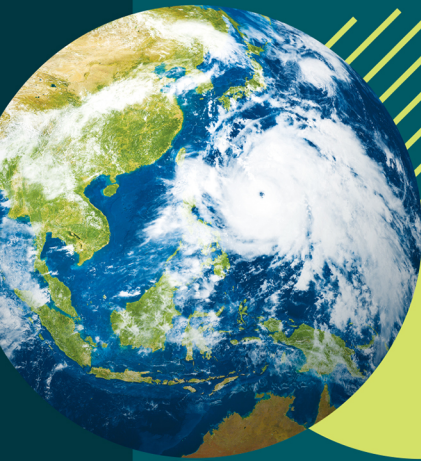


Addressing Climate Risk in Coastal Urban Areas of East and Southeast Asia

Connecting Climate Science, Engineering and Finance

Edited by Bruce Chong



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**Connecting Climate Science, Engineering
and Finance**

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Connecting Climate Science, Engineering and Finance

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Published by Emerald Publishing Limited, Floor 5,
Northspring, 21-23 Wellington Street, Leeds LS1 4DL.

ICE Publishing is an imprint of Emerald Publishing Limited

Other ICE Publishing titles:

Coasts, Marine Structures and Breakwaters 2023: Resilience and adaptability in a changing climate

Edited by Kevin Burgess. ISBN 978-0-7277-6704-2

Landslide Risk Assessment: Third edition

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ICE Manual of Blue-Green Infrastructure

Edited by Carla-Leanne Washbourne and Claire Wansbury.

ISBN 978-0-7277-6542-0

A catalogue record for this book is available from the British Library

ISBN 978-1-80592-085-4

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Cover design by Arup, incorporating images licensed by Getty Images.

Commissioning Editor: Michael Fenton

Content Development Editor: Ryan Molyneux

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Typeset by: KnowledgeWorks Global Limited

Index created by: David Gaskell

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Foreword

Climate change is challenging how we build and maintain coastal cities' infrastructure all over the world. We are observing higher temperatures, more intense storms, and rising sea levels. We engineers can no longer assume that the loads that our structures will be subject to in the future will be statistically similar to what has been observed in the past. The future is uncertain in ways that are profoundly unsettling for engineers. Yet engineers like a challenge! Creating urban infrastructure that is resilience to the impacts of climate change, so that city dwellers can prosper even when faced with a changing climate, is an utmost challenge for civil engineers. Meanwhile, we need to be intensifying our efforts to cut carbon emissions from infrastructure, which are driving climate change. There is much to do, and resources are inevitably limited, so we need to develop new methods and ingenious designs.

This book on *Addressing Climate Risk in Coastal Urban Areas of East and Southeast Asia* is a comprehensive analysis of the threats faced by Asian coastal cities and an authoritative explanation of the methods for addressing these challenges. That involves carefully assessing the risks from climate change, including the many uncertainties about the future, and then appraising options for coastal development that enhance system resilience. This requires engineers to step outside their comfort zone, to understand how climate models work, how insurers assess risks and how the finance sector prices risk. All of those crucial topics are covered in this important book.

Engineering for a changing climate has progressed rapidly over the last two decades, and has now reached a point where an authoritative volume like this one can be published, including some compelling case studies. There is still much more to do, to push forwards the methods for assessment and design, and to bring the whole of the engineering profession up to a high standard of capability for responding to climate change. This book makes an important contribution in that direction, so I commend it to you.

Jim W Hall
FREng FRS
160th President, Institution of Civil Engineers
Professor of Climate and Environmental Risks
Environmental Change Institute
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Preface

This book is a collaborative effort from experts in climate, engineering and finance. It focuses on our coastal cities and infrastructure that face the prospect of stronger tropical cyclones and changes in the intensity of extreme climate events such as coastal storm surges, wind and temperature – all amid existing environmental pressures and challenging social and economic environments.

We embark on this book because there is a need to integrate insights from research and practice in a more accessible way. For over a decade, we have drawn from theory and first-hand experience to show how to assess and reduce vulnerability to climate change impacts, and build adaptive capacity and resilience. Our aim is to provide insights and guidance for a diverse yet specific audience. The interdisciplinary approach of the book ensures that readers from different backgrounds can find relevant and practical information to inform their decision-making processes. While readers can focus on specific chapters tailored to their roles, the case studies included in Part III and Part IV of this book will be of great interest to all.

Policymakers, project proponents and professionals in all related sectors should read Chapters 2 and 3, which provide an overview of climate trends, integrated approaches to addressing climate risk, strategies for enhancing infrastructure resilience, and recommendations for advancing climate resilience. These chapters offer a comprehensive understanding of climate challenges and potential policy interventions to promote resilient infrastructure development.

Climate scientists should focus on Chapters 4 and 5, which detail climate modelling techniques, downscaling methods and the selection of global climate models for projections. These chapters provide insights into creating localised climate projections and understanding the impacts of climate change on extreme weather events. Additionally, Chapters 6 and 7 offer methods for assessing tropical cyclones in the western North Pacific basin, which would be valuable for climate scientists studying this region.

Engineers and hazard modellers should prioritise Chapters 6–8 and the case studies in Part III, which cover hazard modelling, risk assessment and infrastructure resilience enhancement. These chapters offer methodologies for assessing tropical cyclone and coastal hazards, projecting future climate impacts and developing strategies to improve infrastructure resilience against climate-related risks.

Risk modellers, investors, bankers, insurance underwriters and brokers should concentrate on Chapters 9, 17 and 18, which address financial risk

assessment, damage analysis, adaptive investment and regulatory guidelines for climate risk management. These chapters provide frameworks for quantifying climate-related financial risks and benefits and integrating them into decision-making processes for investments and insurance products.

Investing in climate resilience is not only good policy – it has been shown to have a net-positive impact over time. While climate-resilient measures can increase the lifespan of infrastructure, they also play an essential role in protecting investment returns and ensuring business continuity for the whole city and region. This implies that while we enhance our capacity to withstand the next impact, we can in parallel contribute to making our future more sustainable.

Bruce Chong
Chief editor
Fellow¹ and Director (Climate & Sustainability), Arup

¹The Arup Fellows programme is run by Arup University. This is a small, unique cohort of Arup members whose industry knowledge and experience represent the highest technical accolade achievable within Arup. Their remit is to inspire and unlock creativity and innovation in the work of their colleagues and peers. Fellowship is awarded in recognition of an individual's visionary leadership, willingness to explore the boundaries of what is possible and their commitment to technical brilliance and cross-disciplinary collaboration.

About Arup

Through numerous outstanding climate resilience projects, Arup has demonstrated its commitment to addressing global challenges related to climate hazards. We have delivered solutions for a wide range of high-profile and strategic projects, including super typhoon studies for Hong Kong, and coastal resiliency and management analyses for Singapore. Our work on critical infrastructure – including studies on high-speed rails, airports, highways, ports and coastal facilities for city governments, and infrastructure and utilities operators in Manila, Bangkok, Ho Chi Minh City, Kuala Lumpur, Jakarta, Phnom Penh and others – along with our contributions to projects for the Asia Development Bank, Asian Infrastructure Investment Bank and World Bank projects, highlight our leadership in climate resilience engineering and environmental stewardship. Beyond Asia, we have spearheaded key climate initiatives worldwide, including New York City’s water and climate projects, coastal resilience for the future of the UK Fens (Fens 2100+), Heathrow’s climate resilience efforts, Sydney Metro’s climate risk and design plan, and Dubai’s climate adaptation and resilience plan, to name just a few.

Arup advises on, plans and designs the future of the built environment. As a global consultancy with technical and advisory expertise across more than 150 disciplines, we bring a total design approach to our work with our clients. Since our establishment in 1946, Arup has paired design and engineering ambition with social purpose. Today, we harness our deep technical expertise, partnering with our clients, to build a better future for all.

Driving technical excellence – and, in many cases, defining excellence in our fields of expertise – is at the heart of Arup University’s work. Established in 2009, Arup University is home to our strategic foresight, research and innovation capabilities and our learning function. We focus on future needs, preparing both our members and our clients for the opportunities and challenges of a complex world and the markets we operate in.

The publication of this book is enabled by Arup University, with an aim to raise the technical standards of the firm and the industry. This book offers a comprehensive framework for managing climate challenges. It combines insights from climate science, engineering and finance, showcasing Arup’s dedication to pioneering a collaborative and multidisciplinary approach to tackling climate hazards and enhancing resilience in the coastal urban areas of East and Southeast Asia.

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Editors

Dr Bruce Chong – chief editor

Bruce is a Fellow and Director of Climate & Sustainability at Arup. He has overseen the entire publication of this book, providing expert knowledge to ensure the book is comprehensive, accurate and valuable to its readers. His contributions are instrumental in making the content both insightful and practical for those looking to understand and tackle the complex challenges posed by climate hazards in the coastal urban areas of East and Southeast Asia.

Florence Van – managing editor

Florence is a senior editorial specialist at Arup University (AU). Her responsibilities include content planning and production for various publications under AU to promote Arup's technical excellence, and providing editorial support across different functions within AU such as foresight, innovation, research and learning. With a bachelor's degree in English and a master's degree in European Culture, she has over 10 years of experience in editing, translation and interpreting.

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Ruby is a freelance writer, editor and civil engineer with over 25 years' experience in the built environment. Formerly Head of Insight at the Institution of Civil Engineers, she has written extensively on infrastructure, design and engineering innovation, including the book *Arup's Tall Buildings in Asia: Stories Behind the Storeys* (Routledge).

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Dr Ander Chow – Principle Maritime Specialist, Arup

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Pluto holds a bachelor's degree in Physics, an MPhil in Physics and an MSc in Computer Science. His postgraduate research and previous employment at Hong Kong Observatory provided him with solid experience in numerical weather modelling, machine learning, GIS visualisation and environmental science IT projects. Pluto has expertise in open-source simulations like WRF, CMAQ, PALM LES, GEOS-Chem and OpenFOAM for urban airflow simulation on Linux systems.

Dr Goman Ho – Fellow and Director (Structural Engineering), Arup

Goman has 33 years of experience in tall building design, delivering large-scale projects globally, especially in East Asia. Known for his leadership and collaboration, he was the first global leader of Arup's Tall Buildings Skills Network. His impressive portfolio includes iconic structures like the CCTV headquarters, Beijing Olympics National

Stadium and the CITIC Tower in Beijing. He has published over 40 technical papers, received numerous awards and holds a patent on a connection system for steel and RC MiC modules. He also serves as an adjunct professor and advisory panel member at Hong Kong Polytechnic University.

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Acknowledgements

Many people and organisations contributed to and supported us in developing and finalising this book. The editors and authors would like to express their sincere gratitude; they especially appreciate the invaluable contributions of all those who shared their knowledge and wrote case studies. This book would not have been possible without the invaluable support and contributions of the following individuals and organisations.

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The University of Hong Kong

Glossary

Absorptive capacity	A measure of robustness of an asset or system and its ability to withstand the immediate effects of disruption due to climate hazards or disaster.
Adaptation	The process of adapting natural and human systems to avoid the harm from climate change impacts.
Adaptive capacity	The ability of a system to change to deal with future disruptions and uncertainties.
Average annual loss	A long-term average of the expected annual loss due to a climate hazard.
Climate finance	Public and private sector funding to support climate mitigation and adaptation projects, such as loans and grants.
Climate model	A numerical representation of the climate system – atmosphere, oceans, cryosphere and land surface – based on physical principles, used to simulate past, present and future climate conditions.
Climate risk	The potential adverse consequence of climate change that occurs as a result of hazard, exposure and vulnerability, as well as human responses to climate change.
Component	An individual element or a sub-element of an infrastructure asset, such as the foundation within a road segment or transformers within a substation.
Cost–benefit analysis	An evaluation method that compares the total expected costs against the benefits, expressed in monetary terms, to inform decision-making.
Downscaling	Dynamical and statistical methods used to derive finer scale regional climate information from global climate models outputs.
Exposure	The presence of people, assets or ecosystems in places that could be impacted by climate hazards.
Extreme event modelling/ extreme value analysis	The application of climate data to characterise and simulate rare but high-impact extreme weather events, such as storm surges.
Global climate models	Global models that simulate processes and cycles in the atmosphere, ocean, cryosphere and land surface of the planet.
Hazard	The probability of the occurrence of hazardous events.

Infrastructure asset	An individual element within a broader infrastructure system, such as a specific power plant, road segment or pipeline.
Infrastructure sector/type	Various categories of infrastructure system such as power, drainage, maritime, road, railways, buildings, telecommunications etc.
Infrastructure system	The broad system or/and networks of infrastructure, such as a power system comprised of power plants and transmission and distribution networks.
Metric	A quantifiable tool used to assess potential financial losses due to physical climate risks.
Monte Carlo simulation	A simulation technique that uses repeated random sampling to simulate hypothetical future hazard events and compute the probability distribution of extreme events.
Nature-based solution	The use of natural systems and processes to address societal challenges, such as climate adaptation and mitigation.
Pathways	Projections of future emission trajectories that outline the actions needed to meet specific climate targets.
Regional climate models	Localised and detailed regional climate models that refine the broad-scale outputs of GCMs.
Resilience	The ability of a system, such as infrastructure and community, to absorb shocks from climate events and recover quickly.
Restorative capacity	The recoverability of infrastructure after disruption or damage.
Return period	The average interval of time between occurrences of a given magnitude of event, calculated from long-term observational records.
Risk assessment	A process that identifies climate hazards, evaluates exposure and vulnerability, and quantifies potential financial losses under various scenarios.
Scenario	A plausible storyline describing future socioeconomic and technological developments, used to generate climate projections under different assumptions.
Stochastic modelling	The incorporation of random variability into models of climate drivers to produce ensembles of outcomes to capture the possible impacts.

Tropical cyclone	A rapidly rotating storm system with a low-pressure centre, strong winds and intense rainfall, forming over warm tropical oceans.
Uncertainty	The degree to which the outcome of a process or model is unknown.
Vulnerability	The propensity of a system to suffer harm from climate hazards.
Weather and research forecasting model	A regional weather prediction model that is designed for research and operational weather forecasting at regional scales.
Wind field model	A representation of spatial wind speed and direction patterns during storms, used to estimate damage footprints and associated economic loss.

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Abbreviations

AAHK	Airport Authority Hong Kong
AAL	average annual loss
ADB	Asian Development Bank
AR	assessment reports
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BCBS	Basel Committee on Banking Supervision
CDRI	Coalition for Disaster Resilient Infrastructure
CEDD	Civil Engineering and Development Department
CFD	computational fluid dynamics
CFTC	Commodity Futures Trading Commission
CIBSE	Chartered Institution of Building Services Engineers
CMIP6	Coupled Model Intercomparison Project Phase 6
CO ₂	carbon dioxide
CRA	climate risk and adaptation assessment
CRM	climate risk management
DS	damage state
DSD	Drainage Services Department
DV	decision variable
DWL	design work life
ECB	European Central Bank
ECS	equilibrium climate sensitivity
ESG	environment, social and governance
EU	European Union
GCM	global climate models
GDP	gross domestic product
GHG	greenhouse gas
GMSL	global mean sea level
GMST	global mean surface temperatures
GPH	geopotential height
HKIA	Hong Kong International Airport
HKMA	Hong Kong Monetary Authority
HKO	Hong Kong Observatory
HKSAR	Hong Kong Special Administrative Region
HVAC	heating, ventilation and air-conditioning
ICT	information and communication technology
IFRS	International Financial Reporting Standards
IPCC	Intergovernmental Panel on Climate Change
ISSB	International Sustainability Standards Board
JMA	Japan Meteorological Agency
LEWS	landslide early-warning systems
LGD	loss given default
LTV	loan-to-value

MAS	Monetary Authority of Singapore
MCS	Monte Carlo simulation
NBS	nature-based solutions
PD	probability of default
PDF	probability distribution function
PGW	pseudo global warming
PMP	probable maximum precipitation
PUB	Public Utilities Board
PVaR	physical value-at-risk
PWDM	<i>Port Works Design Manual</i>
RCM	regional climate models
RCP	representative concentration pathways
RH	relative humidity
RMSE	root mean square error
RMW	radius of maximum wind speed
SDGs	sustainable development goals
SLR	sea level rise
SSP	shared socioeconomic pathways
SST	sea surface temperature
TCFD	Task Force of Climate-related Financial Disclosures
UHI	urban heat island
UNDDR	United Nations Office for Disaster Risk Reduction
WHO	World Health Organization
WMO	World Meteorological Organization
WNP	western North Pacific
WRF	weather research and forecasting

Part I

Climate change trends and challenges

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Bruce Chong

ISBN 978-1-80592-085-4

<https://doi.org/10.1108/978-1-80592-084-720251001>

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Chapter 1

Introduction

Bruce Chong, Eunice Yip

1.1. Aim of this book

The effects of climate change are prompting urban administrations and corporations to reassess how they plan, design, construct and maintain infrastructure. Multiple sectors need to work together to address the challenges faced by increasing populations exposed to weather-related risks. Key players in this effort are climate scientists, engineers and experts in finance, banking and insurance. Traditionally, these disciplines have worked in isolation, often unaware of each other's efforts or the interconnections that exist between them in tackling climate risks. Climate scientists, for example, may not fully grasp the level of detail required in climate hazard models developed and used by engineers designing infrastructure, while engineers' models may fail to align with financial risk models used by banks and insurance firms.

A recent study by [Cosby *et al.* \(2024\)](#) identified a strong link between population distribution and coastal proximity, with coastal populations growing at a faster rate than inland areas. With many East and Southeast Asian cities located along coastlines, rivers and across deltas, more people in these urban areas are being exposed to the effects of accelerated sea level rise, increased sea surface temperatures, more intense and extra tropical cyclones, extreme waves and storm surges, altered precipitation and runoff and land subsidence ([World Bank, 2010](#)). At the same time, these coastal urban areas are the engines of economic growth and development, presenting great opportunities for innovation and strategic development.

The main aim of this book is to present an integrated, cross-disciplinary and collaborative approach to address climate risks, such that responses from each sector – climate science, engineering and finance – have a collective awareness that enables mutual benefits. Although the book concentrates on East and Southeast Asia, the methodologies, strategies and exemplary practices for evaluating climate risk and identifying adaptation strategies are likely to be applicable to other coastal regions.

1.2. A dynamic environment under a changing climate

The Coalition for Disaster Resilient Infrastructure estimates that the average annual loss (AAL) for infrastructure and buildings due to climate damage is a staggering US \$700 billion or more ([CDRI, 2023](#)). AAL is a measure of expected value of future losses every year over a long span time-frame, derived from probabilistic risk models. This means that investing in new infrastructure, without prioritising enhanced resilience, is akin to pouring water into a leaky bucket – losses will continue until underlying vulnerabilities are addressed. Such compelling evidence means that governments, development agencies and private sector stakeholders should adopt a resilience-first approach to infrastructure planning and development, involving climate risk assessments, adaptive design strategies and innovative technologies, to create infrastructure that can withstand and rapidly recover from climate disasters. Nations will then not only protect long-term investments but also ensure more sustainable and efficient resource allocation.

Global agreements on reducing emissions, such as the Paris Agreement, advocate transitioning from carbon-intensive infrastructure to systems with low, zero or negative emissions. However, the reality for nations already suffering climate disasters is that new capital investment is all too often directed to deal with asset damage and service interruptions, making investing in infrastructure needs and deficits seemingly impossible. This cyclical pattern of destruction and reconstruction hampers long-term economic growth and development.

There is variation in the additional challenges faced globally in enhancing infrastructure resilience too. Developed nations that industrialised early, for example, face the challenge of replacing outdated infrastructure to withstand both new and existing threats, while developing nations, with infrastructure gaps, are hampered by poor governance.

It is predicted that US \$9.2 trillion must be invested annually to address infrastructure deficits, the United Nations' Sustainable Development Goals (SDGs) and achieve net zero by 2050, with US \$2.76 trillion of this sum needed in low- and middle-income countries (CDRI, 2023). While investment in high- and many middle-income nations is growing steadily, infrastructure investment in low-income countries remains significantly below projected needs. Despite this, investing in infrastructure resilience could set nations on a path to high-quality and reliable essential services, reduced infrastructure damage, lower systemic risk and sustainable socioeconomic growth. The benefits are far-reaching. More resilient infrastructure can also lead to enhanced biodiversity, improved air and water quality and more efficient land use.

1.3. Learning from real-world design and practice

This book brings together perspectives on climate risk from the worlds of climate science, engineering and finance, and demonstrates how theoretical frameworks can be applied to practical situations. These examples demonstrate how climate risks can be assessed, modelled and incorporated into infrastructure design. They provide insights into how infrastructure systems can be designed and managed to enhance resilience amidst the continuing threat of climate disasters. A clear pathway is presented for implementing resilience strategies in diverse contexts, from policy and strategy formulation to project execution and infrastructure investment.

1.4. Structure of this book

This book is split into five parts and 19 chapters.

Part I – Climate change trends and challenges

- Chapter 1 outlines the scope and structure of this book, emphasising the need to enhance climate resilience in coastal urban areas of East and Southeast Asia.
- Chapter 2 reviews the climate science, engineering and finance landscape, and explains the importance of developing a holistic framework for assessing and enhancing climate resilience.

Part II – An integrated approach to addressing climate risk

- Chapter 3 provides an overall approach of incorporating climate science, engineering and finance perspectives across project cycles. Each part of the framework is further elaborated in the subsequent chapters of Part II.
- Chapter 4 describes the standard method currently available to obtain localised future climate projections and suggests a best practice approach.

- Chapter 5 explains one of the key steps, selection of global climate models (GCMs), for climate projections in the western North Pacific (WNP) Ocean region.
- Chapter 6 establishes a standard method for assessing infrastructure climate risk. It details methodologies for hazard and extreme event modelling, particularly on tropical cyclones and coastal hazards.
- Chapter 7 presents a more advanced approach for assessing tropical cyclones and wind hazards in the WNP region.
- Chapter 8 covers the strategic approaches of setting out infrastructure resilience pathways, and key principles to guide capacity and resilience enhancement of infrastructure.
- Chapter 9 connects physical climate risks and hazards to financial implications and advanced economic modelling.

Part III – Case studies: climate science, engineering and infrastructure

- Chapter 10 outlines the process of identifying and evaluating critical infrastructure in relation to climate hazards.
- Chapters 11 to 16 illustrate how climate resilience is incorporated into infrastructure and building projects to address the following climate hazards
 - urban flooding
 - coastal flooding
 - tropical cyclone
 - extreme wind
 - landslide
 - extreme heat.

Part IV – Case studies: infrastructure and finance

- Chapter 17 shows the approach of quantifying climate risk and opportunities.
- Chapter 18 emphasises the need for financial institutions to assess how climate risk impacts financial risk, and gives an example for scenario analysis and stress testing in residential mortgage portfolios.

Part V – Summary

- Chapter 19 summarises new directions for the implementation of climate resilience assessments and enhancement.

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ISBN 978-1-80592-085-4

<https://doi.org/10.1108/978-1-80592-084-720251002>

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Chapter 2

The climate science, engineering and finance landscape

Bruce Chong, Eunice Yip

2.1. Introduction

To understand climate science, engineering and finance in relation to the infrastructure of urban areas of East and Southeast Asia requires some grounding in the trends, risks and challenges that currently exist. The role of the Intergovernmental Panel on Climate Change (IPCC) and the rigour with which its assessment reports (AR) capture the latest thinking is foundational to climate change modelling and impacts at global, regional and local levels. Studies currently show the disproportionate economic effect climate change will have on infrastructure in East and Southeast Asia unless action is taken. Despite the challenges, tools and guidelines exist that can help foster cross-sector collaboration and address climate risk.

2.2. Trends in climate science

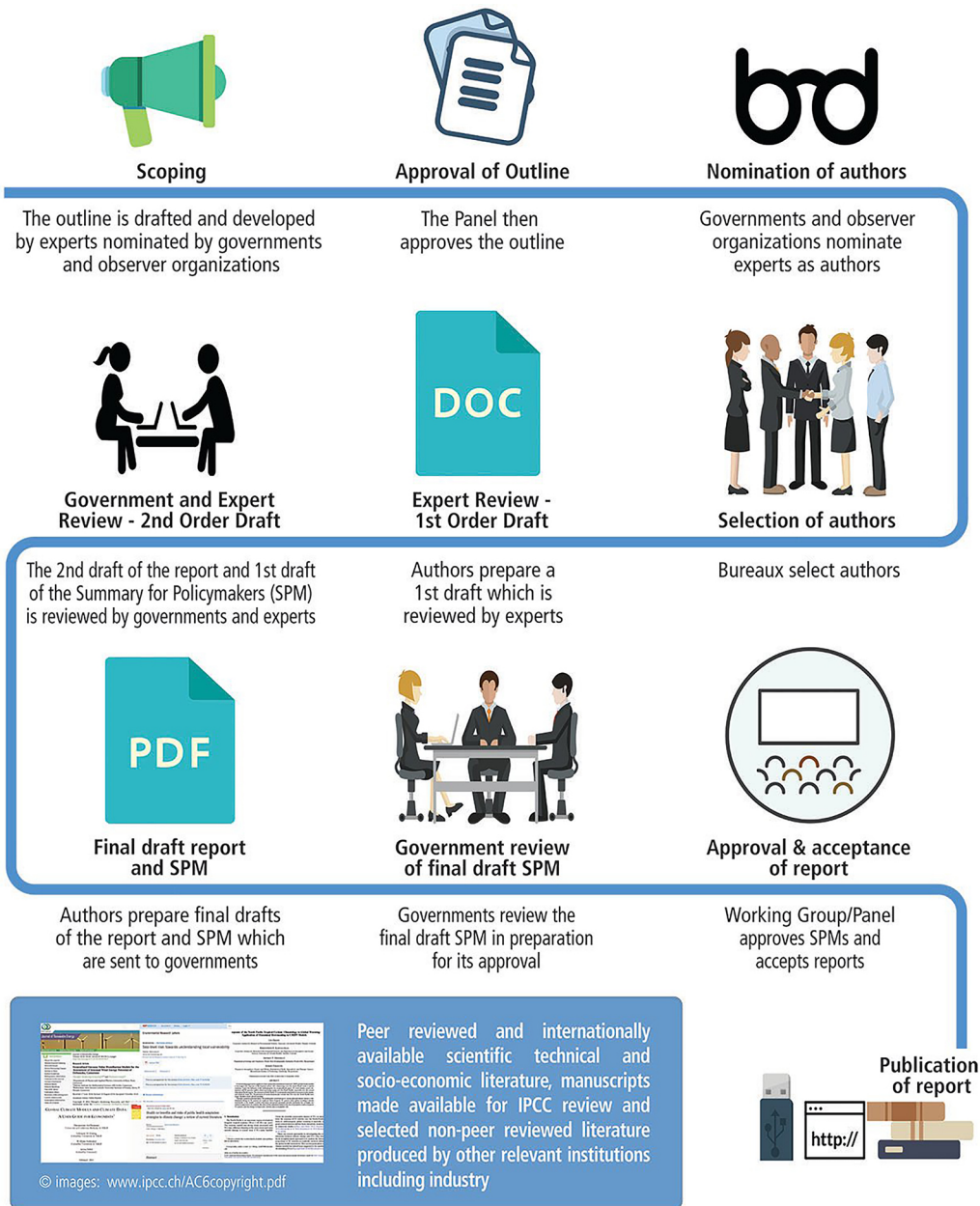
2.2.1 The Intergovernmental Panel on Climate Change (IPCC)

The IPCC is the United Nations body that informs governments of the science related to climate change, which enables them to develop climate policy. The IPCC consists of three working groups (WGs) that assess a broad range of climate-related science: WG I focuses on the physical science basis of climate change, WG II focuses on climate change impacts, adaptation and vulnerability, and WG III focuses on mitigation of climate change. The groups assess scientific papers published on climate science to provide a comprehensive summary of current scientific understanding of climate change. The summary is compiled into assessment reports (AR) published every five to seven years. Each AR includes a summary of policymakers (SPM) that undergoes a line-by-line approval process (see [Figure 2.1](#)) by IPCC member governments to ensure there is consistency with wider governmental and scientific consensus. The most recent, AR6 ([Calvin, 2023](#)), was completed in March 2023, providing critical updates on climate science and impacts.

The WGII report from AR6 is foundational for understanding the impact of climate hazards, both globally and regionally. The report delves into the vulnerabilities and adaptation needs of various regions and includes a chapter on the Asia–Pacific region. The report assesses climate hazards, such as tropical cyclones, coastal flooding and storm surges, which are particularly relevant for coastal urban areas in East and Southeast Asia.

Since AR5, IPCC reports have demonstrated the role of interdisciplinary climate change assessments and the need to integrate physical sciences, social sciences and economic studies to present a holistic view of future risks. AR6 emphasises risk and solution frameworks, as well as the role of social justice, equity and transformation in meeting societal goals. Besides discussing the latest state of climate science, AR6 also presents frameworks for monitoring and evaluating adaptation

Figure 2.1 The preparation, approval and acceptance of IPCC Assessment Reports (©IPCC, 2018. <https://www.ipcc.ch/about/preparingreports/>)



and mitigation efforts. For AR5, the representative concentration pathway (RCP) scenarios were used, where the RCPs are labelled according to a possible range of radiative forcing values in the year 2100 (values in watts per square metre used include: 2.6 low, 4.5 intermediate, 6.0 and 8.5 high emission scenario). Since AR6, the pathways have been considered together with shared