation across the globe in collaboration with local country partners.[126] They have multiple dedicated research facilities focused on climate change, ocean energy, design and innovation among others. One such laboratory is the Cabauw Experimental Site for Atmospheric Research (CESAR) that was established to study atmospheric and land surface

[123] River of Life website. Available at: http://www.klriver.org/
[124] *Thailand's water authority to join up all data across three provinces*, FutureGov, 2014 and, *AGT International helps Hydro & Agro Informatics Institute of Thailand develop advanced flood management system,* AGT International, 2012.
[125] Architectural Digest (2017), "The Dutch Hold the Keys to Withstanding Rising Sea Levels and Worsening Storms". Available at: https://www.architecturaldigest.com/story/dutch-building-design
[126] TU Delft Global Initiative. Available at: https://www.tudelft.nl/global/

processes to enhance climate modelling, and a key source for experimental atmosphere research in the Netherlands.[127]

2. **Encourage private sector investment in research.** The Earth Observatory of Singapore at National Technological University (NTU), funded by public and private institutes such as the Ministry of Education and AXA research fund conducts research on climate change, earthquakes, volcanic eruptions and tsunamis.[128] However, there is room for Singapore's private sector to play a stronger role in investing in research and technology development on sea level rise mitigation and adaptation. Having the private sector invest in climate change solutions could also be beneficial to companies, given the business opportunities identified in climate change. Some examples of private sector efforts include Exxon Mobil's partnership with Nanyang Technological University (NTU) and National University of Singapore (NUS) to develop the Singapore Energy Centre in 2019 to research new technologies on energy efficiency and carbon abatement. The Singapore Energy Centre also builds on Exxon Mobil's collaborative efforts with other academic and research institutes such as its US$20 million grant to Stanford University's Strategic Energy Alliance – a platform to match large global companies with relevant Stanford academics.[129] Building on the existing NUS Deltares Alliance, the National University of Singapore (NUS) and the Dutch applied research institute, Deltares, signed a memorandum of understanding in 2016 to explore the development of a new Singapore Centre on Urban Resilience (SeCURE).[130] The centre aims to address climate change induced issues such as flooding and droughts. Beyond climate change mitigation, there appears to be a large amount of "white space" for private companies to invest in research that deals directly with adaption, and to develop new technologies to make cities more resilient to rising sea levels.

3. **Develop Singapore as a climate change hub in Asia to encourage innovation and international collaboration.** Singapore is already a global hydrohub, attracting global water companies to use the country as a test-bed for water related technology pilots. This has led to investments, such as GE Water and Process Technologies' US$130 million investment to develop a water R&D centre at NUS, as well as collaborations such as the Singapore Delft Water Alliance and SeCURE[131], a partnership between the Netherlands and Singapore that focuses on sustainable water management, climate change and natural disasters.[132] Hence, there is a similar opportunity for Singapore to transform into

[127] CESAR Observatory. Available at: http://www.cesar-observatory.nl/index.php
[128] Earth Observatory Singapore. Available at: https://www.earthobservatory.sg/about/mission
[129] Stanford News (2018), "Stanford launches new energy research program in collaboration with industry". Available at: https://news.stanford.edu/2018/03/01/new-energy-research-program-collaboration/
[130] Deltares (2016), "Deltares and NUS partner to address challenges in urban resilience". Available at: https://www.deltares.nl/en/news/deltares-and-nus-partner-to-address-challenges-in-urban-resilience/
[131] It is a collaboration between Deltares, the Netherlands based research institute and consulting firm specialising in water management, National University of Singapore and the Public Utilities Board between 2007 to 2014.
[132] SDWA Compendium. Available at: https://cpb-us-w2.wpmucdn.com/blog.nus.edu.sg/dist/4/4562/files/2015/03/SDWA-Compendium-Web-vsygvn.pdf

a climate change hub to deepen knowledge and develop a global R&D base for climate change mitigation and, in particular, dealing with sea level rises.

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Rising sea levels pose one of the greatest threats to human civilisation. The good news is that it is not too late to act. However, tackling this challenge will require a transformation of current approaches by businesses and governments, and new insights from academia.