Asia-Pacific Economic Cooperation

APEC Integrated Urban Planning Report

Combining Disaster Resilience with Sustainability

ENERGY WORKING GROUP

March 2021

APEC Integrated Urban Planning Report – Combining Disaster Resilience with Sustainability

APEC Energy Working Group

March 2021

SOM Steering Committee on Economic and Technical Cooperation (SCE)
Energy Working Group (EWG)

APEC Project: EWG 09 2019S

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APEC#221-RE-01.1 ISBN: 978-981-18-0275-1

Foreword

APEC Sustainable Energy Center (APSEC) is pleased to present the *APEC Integrated Urban Planning Report – Combining Disaster Resilience with Sustainability*. This report is the second APEC report produced by APSEC and endorsed by the APEC Energy Working Group (EWG). In 2018, the EWG adopted the *APEC Sustainable Urban Development Report – From Models to Results*, outlining elements of a cooperative strategy for scaling up APEC sustainable urbanization by targeted focus on energy technologies that synergize resilience with better economic performance, social inclusiveness and less environmental impact. Whenever the present report refers to the earlier one, this will be done by indicating *APSEC (2018).*

The APEC High-Level Urbanization Forum having taken place in Ningbo in June 2016 was the first large-scale high-level event under the APEC framework with a focus on urbanization. The Ningbo initiative that started at that occasion affirmed the importance of promoting sound, sustainable and people-oriented urbanization in APEC within the Asia-Pacific Urbanization Partnership that had been endorsed by APEC Economic Leaders in Beijing in November 2014.

The present report has been planned before the outbreak of the COVID-19 pandemic. Its objective is to show ways in which cities can cope with sustainability and improve their long-term resource management while they are at the same time constantly being hit by an increasing number of natural disasters causing more and more harm to their exposed communities. This objective has remained unchanged. However, the pandemic has brought about the necessity to completely reshuffle and restructure the report. Not only are pandemics disasters of the type described in this report, but also have APEC cities been very strongly affected by COVID-19. The reason is that cities are the centres and meeting points of human activity and may, therefore, become decisive elements in spreading epidemics. In the context of epidemics, cities may easily become part of the problem. This report aims, however, at describing measures to make cities disaster resilient and, therefore, becoming part of the solution against disasters in general, including epidemics.

The challenge of COVID-19 is that it is a special kind of disaster that threatens potentially any city of the world, no matter where it is. This contrasts with most other types of disasters such as disasters of geological or hydrometeorological origin that are more likely to hit only specific geographical zones, leaving other zones untouched. In these latter cases, urban planning clearly has a role to play. Land zoning can identify disaster-prone areas and help city authorities to fix rules minimizing disaster impacts, thereby saving lives and property.

This shows that urban planning clearly has a role to play in fighting epidemics, but that this role is not directly related to zoning. In times of a global pandemic of unprecedented extent, the discussion of urban resilience and urban sustainability could not limit itself to issues of urban zoning. Rather, a much broader range of urban planning instruments should be considered. The urban planning methods presented in Chapter 2 of the report have been complemented by a two-fold discussion of urban resilience in Chapter 3. Urban resilience is first discussed under an impact-specific partition, impacting ecological, social, economic and governance systems in turn, and thereafter under a disaster-specific partition comprising in turn resilience against disasters of climatic, geological and epidemic origin, as well as cyber resilience.

Because of its broader focus and greater depth, the report now addresses a readership of greater variety and heterogeneity. The urban policymakers might appreciate the largest part of the report. Depending on their prior knowledge, they might most appreciate Chapter 1 on understanding disasters, as well as the analysis of Chapter 3 on integrating disaster resilience into urban planning, and Chapter 4 on results-oriented monitoring.

The urban planners might be more particularly interested in specific sections such as the analysis of disaster mortality and economic risk of APEC cities in Chapter 1, transit-oriented development, land value capture and best practice cases in Chapter 2, disaster specific resilience in Chapter 3 and the urban SDG tracker in Chapter 4.

The business and finance community could e.g. focus on the sections about economic risk of APEC cities, private-public partnerships, theory of constraints, economic resilience, and the urban SDG tracker.

Academics and scholars might be most interested in the sections on risk appraisal, on the developments from sectoral to integrated urban planning in Chapter 2, on the discussion on complex adaptive systems in Chapter 3 and on the urban SDG tracker in Chapter 4.

Another challenge of COVID-19 is its ongoing nature. Knowledge accumulation about the nature of this pandemic is very rapid. This means that hardly any knowledge about this pandemic can pretend to be final. What we know today, including our most recent findings might be obsolete tomorrow. This is the limitation and caveat of all the evidence presented and discussed in this report about resilience against epidemics.

This report does not necessarily reflect the views or policies of the APEC Energy Working Group or individual APEC member economies. We still hope that it will serve as a useful basis for analytical discussion both within and among APEC member economies for the enhancement of sustainable urban development.

APEC Sustainable Energy Center

Acknowledgements

This study could not have been completed without the invaluable contributions of many individuals who provided insightful comments and suggestions. Specifically, we are grateful to the following experts:

Lead author: DEFILLA Steivan, President Assistant, APEC Sustainable Energy Center

Contributors at both Workshops on Cooperative Network of Sustainable Cities (CNSC), held during the 5th and 6th Asia-Pacific Sustainable Energy Development Forum on 19 September 2019 and 17 September 2020, respectively: APEC Delegates from Australia; Canada; China; Hong Kong, China; Indonesia; Mexico; the Philippines; Thailand; United States; Viet Nam, and participants from UK; International Renewable Energy Agency (IRENA); Asian Infrastructure Investment Bank (AIIB); UN Economic and Social Commission for Asia and the Pacific (ESCAP); World Resources Institute (WRI); Regulatory Assistance Project (RAP); and Rocky Mountain Institute (RMI).

Special thanks go to the reviewers who commented on the first draft:

CHEN Yong, Program Officer Sustainable Urban Energy, IRENA

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Purposes, Key Findings and Recommendations

Purposes

- to analyse and understand the main disasters threatening APEC and its cities and to understand the specific nature of climate-related risk as a type of systemic risk.
- to give an overview of traditional urban planning and of new approaches of integrated urban planning designed to improve sustainability under SDGs.
- to show that disaster resilience and sustainability are like Siamese twins that should both be integrated into urban planning.
- to propose a step-by-step methodology for cities to introduce results-oriented monitoring of sustainability and disaster resilience by means of an urban SDG tracker.

Key Findings – Chapter 1

Uncertainty has become the main characteristic of the COVID-19 world. Even the best-informed people of the World Economic Forum were not capable in autumn 2019 to foresee the planetary pandemic that shook the world a few months later and penetrated every aspect of cities and communities worldwide. As a result, the global UN sustainability frameworks may have to be completed by a tool on systemic risk management. Understanding and assessing the risks of urban and local communities requires familiarity with several types of risk definitions which are currently in use in different disciplines, such as risk of loss of life and risk of loss of wealth (or GDP), tolerance, and with terms such as hazard, exposure, vulnerability, end coping capacity. The report presents *We Inform,* the risk terminology proposed by the UN which harmonizes the traditional approaches of disaster risk reduction (DRR) and climate change adaptation (CCA).

The report shows that loss of life due to disasters has made sensational progress in APEC region since 1900. 85% of lives lost in disasters in all APEC economies combined in the period 1900 to 2018 are attributable to eight large disasters having all taken place in China before 1976. In the period 1900 to 1959, the average number of deaths per disaster in the APEC region was 200 times higher than in the period 1960 to 2018. Floods cause 63 times less deaths in the second period (1960 – 2018) than in the first one (1900 – 1959); droughts 258 times less. Epidemics (before COVID-19) caused 73 times less deaths, whereas earthquakes caused only 7% less deaths between the two periods compared. On the other side, since 1960, deaths due to storms and heat waves, both related to the warming atmosphere, have been on the rise and show an ascertained increase of 2% per year in APEC. Since 1960 also epidemics show a slight increase, whereas earthquakes show a slight decrease, neither of them being statistically significant.

Expected GDP loss of 279 cities worldwide increased by 5.6% between 2018 and 2019, of which 1.3% is due to higher hazard or probability of event, 4% due to higher GDP, and 0.2% due to higher exposure (i.e. vulnerability minus protective capacity). All disasters cumulated cause annual average GDP loss of 1.39% or 2.79bn$ in each of the sampled 120 APEC cities. Tropical windstorms are the most destructive natural hazard causing 508M$ GDP loss per year and per city in APEC compared to 235M$ for the global average city. The biggest specific single threat to GDP worldwide remains the economy itself. In the past 50 years, the world's major 279 cities have lost five times a third or more of their economic capital in average due to market crash. Cyber-attacks are the fastest rising threat to GDP. Manila is worldwide the most threatened city in terms of percentage loss of GDP, apart from cities in war-torn areas. Manila loses in average 9.7% of its GDP per year to all disasters cumulated. Within APEC, Taipei (7.2%) and Xiamen (5.8%) are the second and third most threatened cities. In these three cities, tropical windstorms are by far the most threatening type of disaster.

Key Findings – Chapter 2

Urban planning has been a tool for shaping cities since the most ancient times. Many APEC cities or capitals have been planned and built according to a masterplan. The report shows how industrial revolution favoured urban monocultures, individual housing and car mobility, but excluded the vulnerable. Facing sustainability issues such as a general lack of circularity, insufficient disaster resilience, rising CO_2 emissions, the danger of slum formation and insufficient local data, cities are advised to overcome sectoral planning and management of their urban infrastructures, namely transport, energy, water, waste and social infrastructures, in view of developing integrated long-term planning. Integrated planning also includes cooperation with the private sector in a vast array of possible public-private partnerships, most often in view of securing the most advanced technologies. Budget planning is presented as part of integrated urban planning.

Successful integrated urban planning builds upon certain theoretical concepts which are borrowed not only from urbanization theory in the strict sense, but also from optimal geographic location theory, from management cycle theory, or from public policies against economic cycles. Essential elements of the modern theoretical planning toolbox are adaptive cycles borrowed from the theory of complex adaptive systems (CAS), the post-Maslow panarchy of psychological needs, and the theory of constraints (TOC).

The Sustainable Development Goals and their indicators offer useful guidelines for urban planning targets in the context of integrated urban planning. The report relates the SDGs back to the original pillars of environment, society, and economy, to which it adds governance as a fourth pillar, and it shows why these four pillars should be shown as concentric circles. The concentric SDG model allows identifying three thematic clusters, namely food and biodiversity, green urban economy, and social inclusion. While integrated urban planning can address the latter two clusters, it largely fails to address the first cluster. A systems-theoretic look on SDGs shows that if sustainability is the goal, then disaster resilience may deliver the necessary instruments, hence the two are like Siamese twins. A comprehensive form of integrated urban planning is Transit-Oriented Development (TOD) combined with Land-Value Capture, which allows implementing the UN Habitat's five principles of sustainable neighbourhood planning. Two best-practice TOD examples, Hong Kong and Tokyo, are presented.

Key Findings – Chapter 3

Resilience is presented as an emerging property of complex adaptive systems (CAS) to which all socio-economic systems belong. Any resilient system breaks down if a shock is too strong. Resilience is very similar to sustainability, to which it adds mainly the notions of tipping points and of essential functions but lacks the long-term dimension. The report analyses resilience for each of the four sustainability domains ecology, society, economy and governance, and discusses the numerous resilience frameworks, most importantly the Disaster Resilience Scorecard for cities elaborated by the UN. Ecological resilience of cities involves an equilibrium between efforts to increase biodiversity in cities on one side, and integrated pest management to stop massive development of unwanted pests on the other.

Social resilience of cities means strengthening the social fabric of communities. The most important aspect of social resilience involves setting socially accepted tolerance levels for specific risks. Economic resilience is the capacity of an economy to withstand shocks and rapidly build-up economic activity after a shock. Economic fitness is identified as key concept determining economic resilience. This concept has not yet been applied to cities. The analysis of integrated governance for sustainability and disaster resilience is made with the help of the framework of the International Risk Governance Center IRGC. The report then addresses the conflict between disaster resilience and sustainability which can be resolved by mimicking the governance of the human body, namely the so-called autonomic balance.

As resilience analysis should be described in relation to specific disasters, the report describes resilience against climate-related or hydrometeorological disasters comprising inland water flooding, coastal flooding, and extreme temperatures including wildfires. Resilience against inland water flooding can be addressed by integrated water resources management as provided for in SDG 6.5. The report recalls the challenges and presents a host of measures, among them the sponge city. Resilience against coastal flooding includes measures against sea-level rise as well as cyclone-resilient architecture. The Saffir-Simpson hurricane scale underestimates the effects of local coastal shape on storm surge. Resilience against extreme temperatures bases upon local climate change as reflected in the Köppen-Geiger climate classification. Forecasts point to a more general requirement of urban cooling and heating. Wildfire resistant architecture and landscaping needs to be further developed in affected APEC regions.

Geological disaster resilience includes earthquake-proof architecture, protection against tsunamis and against damage from volcanic activity. APEC region hosts the world's 20 strongest ever measured earthquakes. Earthquake magnitude scales underestimate the destructive capacity of strong (>7) earthquakes as they fail to measure earthquake duration. Thousand-year-old earthquake resistant architecture in China, Japan and Korea offers solutions to earthquake-resistant skyscrapers. Earthquake-upgrading of existing buildings can be done in combination with thermal upgrading, making both cheaper. Tsunami resilience requires a combination of all available measures. The March 2011 tsunami brought about a paradigm change in Japan. For smaller 150year events, protective walls suffice, whereas for bigger events, supplementary measures such as retreat of habitat, protective forests, and vertical evacuation are taken. Most volcanic eruptions are local events that are being addressed by local planning measures. Historically observed large eruptions (1815 AD, 1257 AD, and 1613 BC) as well as pre-historic extreme eruptions are global events that have temporarily impacted the global climate.

Epidemic resilience based upon experience from SARS in 2003 has shown its insufficiency for COVID-19. The biggest challenge of COVID-19 is the rapid aerosol-based spread of the virus. This report proposes to make all interior spaces in infrastructures pathogen-resilient by adding UV-C light sources with sterilizing effect within heating, ventilating and air condition (HVAC) equipment or at other appropriate locations. This is a low-cost and high efficiency measure. To bridge the absence of vaccine, this report echoes the proposal made by a microbiologist of John Hopkins University to treat infected cases by using human convalescent serum (or passive antibody administration). This is low-cost measure is best adaptable to cities hosting enough recovered cases. To avoid the conflict between epidemic resilience and sustainability, economic stimulus packages should consistently be used as instruments to implement SDGs and targets.

Cyber-resilience is not yet a commonly used term. IT systems are still not designed to be intrinsically cyber-resilient. To guarantee continuity of computer services, cities are advised to use all available means to protect their IT infrastructure such as grass-root bottom-up protection, modularity, firewalling and virus-protecting all components. An important threat to cybersecurity stems from human nature and inattentiveness in handling sensitive data, a situation that can be improved by training.

Key Findings – Chapter 4 Conclusion

The report recommends specifying the strategy outlined in *APSEC (2018)* in more detail so that implementation can start. The cornerstone of the proposed cooperation within the Cooperative Network of Sustainable Cities (CNSC) is an urban SDG tracker or publicly accessible website allowing cities to showcase their results. The SDG tracker should monitor those urban SDG indicators that are relevant to cities, either because they apply directly to them, or because cities own infrastructures which allow attaining the SDG targets. The report proposes and to introduce the tracker in an evolutionary multi-level approach. The relevant disaster resilience criteria are added at each appropriate level.

In commitment level one ("basic showcasing of indicators"), the objective is basic showcasing of indicators on a publicly accessible website or SDG tracker. The city commits to showcase three SDG indicators, namely local energy intensity, annual growth rate of local per capita GDP, and local CO_2-intensity of GDP, and the disaster resilience criteria relating to effective disaster response.

In commitment level two ("local 2050 vision with 2030 targets and action plans") the objective is planning the future along four lines that are known to have the capacity to drive change: the SDG targets on sustainable energy, industrial innovation, IT, and the disaster resilience criteria on corporate urban governance (including financial planning).

In commitment level three ("holistic results-oriented monitoring and implementation") the focus lies on effective realization and implementation of the local 2050 vision with 2030 targets and action plans. It also includes specific questions such as inclusiveness of vulnerable groups. Level three has three subparts: one on implementing the indicators of SDG11 and the disaster resilience essential on pursuing resilient urban development, the second one on implementing the SDG indicators specifically addressing local communities and the disaster resilience criteria on safeguarding natural buffers, strengthening institutional capacity, and strengthening societal capacity, and the third one on implementing those SDG indicators that relate to local infrastructures and the disaster resilience criteria on increasing infrastructure resilience.

Recommendations

The main recommendation of this report is to implement the urban SDG tracker as outlined in the report by inviting APEC cities and local communities to join the Cooperative Network of Sustainable Cities (CNSC).

For improving epidemic resilience of APEC cities, this report recommends examining, and possibly implementing, massive deployment of UV-C light disinfection in all interior spaces as a way for making these free from pathogens causing infectious diseases.

The report makes many specific other recommendations in relation to specific disasters.

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1. Understanding Disasters

Uncertainty has become the main characteristic of the COVID-19 world. Even the best-informed people of the World Economic Forum were not capable in autumn 2019 to foresee the planetary pandemic that shook the world a few months later and penetrated every aspect of cities and communities worldwide. As a result, the global UN sustainability frameworks may have to be completed by a tool on systemic risk management. Understanding and assessing the risks of urban and local communities requires familiarity with several types of risk definitions which are currently in use in different disciplines, such as risk of loss of life and risk of loss of wealth (or GDP), tolerance, and with terms such as hazard, exposure, vulnerability, end coping capacity. The report presents *We Inform,* the risk terminology proposed by the UN which harmonizes the traditional approaches of disaster risk reduction (DRR) and climate change adaptation (CCA).

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Expected GDP loss of 279 cities worldwide increased by 5.6% between 2018 and 2019, of which 1.3% is due to higher hazard or probability of event, 4% due to higher GDP, and 0.2% due to higher exposure (i.e. vulnerability minus protective capacity). All disasters cumulated cause annual average GDP loss of 1.39% or 2.79bn$ in each of the sampled 120 APEC cities. Tropical windstorms are the most destructive natural hazard causing 508M$ GDP loss per year and per city in APEC compared to 235M$ for the global average city. The biggest specific single threat to GDP worldwide remains the economy itself. In the past 50 years, the world’s major 279 cities have lost five times a third or more of their economic capital in average due to market crash. Cyber-attacks are the fastest rising threat to GDP. Manila is worldwide the most threatened city in terms of percentage loss of GDP, apart from cities in war-torn areas. Manila loses in average 9.7% of its GDP per year to all disasters cumulated. Within APEC, Taipei (7.2%) and Xiamen (5.8%) are the second and third most threatened cities. In these three cities, tropical windstorms are by far the most threatening type of disaster.

1.1. Risk Appraisal

1.1.1. Perceived Uncertainties and Major Risks in Early 2020

The year 2020 marks not only the start of the new decade of the 2020s, but also the beginning of an entirely new era, an era of uncertainty. The meaning of uncertainty and the extent to which it caught everyone can best be shown by comparing the perceptions expressed in the Risk Report 2020[1] of the World Economic Forum (WEF) with the effective risks incurred worldwide at the beginning of the year 2020. The WEF's Global Risk Report reflects the 30 highest risks as they are being perceived by the world's leading decision-makers. The 2020 report reflects the opinion poll made in September and October 2019 among the WEF's multi-stakeholder communities (including the Global Shapers Community), the professional networks of its Advisory Board, and members of the Institute of Risk Management.

According to the 2020 edition of the report, the risks with highest impact are, in the order of decreasing perceived impact: Climate action failure, weapons of mass destruction, biodiversity loss, extreme weather, and water crises. Not all these risks are perceived as equally likely. The four risks that are perceived as most likely at the beginning of 2020, are extreme weather, climate action failure, natural disasters, and biodiversity loss. Weapons of mass destruction, on the other hand, are perceived as least likely. Infectious diseases are perceived in the WEF's 2020 Global Risk Report as medium- impact (rank 10 of 30), but with low likelihood (rank 27 of 30). The failure of urban planning is seen as event of medium likelihood (rank 19 of 30) but with low impact (rank 28 of 30).

These 30 risks are not perceived as being isolated but may depend upon one another. The survey of the WEF Global Risk Report asked the respondents to associate three to six pairs of these risks. The result is shown in the Global Risks Interconnections Map. The strongest perceived association is between extreme weather and climate action failure. Failure of urban planning has its strongest link with the failure of critical infrastructures, but it has also perceived links to infectious diseases, natural disasters, extreme weather conditions, biodiversity loss, climate action failure, water crises, national government failure, involuntary migration, social instability, unemployment, fiscal crises, cyberattacks and information infrastructure breakdown.

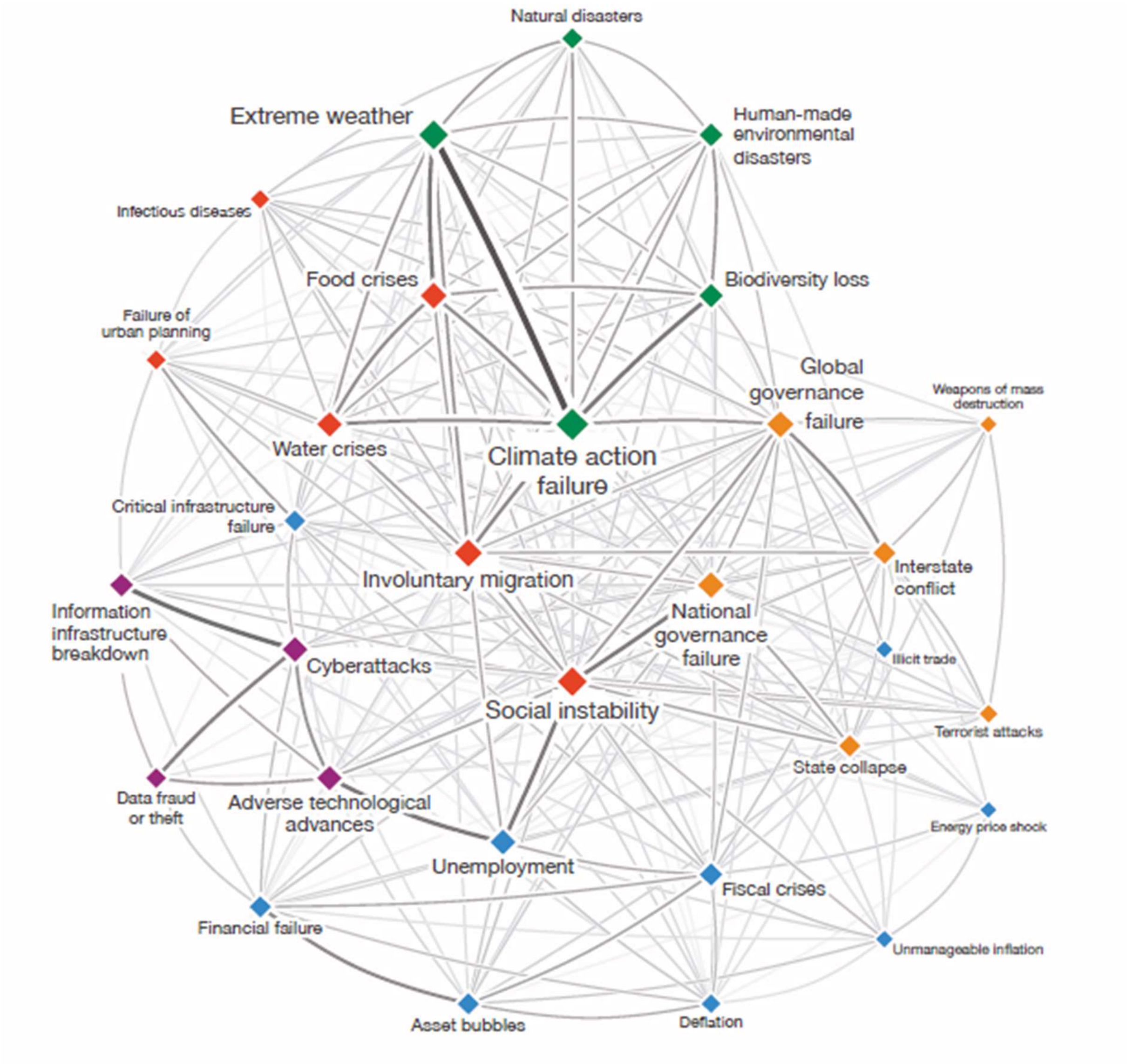


Figure 1: Global risks interconnections map

Source: WEF Global Risk Report 2020

The reality of the risk landscape of the beginning of 2020, as we all know, has turned out to be quite different from the perceptions made by what are probably the best-informed people of the world. On 29 December 2019, a hospital in Wuhan, Hubei Province, China, reported an outbreak of a severe unexplained viral pneumonia among workers and visitors of a seafood market in Wuhan. The pathogen of this disease has been identified on 8 January 2020 and called the novel coronavirus 2019 (2019 nCoV). On 9 January the first person died in Wuhan due to the coronavirus[2]. On 20 January, the WHO announced first case of person-to-person transmission[3]. On 23 January, the city of Wuhan declared itself under quarantine, locking up 11 million people, an extra-ordinary measure that is totally unprecedented in history[4]. On 30 January 2020, the WHO declared the outbreak of the novel coronavirus pneumonia (NCP) as a public health emergency of international concern (PHEIC). On 12 February 2020, the International Committee on Taxonomy of Viruses (ICTV) declared that the new pathogen was officially named as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), and the disease caused by SARS-CoV-2 was officially named as corona virus disease 2019 (COVID-19)[5]. On 24 February, the WHO declared that it no longer uses the term "pandemic"[6]. On 11

March, while the epidemic has affected 118'000 cases and caused 4291 deaths in 114 economies, the WHO declared the coronavirus outbreak a pandemic[7]. The COVID-19 has been recognized to have a natural origin, probably in bats, from where they have been transmitted to humans by an intermediary[8].

This epidemic outbreak has not only changed the risk-perception of the public and the specialists and put the epidemic as main risk into the first place. The quarantine measures that have been taken to limit the spread of the virus have also impacted the daily activities of most people in all those cities where cases have been identified. Furthermore, this situation has completely changed the vulnerability landscape which existed before the outbreak of the epidemic. Some socio-professional categories who previously had little disaster risks have suddenly very high risks. One of the socio-professional categories that is heavily concerned by this risk upheaval is the category of medical workers. During the pandemic, they face high risks up to risking their lives. Another category that is suddenly much more exposed are the cultural workers. Many of them lose their economic basis of existence as the possibility to make live presentations has been restricted in many cities. Finally, the pandemic is also affecting risk analysis and the role of science in politics.

The lessons learnt from epidemics are examined further down in Chapter 3. The following sections are designed to introduce the tools of risk analysis and to develop them to allow the reader to have a clear understanding of risks, hazards, and disasters and how they affect APEC cities.

1.1.2. Basics of Uncertainty and Risk Analysis

Uncertainty and risk analysis are the negative side of scientific knowledge and understanding. Scientific knowledge and technological progress are both essential ingredients of any strategy to improve disaster resilience and to increase sustainability of cities. For this reason, the present section explains some fundamentals of uncertainty and risk in science and technology.

In risk analysis, it is possible to identify alternative events or outcomes and attribute probabilities – even subjective or hypothetical ones – to each of them, whereas in uncertainty the events are not even known, the attribution of probabilities is, therefore, impossible.

Risk analysis and uncertainty have in common to touch upon the frontier of science and human knowledge. This frontier is dynamic and constantly expanding. For introducing this subject, it is convenient to distinguish between two different types of knowledge: the knowledge that is ascertained by observation, and the knowledge that is hypothetical:

- Knowledge ascertained by observation. These are the things that are known to be known. Today, it is, e.g., part of mainstream knowledge that the Earth is round. That does not stop some from claiming that it is flat[9]. Their motivation is, however, not scientific, but social, driven by the desire to differentiate themselves from mainstream. They might even make their claim *because* they know that the Earth is round. At the times of Kepler and Galileo during the 16th and 17th century, the situation was different. Mainstream theory was that the Earth was flat. It required collecting hard and convicting evidence to make the heliocentric world become mainstream. As a matter of interest, it should be added that for the urban planner the earth is flat. This is not a question of belief, but of pragmatism. It does not make sense to consider rounding of the earth at the level of the cities because it is not relevant at urban scale.

- Hypothetical knowledge (risk analysis): things that are known to be unknown. It describes all the domains on which hypotheses have been made, but observations still lack to prove or disprove them. Today, this domain contains, e.g., the knowledge about the early phases of the Universe, as well as what was before the Big Bang, or the interior of the Earth. The difficulty to make reliable early warning systems for disasters points to numerous domains where knowledge is still hypothetical, see further down in this chapter as well as chapter 3.

- Unknown unknown things (uncertainty): things that may possibly exist but have never been observed nor discussed nor even imagined nor hypothesized. It is impossible to describe any elements of this category as the mere imagination or description of any one of its elements will move it to the category of hypothetical knowledge. Things that cannot be expressed as hypotheses are neither imaginable nor can they be described nor understood. They are not part of knowledge.

Hypothetical knowledge is an important but limiting factor of expansion of factual scientific knowledge. Hypotheses drive the conquest towards acquiring factual or observed knowledge. Most scientific discoveries have first been hypothesized, then contested, and thereafter investigated and confirmed, and in the end partially invalidated due to better knowledge. The sad destiny of all hypotheses is to be eventually invalidated due to better and more precise knowledge. Before that, however, they are indispensable to make scientific progress.

Take the hypothesis that the Earth is flat. During Antiquity, the so-called Ptolemaic mainstream view was that the Earth is flat. Only few scholars hypothesized that the Earth is round and made corresponding observations. They were contested by the mainstream view. Even a precise measurement made by the Ancient Greek scholar Eratosthenes in 240 BC who calculated the Earth circumference with an error of only 300km could not change mainstream view. It required the 16th century and the practical proof by seafarers such as Magellan who sailed around the whole world in 1522 to prove that the Earth is round. Today we know that the Earth is not exactly round, but slightly elliptic, flattened on the poles due to the centrifugal force of its own rotation. Taken even more precisely, the shape of the Earth is dynamic as it varies with the gravity of the moon and the sun. In clear, this means that the hypothesis that the Earth is spherical has now already been invalidated.

Another example of hypothetical knowledge is the knowledge about the number of dimensions of the Universe (see figure below). We experience the Universe as having a time and three space dimensions. This view is increasingly being challenged by theoretical physics which accumulates hypothetical knowledge that the Universe might have many more dimensions but attempts to explain that only the one Universe we experience is stable. The prediction of theory is that in ultra-hyperbolic and in elliptic Universes science would have no predictive power. A Universe with, e.g., one spatial dimension and three dimensions of time would only allow for movements faster than the speed of light. For the moment, this hypothesis cannot be directly tested. Another example of hypothetical knowledge is the hypothesis that the Universe has a mirror at the other side of the Big Bang where time would be running in opposite direction to ours[10]. These kinds of hypotheses will be more and more refined in future research and combined with similar other hypotheses until one day they become indirectly and, later, also directly verifiable before they will be invalidated due to even better knowledge.

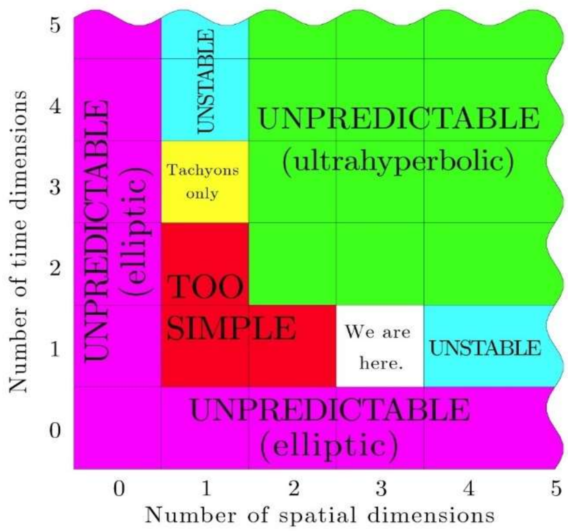


Figure 2: Number of dimensions of the universe

Source: Tegmark[11]

The sum of all the things that are imagined is large. It includes all the logical and mathematical concepts such as, e.g. numbers, straight lines, sets, etc. These objects are not real. Nobody has ever seen a number or a straight line, but we all use them as tools in our imagination. They are intellectual tools or instruments that determine to what extent we can understand a reality. The precise description of a physical phenomenon is limited by the existence and scope of the required mathematical tools. During Antiquity, Euclid has imagined the laws of Euclidian geometry which describe very well the geometrical properties of a flat surface. They may have contributed to the idea that the Earth was flat. The description of non-Euclidian geometry was a prerequisite for the idea that the Earth was round.

As another example of things that are imagined and then applied to reality, take the fractal objects. They were described by Mandelbrot in 1975. Fractal objects are objects that have a fractional (i.e. non-integer) dimension. They do not occupy the entire phase space. Their dimension is, therefore, a fraction of the dimension of the phase space. Another important definitional property of fractals is their self-similarity. Perfect fractal objects remain fractal or self-similar at all scales. The mathematical description of fractals has been the prerequisite to describe objects whose dimension is non-integer. Today, fractals can be observed and described in many different areas in nature. Typical examples are clouds, coastlines, snowflakes, broccoli, ferns, trees, or lightening. In finance, fractals describe the movement of prices in time. Computers allow nowadays calculating fractals and visualizing them in two dimensions so that they have now entered artistic creation and everyday life[12].

Risk analysis has been a long-standing practice in some academic professions. Among these are all the engineering professions (e.g. nuclear, mechanical, electrical, aeronautical, chemical, computer and civil engineering). Risk analysis has traditionally also been high in the medical profession and in the military domain as well as in the food industry. Risk analysis is a vital component of insurance, banking, and finance. In other professions such as in urban planning, risk analysis is not yet as strongly developed as in the above-mentioned professions. The methods and concepts of risk appraisal are different from one discipline to the other and cannot automatically be transposed from one discipline to another.

Risk analysis typically focuses on the following elements:

- Understanding what can happen to a system (disturbance), and the causes of each disturbance
- Evaluating what are the potential consequences of disturbances
- Evaluating the probability of occurrence of disturbances
- Defining the levels of tolerance
- Means to mitigate those risks that are not deemed acceptable

The key to risk analysis is the determination of two figures: probability of occurrence and the impact. This can be shown in the following table. The five colours indicate five possible tolerance levels for a given community which, in this example, would e.g. tolerate both green risks (level 4 and less), maintain some degree of preparedness to face the yellow risks (level 5 to 8) and do everything possible to avoid being affected by red risks (level 9).

Very High	*8 - 10*	M5	M6	H7	H8	VH9
High	*6 - 8*	L4	M5	M6	H7	H8
Moderate	*4 - 6*	L3	L4	M5	M6	H7
Low	*2 - 4*	VL2	L3	L4	M5	M6
Very Low	*0 - 2*	VL1	VL2	L3	L4	M5
		Insignificant *0 - 10*	Minor *11 - 25*	Moderate *26 - 50*	Major *51 - 75*	Catastrophic *76 - 100*

Table 1: The two components of risk: impact (horizontal axis) and probability (vertical axis)

Source: APSEC, based upon QRE tool[13]

The probability is either based upon historical data, in which case the vertical scale above is interpreted to be between 0 and 1. Alternatively, for new risk types that have not yet been observed in historical data, the scale indicates estimated likelihood, expressed on a 0 to 10 scale. The table below sets an event probability for a human-kind time scale.

Very High	Has occurred 3 or more times in the last 5 years
High	Has occurred twice in the last 5 years
Moderate	Has occurred once within the last 5 years
Low	May occur and has occurred once in the last 10 years
Very Low	May only occur in exceptional circumstances and has occurred in the last 20 years

Table 2: Event probability for a human time scale

In principle, impacts can be positive or negative. An example of a positive impact is the earning from a lottery. Examples of negative impacts are disaster losses of all kinds. If only negative impacts are of interest, the impact is a potential loss. The key difficulty of risk analysis is that both, the probability of occurrence as well as its impact or loss, are sometimes hard to measure.

The general formula expresses individual risk R of a disturbance j as product of the probability (p) and the impact (I) of this disturbance:

$$R_j = p_j \times I_j$$

Probability is always limited to the range between 0 (excluded) and 1 (certain). As for impact, the measure varies between disciplines. In insurance, the impact is economic (i.e. insured) damage, hence expressed in money terms. Monetary impacts are also used in all other economic fields where the damage is economic. In medicine, however, the impact is measured as number of cases (i.e. number of affected humans). Because of these two very different ways to measure impact, the above general formula is an unhappy merger of two totally different quantities, namely money and affected humans. In disaster risk analysis, both metrics are (or should be) used: Expressing a damage in terms of money loss and in terms of loss of human life. This is also what the Sustainable Development Goals (SDG) postulate. The SDGs are presented in section 2.3.2. The formula above should be disaggregated into the two formulae below. One formula expresses the number of potentially affected individuals or persons (P) as product of the probability of an event times the number of affected individuals (A), whereas the other formula expresses monetary risk (M) as probability of the event j times the associated monetary loss L:

$$P_j = p_j \times A_j$$

$$M_j = p_j \times L_j$$

These two formulae should be interpreted as follows. The first formula expresses the fact that an event that happens e.g. once in 100 years and kills 10'000 persons each time has mathematically the same risk as one that happens every year and kills 100 persons each time. The second formula expresses the analogous idea of risk with respect to economic losses: an event that occurs e.g. every 50 years and causes a loss of 1'000'000 USD each time has the same risk as an event that happens every year and causes a loss of 20'000 USD. While mathematically in each of the two cases, risk of the first is equal to the risk of the second, the rare events with large losses are quite different from the frequent events with small losses. This difference also reflects the attitude towards insurance: It is useless to insure against daily events, even if their risk is significant and perceptible. Such insurance is neither demanded nor supplied. The cost of daily events is covered by current spending. It does, however, clearly make sense to insure against rare events, and this even more (but not only) if such events are costly. The mathematical concept of risk also conceals a distinction that is important for disaster management. The prevention and management of big but rare accidents is totally different from prevention and management of small but frequent accidents.

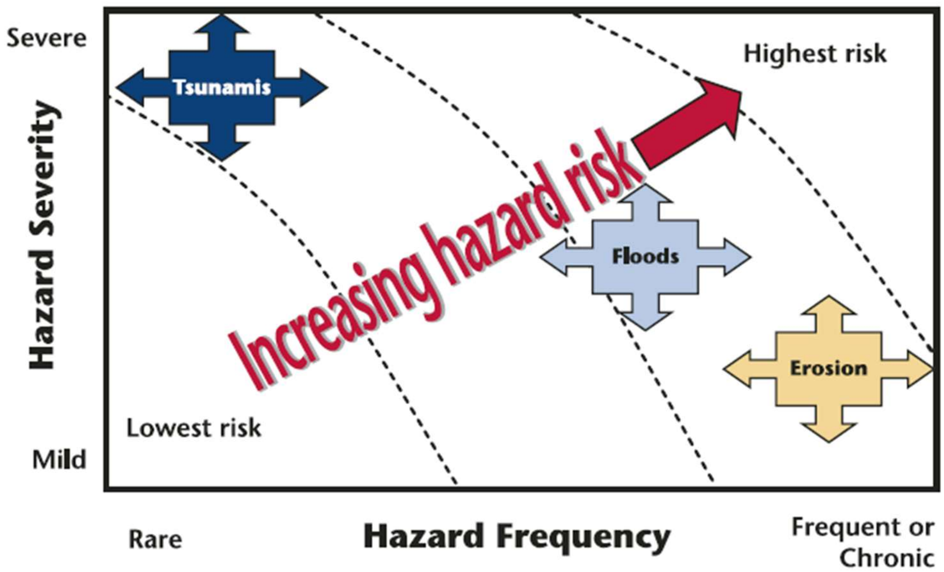


Figure 3: Frequency vs impact

Source: IOTWS 2007[14]

In economic and financial sciences, events that are extremely rare and have catastrophic impacts such as the 2009 financial crisis are sometimes called black swans[15]. The equivalent of black swans in natural sciences are e.g. the 2004 Tsunami, the 2011 Tohoku earthquake followed by the Fukushima nuclear accident, the 9/11 events and the 1912 sinking of the Titanic. Black swans or their equivalents are impossible or at least exceedingly difficult to predict. Usual forecasting models might understate their occurrence and offer false security, but once a black swan event has occurred, most people have the feeling that it would have been easy to predict and to prevent.

The above-mentioned fact that there are two totally different kinds of risk, namely potentially affected persons and monetary losses, makes the comparison difficult between events that cause large economic losses but less human losses (e.g. nuclear industry) and events that cause limited economic losses but large human losses (e.g. coal industry)[16]. Sections 1.2.1. and 1.2.2. discuss both categories of risks of APEC cities.

The simple risk measures introduced above not only fail to differentiate between the size of events, but also, they do not say anything about their appearance (sudden or gradual) and their duration. A sudden event, especially if it is unforeseen or even unforeseeable, is much more frightening than a gradually appearing event of the same magnitude. If a gradual event arrives, preparation time may suffice to eliminate a considerable part of adverse impacts so that the final effect of a gradually arriving event might be much lower than the effect of a sudden event. Examples of sudden events that are difficult to predict and may have high impacts are earthquakes, tsunamis, and landslides. Events should also be differentiated as to the duration of their effect. If the impact of an event is punctual or short-lasting like the just mentioned types of events, this entails totally different consequences than if an event is long-lasting such as overfishing, overgrazing, or desertification, the drying up of water systems such as the Aral Sea, or even irreversible events such as sea level rise or coastal erosion.

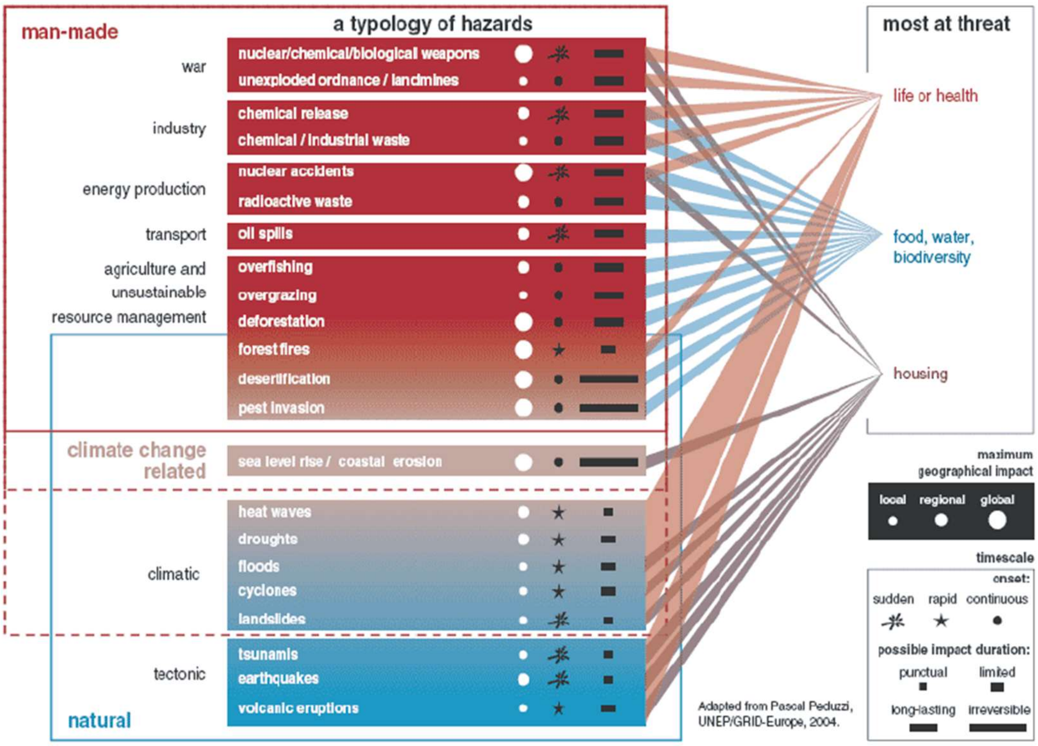


Figure 4: Typology of hazards

Source: Pascal Peduzzi[17]

Looking only at measures of risk like the ones mentioned above may also have another limitation. Simple measures of risk only relate to the effects of events that already happened. Often, events take considerable precursor time before they materialize. During this precursor time, the systems accumulate internal stress or tension. The system reacts against these internal forces but keeps equilibrium or returns to equilibrium when the internal force or disturbance stops acting. The event itself is then only the tipping point when the system breaks and no longer resists. Seen in this manner, stress or pressures within the system are disturbances that are below the critical threshold or tipping point, which marks the point at which the system breaks. Stressors and tensions are part of the disaster risk and resilience analysis of cities. Some pressures or stressors and their causes are shown in the table below[18].

Stressor, pressure	Causes
High unemployment	Lack of investment, poor labour market
Traffic congestion in cities	Inefficient public transport
Endemic violence	Poor local public security services
Chronic food and water shortages	Inadequate infrastructure, poverty

Table 3: Common urban stressors and pressures and their causes

Source: APSEC based on information from 100 Resilient Cities

1.1.3. New Risk Terminology *We Inform*

Given the abstract nature of commonly used terms of risk analysis, there is some confusion on key terms used in risk analysis. The *Sendai Framework for Disaster Risk Reduction 2015 – 2030*[19] charges the UN to elaborate an internationally harmonized framework of disaster risk analysis together with a harmonized terminology. The UN Statistical Division oversees the elaboration and publication of this terminology[20] which is also known as *We Inform* and is now gradually penetrating the risk analysis made by the UN as well as by all other public and private bodies. The new framework is presented by the Global Assessment Report on Disaster Risk Reduction 2019 (GAR), published by the United Nations Office for Disaster Risk Reduction[21]. This new framework and terminology are also designed to narrow the gap between the two different approaches of Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA).

In a theoretical perspective, DRR, the more traditional approach, considers how to reduce the impact of single disaster events (see the detailed description of disaster types in section 1.2.2. further down). Disasters are sudden shocks that affect a system. The scope of DRR has been focusing on preventing emergencies, on maintaining essential functions during a disaster, and on re-establishing functioning systems after disasters. DRR analysis received high attention after the 2004 tsunami. In line with its traditional approach, DRR has a shorter time horizon (10 to 30 years) than CCA. Climate change materializes in changing the frequency and type of disasters over a long period. As the climate is a Complex Adaptive System (CAS) of the type that will be described below in section 3.1.1., climate change represents a totally new phenomenon in form of an ongoing long-term stress to the climate and its sub-systems. It is an example of a long-term disaster whose tipping points are not constants, but functions of the state of its subsystems. Climate change adaptation (CCA) is a long-term challenge that is quite different from DRR preventing specific types of threats. CCA is developing as a forward-looking approach attempting to minimize losses arising from moving beyond tipping points.

The effect of COVID-19 in this debate may well be to add pandemic as major long-term hazard to this picture.

The UN has been charged to harmonize both, the CCA and the DRR approaches. This harmonization includes the new unified terminology “We Inform”. In this new perspective, Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) both become complementary. This does not mean that they merge. On the contrary, each retains its own specificity and area of validity. The synoptic table below shows some of the main differences between the two.

DRR	Climate change adaptation
Relevant to all hazard types	Relevant to climate related hazards
Origin and culture in humanitarian assistance following a disaster event	Origin and culture in scientific theory
Most concerned with the present- i.e., addressing existing risks	Most concerned with the future i.e., addressing uncertainty/new risks
Historical perspective	Future perspective
Traditional/indigeneous knowledge at community level is a basis for resilience	Traditional/indigeneous knowledge at community level may be insufficient for resilience against types and scales of risk yet to be experienced
Structural measures designed for safety levels modelled on current and historical evidence[2]	Structural measures designed for safety levels modelled on current and historical evidence and predicted changes
Traditional focus on vulnerability reduction	Traditional focus on physical exposure
Community-based process stemming from experience	Community-based process stemming from policy agenda
Practical application at local level	Theoretical application at local level
Full range of established and developing tools[3]	Limited range of tools under development
Incremental development	New and emerging agenda
Political and widespread recognition often quite weak Funding streams ad hoc and insufficient	Political and widespread recognition increasingly strong Funding streams sizeable and increasing

Table 4: Synoptic table showing differences between DRR and CCA

Source: IDRC 2011[22]

In a more technical explanation, the specificity of the DRR approach is a contextual or factor approach that uses intrinsic social or economic factors or dimensions to define vulnerability. DRR focuses on people and has, therefore, a social science perspective. It becomes a starting point which is suitable for setting targets for risk reduction and combined risk determinants that have no common unit of measurement, but relative statistics for ranking that can identify generic leverage points for reducing impacts. In contrast, the specificity of the CCA approach is more an outcome or impact approach that uses regression models and the stressor-response relation as well as quantitative measures of historical impact as proxies for vulnerability. CCA is based on the analysis of complex adaptive systems (see section 3.1.1. below) and has a natural science perspective. CCA is the end point which is important for preparedness plans and for climate mitigation activities[23].

In the new terminology, the basic source of disasters are hazards, some of which are natural (e.g. environmental, biological, geological) while others might be man-made (e.g. technological, social) or a combination of both.

Everyone makes choices as to where to live, where to work, which places to visit, and how much information to have about all these environments. By making these choices, everyone choses the exposure level. Exposure is the specific vulnerability of the built environment. The total vulnerability is composed of (physical) exposure and (socio-economic) vulnerability, see further down the section on exposure and vulnerability.

Risk is now defined as combination of hazard, exposure, and vulnerability. As individual choices are determining individual exposure levels that determine risk levels, risk is regarded as everyone's business, not only the business of civil protection authorities or firefighters or similar organized bodies.

Disasters are defined by their impacts, i.e. death, loss, or damage, which are the function of the risk context. Disasters can be of small-scale or large-scale, sudden or slow-onset, frequent or rare, caused by a single hazard or multi-hazard.

Graphically the new terminology may be shown as follows:

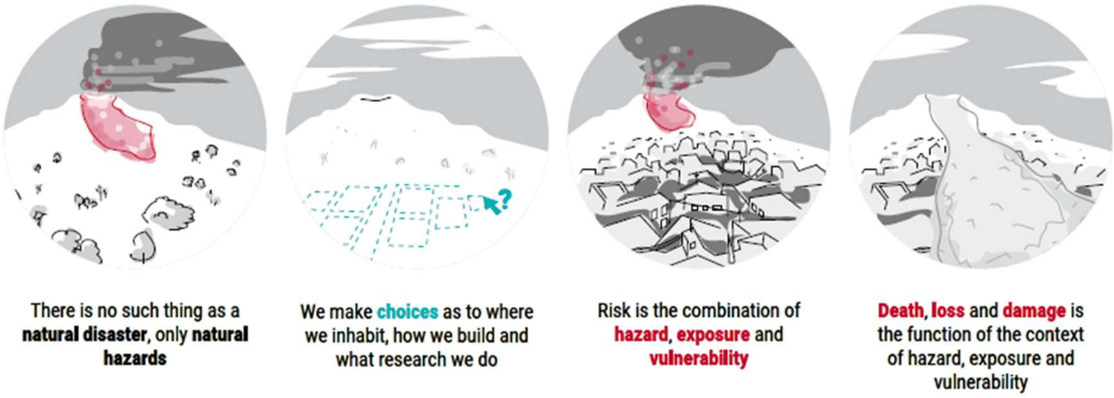


Figure 5: New disaster risk reduction (DRR) terminology

Source: UN GAR DRR Report 2019[24]

The new terminology creates one major difference with respect to practices used in the earlier DRR analysis and with respect to everyday language. The very frequently used term of "natural disaster" should now be called "disaster caused by a natural hazard". For practical reasons and due to the widespread everyday use of the term "natural disaster", the present report still uses the old terminology but intends across the board to interpret it as "disaster caused by natural hazard", acknowledging that it is not nature that causes the disaster, but nature together with the exposed and vulnerable communities. Much of the solution to the problem of disasters is to make the latter less exposed and more resilient. The main message of the *Sendai Framework* is to exhort everyone to reduce risks by avoiding decisions that create risks, by reducing risks and by building resilience.

The UN terminology of the following key concepts should enable the reader to clearly understand them:

Hazard: A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental degradation.

Disaster: A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.

Disaster Risk: The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.

Exposure: The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas. NB: Exposure may increase through vulnerability and decrease through capacity.
Vulnerability: The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. NB: Vulnerability is the opposite of capacity.
Capacity: The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience. NB: Capacity is the opposite of vulnerability.
Mitigation: The lessening or minimizing of the adverse impacts of a hazardous event.
Resilience: The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.
Recovery: The restoring or improving of livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and “build back better”, to avoid or reduce future disaster risk.

Table 5: Definitions of key DRR terms

Source: UN GAR DRR 2019[25]

Resilience is sometimes wrongly used to describe recovery. These two must be distinguished in the sense that resilience is much broader than just recovery, or that recovery is just one part of resilience.

Pursuant to this terminology, risk is a function of natural hazard (i.e. the probability of event), the exposed assets (i.e. the entities at risk) and their inherent vulnerability. The mathematical relationship between these factors can be expressed as follows.

Figure 6: Definition of risk with exposure factor

Source: APSEC

The UN established the *Sendai Framework Monitor* (SFM) which started in March 2018, comprising harmonized indicators and reporting[26].

Since 2012, the UN in cooperation with the EU and donor agencies have also compiled another system, namely the INFORM Global Risk Index (INFORM GRI) in view of assessing the worldwide need for humanitarian aid and supporting a proactive crisis management framework. This index is helpful for an objective allocation of resources for disaster management as well as for coordinated actions focused on anticipating, mitigating, and preparing for humanitarian emergencies. It is elaborated on annual basis and is based on risk concepts taken from relevant scientific literature, including elements of the new risk terminology of the UN. The INFORM GRI is calculated as the geometric mean of its three main sub-components: hazards & exposure, vulnerability, and lack of coping capacity, whereby each of these is normalized to values between 0 and 10. Deviating slightly from the above fig. 6 the term exposure has another meaning; the term designates primarily the conflict hazard and is grouped together with the hazards (see figure below). Furthermore, the GRI disaggregates the exposure factor shown above into the two factors vulnerability and lack of coping capacity, whereby vulnerability includes aid dependent and uprooted groups (see below). The general structure of the framework can be seen from the figure hereafter.

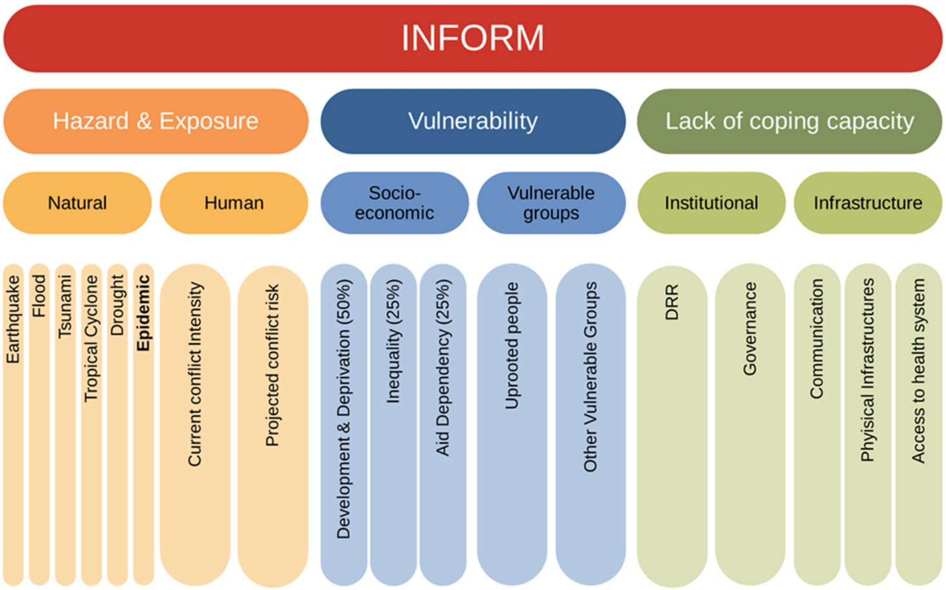


Figure 7: Structure of the INFORM GRI Index

Source: INFORM GRI[27]

The INFORM GRI index is split into different levels to provide a quick overview of the underlying factors leading to humanitarian risk. For information, the INFORM GRI of 19 APEC economies is shown hereafter. The figure shows that hazard and exposure are highest in Mexico, the Philippines, Indonesia, China, and the United States (blue bars). Vulnerability is highest in Papua New Guinea, the Philippines, and Mexico (orange bars). The lack of coping capacity is highest in Papua New Guinea, Indonesia, Mexico, Peru, Russia, and Viet Nam (grey bars). The resulting overall risk is highest in Papua New Guinea, the Philippines and Mexico (yellow bars).

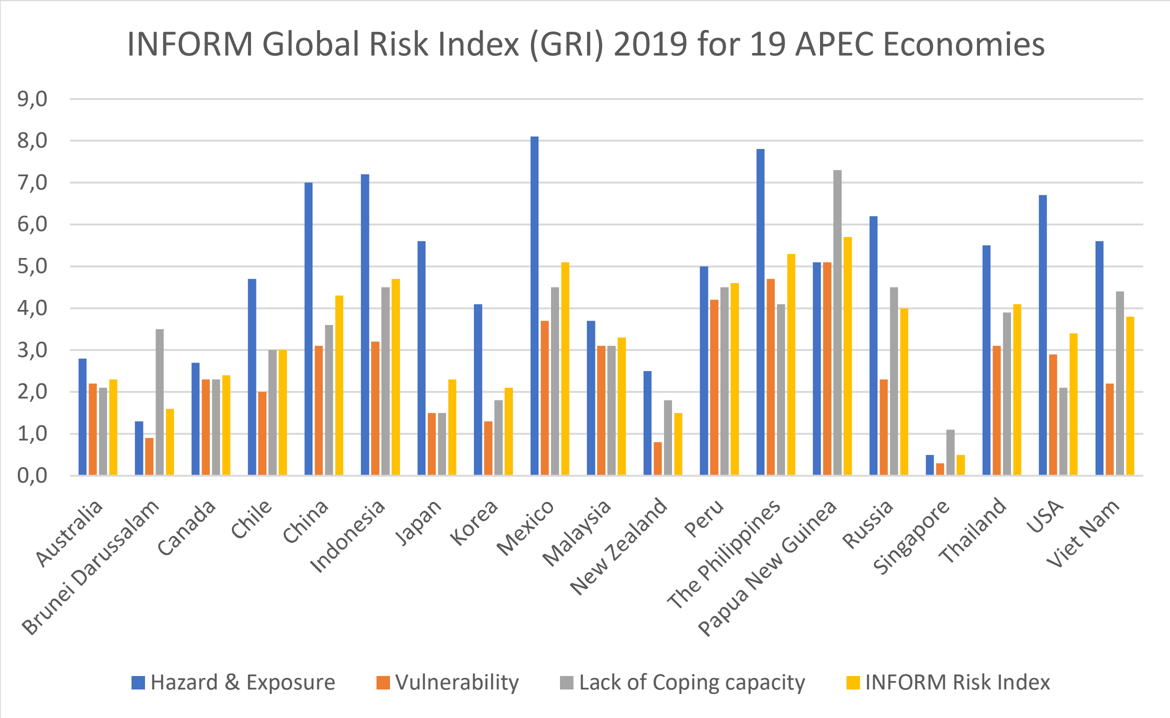


Figure 8: GRI of 19 APEC Economies

Data source: INFORM GRI

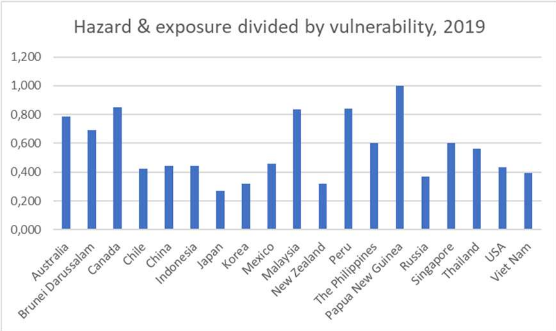
The following explanations are destined to help understanding and interpreting the components of the INFORM GRI.

Firstly, it may be noted that hazard & exposure are difficult to influence; they are determined by natural factors, e.g. the probability to have earthquakes or tsunamis (for the hazard part) and the probability of having conflicts (called exposure in the INFORM GRI). On the other hand, side, both, vulnerability and lack of coping capacity can be influenced by policy. Vulnerability can normally be diminished e.g. by prohibiting construction in danger zones and/or by enforcing building codes improving disaster-resilience of settlements. Lack of coping capacity can be diminished by increasing strength and efficiency of disaster response.

Policy should e.g. care for keeping the relative contribution of both, vulnerability, and lack of coping capacity, lower than the relative contribution of hazard & exposure. This target can be measured by looking at the ratio of vulnerability divided by hazard & exposure, and the ratio of lack of coping capacity divided by hazard & exposure. Ideally, both ratios should be as small as possible, meaning that vulnerability as well as lack of coping capacity are both much smaller than hazards.

No APEC economy has higher contribution of vulnerability than hazard & exposure. In Papua New Guinea, the two relative contributions are of equal magnitude. Best (i.e. lowest) values are seen in Japan (0.268), Korea (0,317), and New Zealand (0,320).

As for lack of coping capacity, three APEC economies show that the relative contribution of the lack of coping capacity is larger than the relative contribution of hazard & exposure. This is the case in Brunei Darussalam (2,692), Singapore (2.200), and Papua New Guinea (1.431). In these three economies, lack of coping capacity contributes more to the overall risk than hazard & exposure. Singapore has e.g. by far the smallest hazard and exposure risk among all APEC economies but has a comparatively greater risk from its relative lack of coping capacity. The best (i.e. lowest) relative values for coping capacity (as compared to hazard and exposure) are seen in Japan (0.268), the USA (0.313), and Korea (0.439). In these economies, the lack of coping capacity contributes least to the overall risk as compared to hazard & exposure.



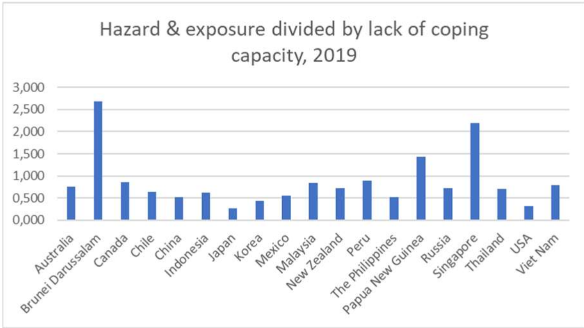


Figure 9: Relative weight of vulnerability and lack of coping capacity in APEC economies

Data source: INFORM GRI

1.1.4. Growing Role of Systemic Risk

Systemic risks are a comparatively new phenomenon. They have been empirically discovered only in the last 50 years, when large electricity blackouts have been shown to cascade and propagate through interconnected electricity systems. Another early source of systemic risk has been the internet since its emergence in the early 1990s. In future, systemic risk will receive much higher importance in the digital sphere, essentially due to the combined action of factors such as internet of things (IoT), artificial intelligence, and cyber criminality. In finance, systemic risk became an issue with the failure of Lehman Brothers in 2007.

The theoretical approach analysing systemic risk is the theory of complex adaptive systems (CAS). This will be introduced in more detail in section 3.1.1. below. Hereafter, only some basic definitions and a few examples are given.

In the UN, the competent body for analysing and addressing systemic risks is the Office for Disaster Risk Reduction (DRR). This office publishes an annual Global Assessment Report (GAR) on Disaster Risk Reduction (DRR). The UN has recognized in the GAR DRR 2019 Report that systemic risk is not yet adequately addressed in the global frameworks adopted by the UN in 2015[28]. These frameworks define the essential elements of sustainable development, but do not yet define how sustainable development could become risk-informed sustainable development. The 2015/2016 frameworks comprise the *Sendai Framework*, the *2030 Agenda for Sustainable Development* (which includes the SDGs as well as the *Addis Ababa Action Agenda* addressing development finance), the *Paris Climate Agreement*, and the *New Urban Agenda* adopted in 2016 within the Habitat III Conference. Hence, further academic research must be developed and incorporated into a broader framework that addresses specifically systemic risk and systems-based approaches. This is illustrated in the figure below.

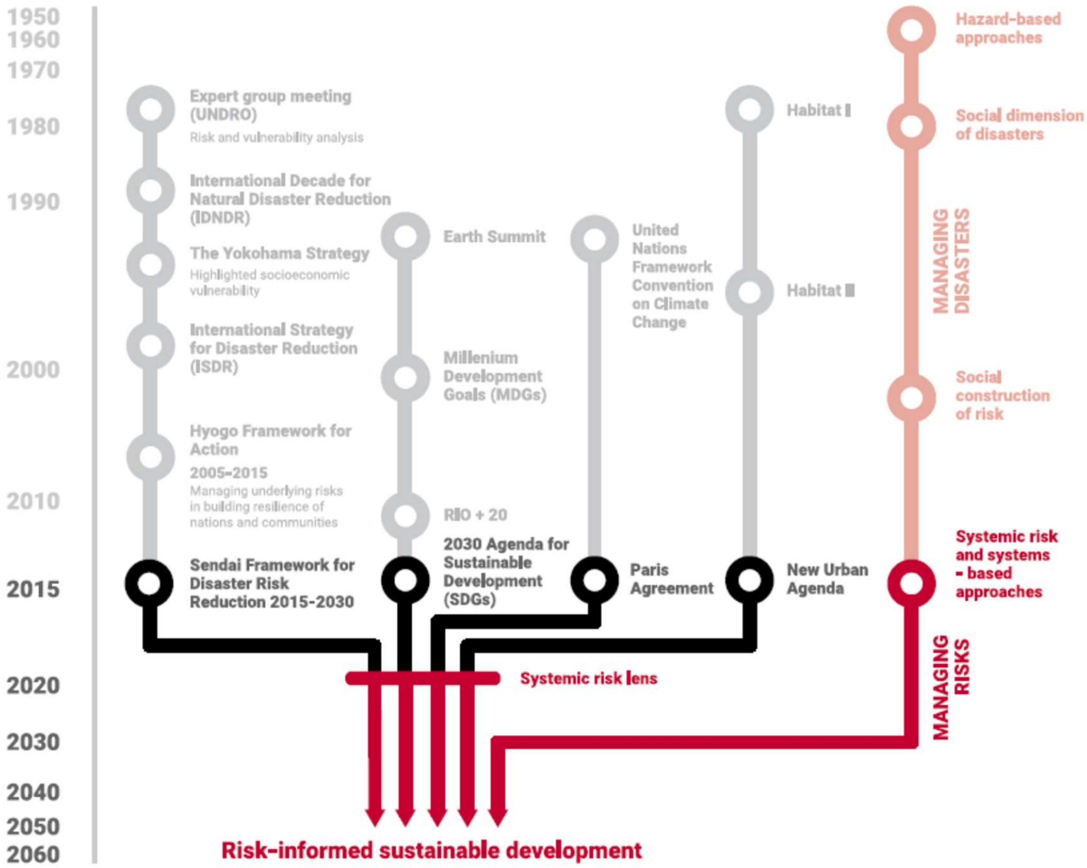


Figure 10: Global sustainability and resilience frameworks

Source: UN GAR DRR (2019)

As the world becomes more and more interdependent, entirely new types of risks emerge. These new types of risk are e.g. systemic and systems risks, femto-risks, and network-hyper-risks. The inadequate response of the global community facing these new types of risk can be summarily described by the quote of the UN Secretary General made in January 2019:

> *If I had to select one sentence to describe the state of the world, I would say we are in a world in which global challenges are more and more integrated, and the responses are more and more fragmented, and if this is not reversed, it's a recipe for disaster.*[108]

Figure 11: Quote by UN Secretary General A. Guterres, Jan 2019

Source: UN GAR DRR (2019)

The UN GAR DRR 2019 Report defines these new types of risk as follows:

Systemic risk is defined as risk that is endogenous to, or embedded in, a system that is not itself considered to be at risk and is therefore not generally tracked or managed, but which is understood through systems analysis to have a latent or cumulative risk potential to negatively impact overall system performance when some characteristics of the system change.
Systems risk is the inherent risk of a system when substantive elements of the system contribute to the entire system having a certain risk profile, which could be anywhere on the risk spectrum from very low risk […] to very high risk […].
Femtorisk is a seemingly small-scale event that can trigger consequences at a much higher level of organization, often through complex chains of events.
Network (hyper-) risk or cascading (multiple systems) risk is the inherent risk across multiple systems when there are substantive elements contributing to the system of systems having a certain risk profile, which could be anywhere on the risk spectrum from very low risk to very high risk.

Table 6: Definitions of new types of risks that are related to systems

Source: UN GAR DRR (2019)

Systemic risk and systems risk are essentially identical; the distinction is a matter for specialists and need not be discussed here. In both cases, the overall system is not itself at risk, but the risk is endogenous, embedded, or inherent in one or more of the sub-systems. This situation can best be understood in the framework of general systems theory (GST). The first precursor ideas of what later became the general system theory (GST) were written by the Austrian biologist L. von Bertalanffy in 1934. In an article, he analysed the laws of growth of marine animals. After another article published in 1962, he summarized and updated his findings in the book General System Theory: Foundations, Development, Applications in 1968[29]. Meanwhile, K. Boulding had published an article on General Systems Theory – The Skeleton of the Science in 1956[30]. Since these early days, general systems theory has become an important area of interdisciplinary science. Proponents of the general systems theory attempt to show the unity of science and adopt a holistic view, considering that new properties emerge from interacting parts of a system, no matter whether the system is composed of particles, cells, transistors, people or socio-economic entities. It is known that some so-called emerging physical properties of systems, e.g. temperature, do not exist at the level of elementary physical particles, but only at macroscopic level. Further down in section 3.1.1., resilience of complex adaptive systems (CAS) will be described as emerging property of such systems. The holistic view contrasts with the reductionist view which attempts to reduce characteristics of complex systems to single elements or components of such systems.

Femtorisk is a term that was proposed by Joshua Ramo and Simon Levin during a 2011 IIASA conference on risk modelling in complex adaptive systems (CAS)[31]. Femtorisks are extreme cases of systemic or systems risk, in which the triggering event is small compared to the effects it has on the entire system. The principle underlying femtorisks can be used in engineering of complex systems. If an engineered complex system (e.g. intercontinental ballistic missiles) can be switched on by a simple switch, this switch embodies the femto-risk. For avoiding unwanted switching on of the system, the simple switch is replaced by a multiple switch. The system will then only switch on if all switches are set to “on” simultaneously.

Even though the term femtorisk was proposed relatively recently, it can perfectly well describe events that happened earlier. An example of a femtorisk event is the assassination of Archduke Franz Ferdinand of Austria and his wife on 28 June 1914 in Sarajevo which triggered off the First World War, an event of unprecedented magnitude. It lasted from 2014 to 2018, involved in some way or another all the major powers of the world, killing around 17 million persons, wounded many more and made the survivors to such an extent vulnerable that a global influenza pandemic of the years 1918 – 1919 affected an estimated one third of the world population and killed possibly around 50 million, i.e. tree percent of the world population[32]. The pandemic owes its nickname "Spanish flu" to the fact that Spain was neutral during the war and had no press censorship. News about the flu and the fact that it affected the Spanish King Alfonso XIII were therefore abundant in Spain before spreading to other places[33].

A more recent example of a femtorisk event was the jump of the novel coronavirus from an animal species to human beings in December 2019. This has caused the COVID-19 pandemic and a chain of associated global events whose end point is not yet visible. Further information on epidemics can be found in sections 1.2.2. and 3.2.3. below.

Network risks are frequently observed in electricity and IT grids, but occur also in transportation systems, finance, food chains and in the human body. One of the prominent examples of cascading risks is given in the electricity blackout of 14 August 2003 that occurred in USA and Canada[34]. This blackout affected an estimated 50 million people in the US States of Ohio, Michigan, Pennsylvania, New York, Vermont, Massachusetts, Connecticut, New Jersey and the Canadian province of Ontario. The blackout began a few minutes after 4:00 pm Eastern Daylight Time (16:00 EDT) on 14 August 2003. Power was not restored for 4 days in some parts of the United States. Parts of Ontario suffered rolling blackouts for more than a week before full power was restored. Estimates of total costs in the United States range between $4 billion and $10 billion (U.S. dollars). In Canada, gross domestic product was down 0.7% in August, there was a net loss of 18.9 million work hours, and manufacturing shipments in Ontario were down $2.3 billion (Canadian dollars).

The risk created by climate change is of the systemic risk type. Research made during the last decades in understanding and measuring climate change-related risks has shown how complex the matter is and how much concrete effects of climate change depend on conditions and interactions between sub-systems. The reports of the intergovernmental panel on climate change can be found on the IPCC website https://www.ipcc.ch/reports/ .

The COVID-19 pandemic is a perfect illustration that the systemic risks of the types described above require an entirely new approach to risk management, different from the approach of managing simple risks. One of the difficult issues of measuring systemic risk is that it includes analytic description and measurement of socio-economic sub-systems, whose behaviour is not only difficult to predict, but whose actors may be characterised by stakeholder disagreement about causes of events and strategies to be chosen for responding to disasters.

Today's highly interconnected systems are vulnerable to failure at all scales, posing serious threats to society, even when external shocks are absent. As the complexity and interaction strengths in this networked world increases, man-made systems can become unstable, creating uncontrollable situations even when decision-makers are well-skilled, have all data and technology at their disposal, and do their best. To make these systems manageable, a fundamental redesign is needed. A "Global Systems Science" might create the required knowledge and paradigm shifts in thinking[35]. Systemic risk governance in the context of sustainability and resilience is further discussed in section 3.1.5. below.

1.2. Risk Profile of APEC Region

1.2.1. Disaster Mortality in APEC Region

This section presents the analysis of loss of human life due to natural disasters in APEC. The purpose of this analysis is to give a tool for implementing the first global target of the *Sendai Framework for Disaster Risk Reduction 2015 – 2030* (*Sendai Framework*)[36]. The *Sendai Framework* was the first major agreement of the 2015 development agenda. It was endorsed by the UN General Assembly in June 2015 following the 2015 Third UN World Conference on Disaster Risk Reduction (WCDRR) held in Sendai, Japan. The *Sendai Framework* is linked to the other 2030 Agenda agreements, including The *Paris Agreement on Climate Change*, the *Addis Ababa Action Agenda on Financing for Development*, the *New Urban Agenda*, and ultimately the Sustainable Development Goals.

The *Sendai Framework* has seven global targets. The first target reads:

Substantially reduce global disaster mortality by 2030, aiming to lower the average per 100'000 global mortality rate in the decade 2020 – 2030 compared to the period 2005 – 2015.

Similar targets are found in the sustainable development goals and their indicators. The global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development has been adopted by the UN General Assembly in Resolution A/RES/71/313 and refined in 2018 (E/CN.3/2018/2), in 2019 (E/CN.3.2019/2) and in 2020 (E/CN.3/2020/2). It states a similar indicator which it associates, however, with three different targets in three different SDGs as shown in the figure below. SDG target 11.5 relates to sustainable cities and re-formulates the language on significant reduction of the number of deaths that was stated in the *Sendai Framework*.

For the analysis of the first global target of the *Sendai Framework*, data was used from EM-DAT, the Emergency Events Database created in 1988 by the Centre for Research on the Epidemiology of Disasters (CRED) at the Universite catholique de Louvain (UCL) in Brussels with the support of the Belgian Government and the World Health Organization. EM-DAT contains data of 22'000 disasters worldwide since 1900 and is continually being updated with new disasters. Each disaster has a specific number as well as available description. This data is available for all types of disasters and all APEC economies. For the present analysis, data on all types of natural disasters (biological, climatological, extra-terrestrial, geophysical, hydrological, and meteorological disasters) have been incorporated. However, technological disasters have been excluded in the present analysis. Technological disasters represent a large number (2931 for APEC) of small events of the categories transport accidents, miscellaneous accidents, and industrial accidents. The scope of this report is on climate-related disasters, hence technological disasters such as accidents have been excluded. Another limitation of this analysis arises from the strict focus on deaths from disasters. This limitation excludes the analysis of affected persons from disasters which can be much higher.

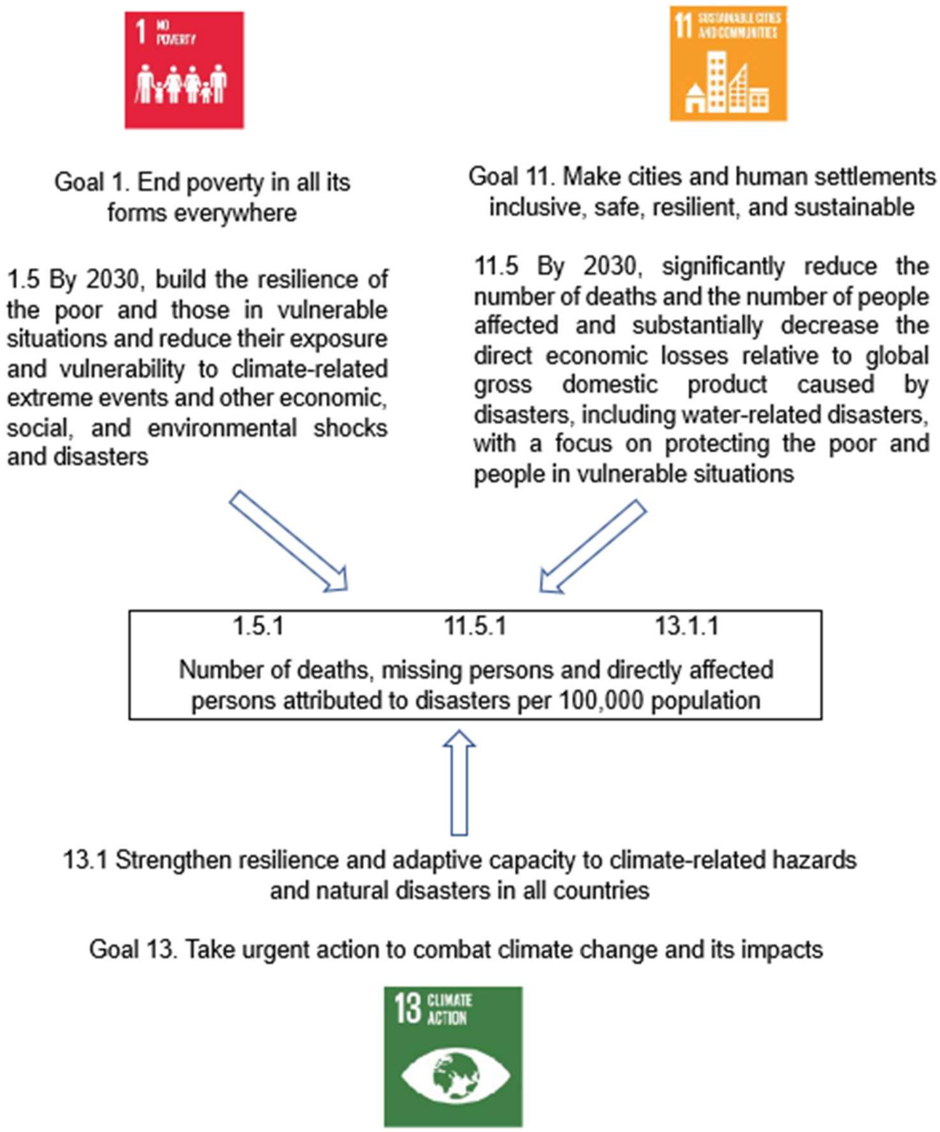


Figure 12: Three SDGs and targets associated with one SDG indicator

Source: APSEC

The data set analysed for the purpose of the present report contains 5530 natural disaster events specifically filtered from what are today's APEC economies, but dating back in some cases to as early as 1900. Data contain loss of life and regional assignment of each natural disaster event. The period 1900 – 2018 has been divided into two halves, 1900 – 1959 and 1960 – 2018. The reporting density has a bias towards more recent events. From the 5530 events registered during the whole period, 5170 events or 93.5% are from the second half of the period. Between 1900 and 1959, mostly major events were registered. The average number of deaths per event in the period 1900 to 1959 was 35'333 but dropped down to 202 for the period 1960 to 2018, i.e. to little more than half a percent of the mean value of the first half period. For this reason, some part of the analysis has been made separately for the period 1900 to 1959 and the period 1960 to 2018.

The start of disaster registering by APEC economy is given in the table below:

APEC economy	Date of first registered events	Total number of events
Japan	1900	355
United States	1900	1022
Canada	1903	138
The Philippines	1905	637
Chile	1906	118
China	1906	923
Hong Kong, China	1906	137
Chinese Taipei	1906	110
Indonesia	1907	512
Peru	1913	183
Russia	1918	165
New Zealand	1918	71
Mexico	1929	266
Papua New Guinea	1930	82
Korea	1936	116
Australia	1939	239
Viet Nam	1953	224
Thailand	1955	145
Malaysia	1965	82
Singapore	1998	4
Brunei Darussalam	1998	1

Table 7: Number of natural disasters of the EM-DAT data base, per APEC economy

For Russia initial events have first been reported in 1918 and continued after the independence of Russia in 1992. The events that happened during the existence of the Soviet Union 1919 – 1992 are recorded under the Soviet Union, comprising all 15 ex-soviet republics. To avoid mixing the analysis with events from outside APEC, the Soviet Union was excluded from this analysis. The Soviet Union would have added 110 disasters, among them 56 technological disasters.

The natural disaster categories of the EM-DAT data base comprise storms (tropical storms or convective storms), wildfires (land fires, i.e. brush, bush, pasture, or forest fires), floods (riverine floods or flash floods or coastal floods), extreme temperatures (heat waves or cold waves), epidemics (viral diseases or bacterial diseases or parasitic diseases), droughts, earthquakes (ground movements or tsunamis), volcanic activity (ash fall), landslides (mass movements (dry) or rockfall or avalanches or mudslides), and insect infestation (locust or unspecified). The meteorite impact of 5 February 2013 in Chelyabinsk in the Ural Region of Russia represents an additional category which is recorded in the data base but has not caused any loss of life. A data base for meteorite impact is maintained by International Comet Quarterly[37].

The distribution of the disaster events by rank order, arranged according to the number of human lives lost, shows the predominance of a few very large events. 85% of lives lost in disasters in all APEC economies combined in the period 1900 to 2018 are attributable to eight large disasters having all taken place in China before 1976.

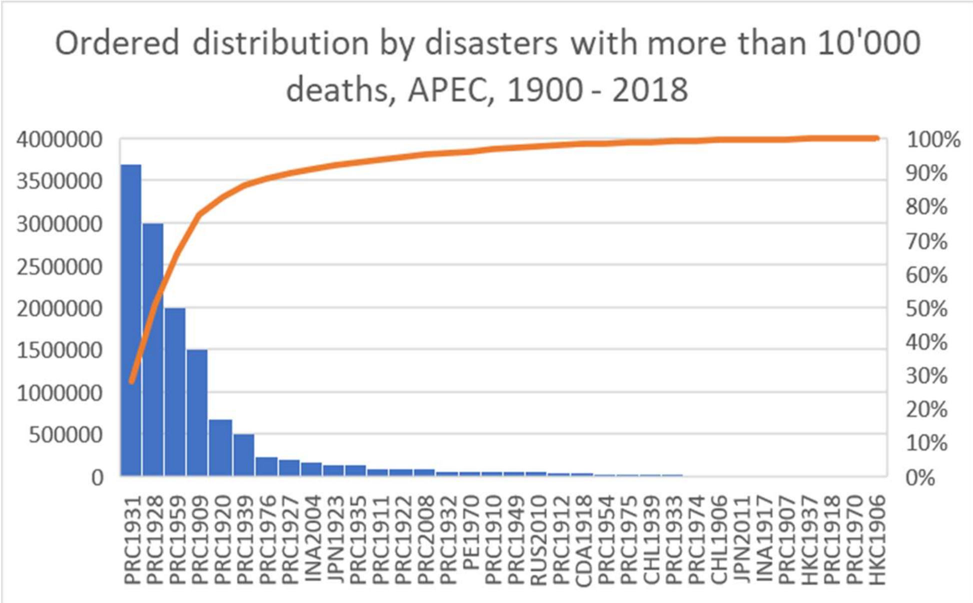


Figure 13: Ordered distribution of deaths by disasters with > 10'000 deaths, APEC, 1900 – 2018

Source: APSEC based on EM-DAT data

The eight biggest single disasters registered in the data set are given below, by order of magnitude, namely three floods, one drought, one epidemic, and three earthquakes.

Economy and year	Number of deaths	Disaster	Description (as in the data base)
PRC1931, July – Aug	3700000	Flood	Riverine flood
PRC1928	3000000	Drought	Shensi, Honan, Kansu
PRC1959 July – July 1961	2000000	Flood	North of China
PRC1909	1500000	Epidemic	Bubonic (bacterial disease)
PRC1920 16 Dec	180000	Earthquake magnitude 8.6 on Richter scale	Gansu Province, 39.40 N, 74.45 E
PRC1939 July	500000	Flood	Riverine flood, Honan province
PRC1976 27 July	242000	Earthquake magnitude 7.8 on Richter scale	39.37 N, 118.05 E, Tangshan, Peking, Tientsin

Table 8: The eight largest disasters of the period 1900 to 2018

Source: APSEC based on EM-DAT data

Over the total period 1900 to 2018, the ordered distribution of natural disasters by disaster category shows that floods caused 48% of disaster deaths, drought 26%, epidemics 12%, and earthquakes 11%.

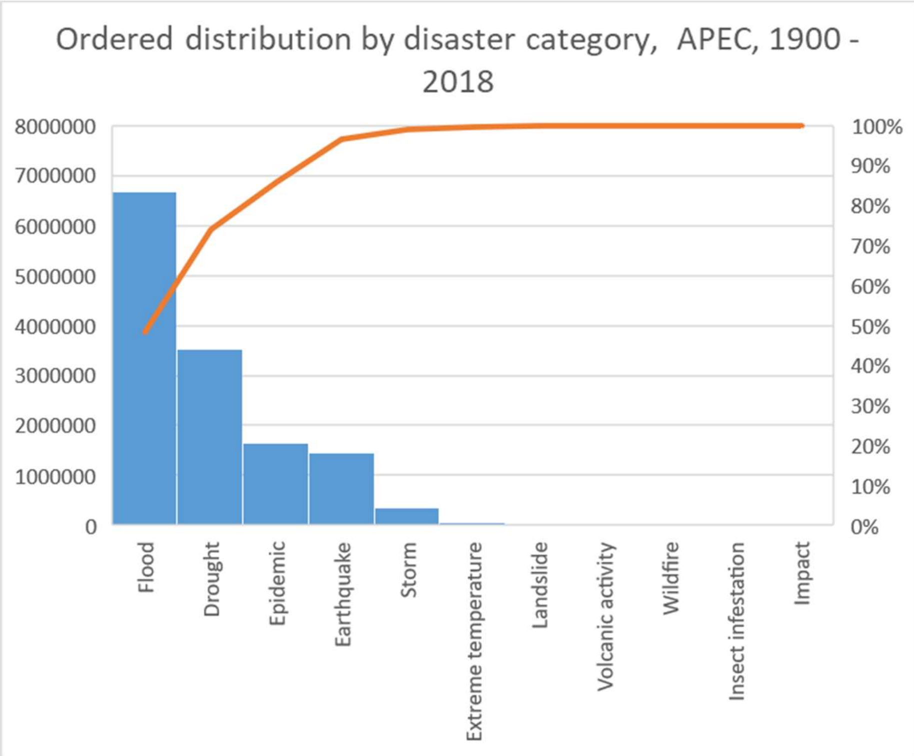


Figure 14: Ordered distribution of deaths by natural disaster category, events >10’000 deaths, APEC, 1900 – 2018

Source: APSEC based on EM-DAT data

In the first half period 1900 to 1959, the rank order of the five biggest disaster categories was identical to the rank order of the overall period, but the percentages changed slightly: floods caused 52% of disaster deaths, drought 28%, epidemic 13%, and earthquakes 6%.

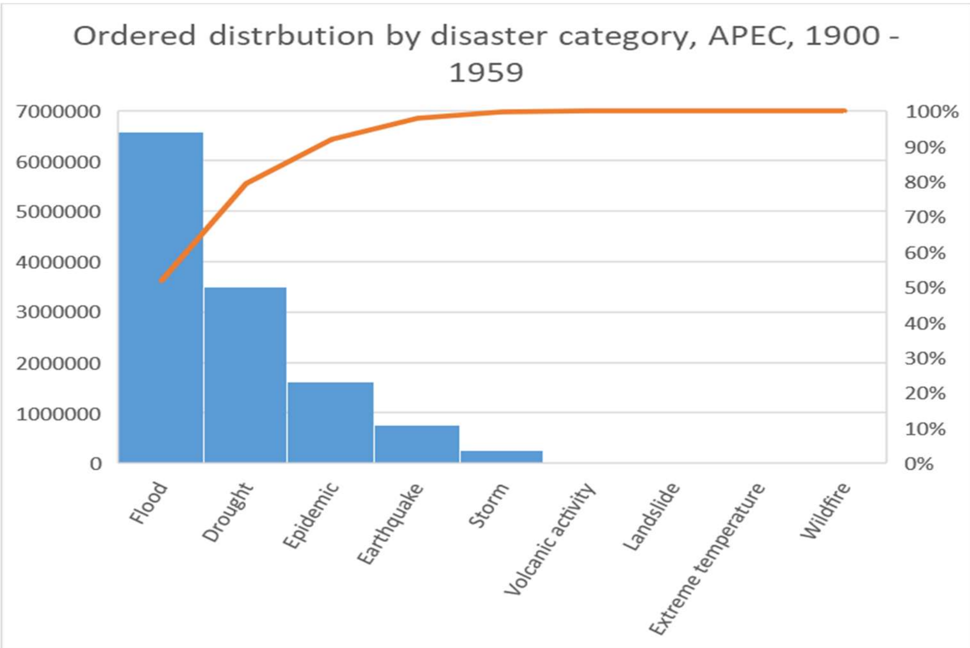


Figure 15: Ordered distribution by disaster category, APEC, 1900 – 1959

Source: APSEC based on EM-DAT data

The rank order totally changes in the second half period 1960 to 2018 as compared with the first half period. Earthquakes now cause 68% of disaster deaths, storms 11%, floods 10%, extreme temperatures 6%, and epidemics 2%, landslides (2%), whereas droughts have dropped to 1%. Volcanic activity and wildfires account both for half a percent of disaster deaths. Insect infestations did not cause any death in APEC in the period 1960 – 2018.

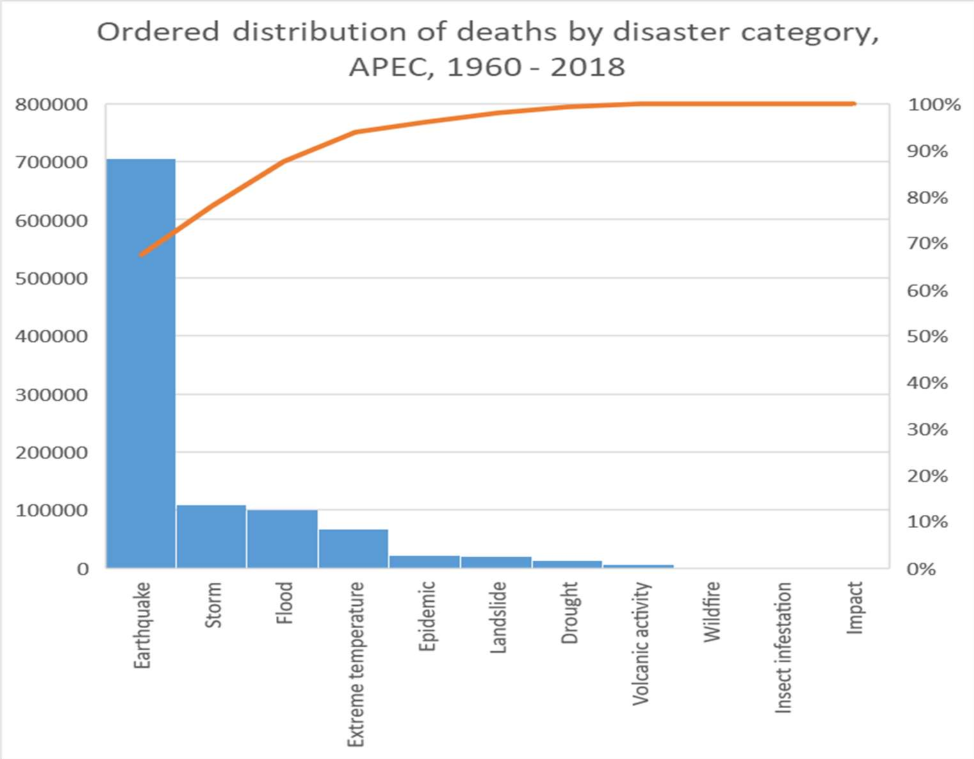


Figure 16: Ordered distribution of deaths by disaster category, all events, APEC 1900 – 2018

Source: APSEC based on EM-DAT data

The striking difference between the two periods before and after 1960 is the dramatic decline of deaths from floods (65 times less) and droughts (258 times less), which were the biggest treats to lives before 1960. Both these improvements are related to better water management, i.e. better flood prevention and better irrigation. Floods and droughts still exist after 1960 but cause a lot less victims. Besides better infrastructures, vulnerable populations may also have more possibilities to emigrate from flood and drought-struck areas today than 100 years ago. Furthermore, epidemics cause 63 times less deaths in the period after 1960, while earthquakes cause only 7% less deaths in the period after 1960.

Consequently, earthquakes become in relative terms the predominant cause of death by disasters in APEC after 1960. The biggest events in this category affecting APEC since 1960 were the earthquake of magnitude 7.8 on the Richter scale of 27 July 1976 in Tangshan (China) causing 242’000 deaths, followed by the earthquake and tsunami of magnitude 9.1 on the Richter scale of 26 December 2004 that caused 166’000 deaths in Indonesia and many other parts of the Indian Ocean, and the earthquake of magnitude 7.9 on the Richter scale of 12 Mai 2008 in large parts of China that caused 87’476 deaths, and the earthquake of magnitude 7.8 on the Richter scale of 31 May 1970 in Peru that caused 66’794 deaths. By comparison, the earthquake of 9.0 on the Richter scale of 11 March 2011 in Japan caused 19’846 deaths, which indicates that seismic protection may have been significantly improved in Japan during the past decades.

Similarly striking is the fact that new disaster categories appear since 1960: storms are now in rank 2 and extreme temperatures in rank 4. Both have a link to climate change and to the warming atmosphere. The single hydrometeorological event in the APEC region that caused the greatest number of deaths since 1960 is the heat wave in western Russia in late July 2010 which caused almost 56’000 deaths.

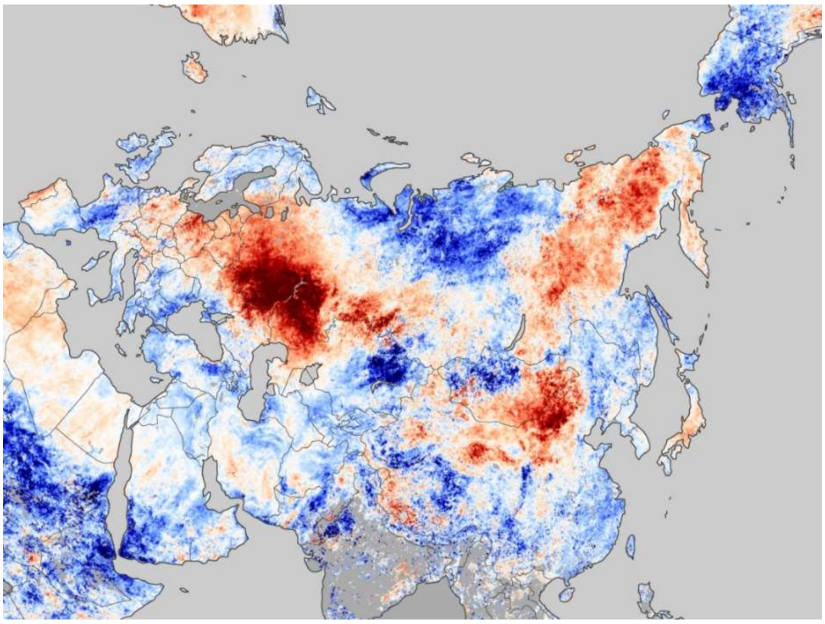


Figure 17: Heat wave over Russia between 20 and 30 July 2010

Source: NASA[38]

Notable is also the declining relative role of epidemics which drop from rank 3 (13%) to rank 5 (2%) between the period before 1960 and after 1960. These figures do not yet consider the 2020 pandemic.

The second half period 1960 – 2018 was specifically analysed for trends of three categories of disasters. For this purpose, the category hydrometeorological disaster was formed by adding storms, wildfires, floods, extreme temperatures, landslides, and insect infestations. The category of geological disasters is the sum of earthquakes and volcanic activity. The category of microbiological disasters contains only human epidemics. During the period 1960 – 2018, 68% of all deaths by disasters are caused by geological, 30% by hydrometeorological and 2% by microbiological disasters. By type of disaster, 68% are from earthquakes, 11% from storms, 10% from floods, 6% from extreme temperatures, 2% from epidemics, 2% from landslides, 1% from drought, and 1% from volcanic activity. Insect infestation has caused no recorded deaths in APEC in that period.

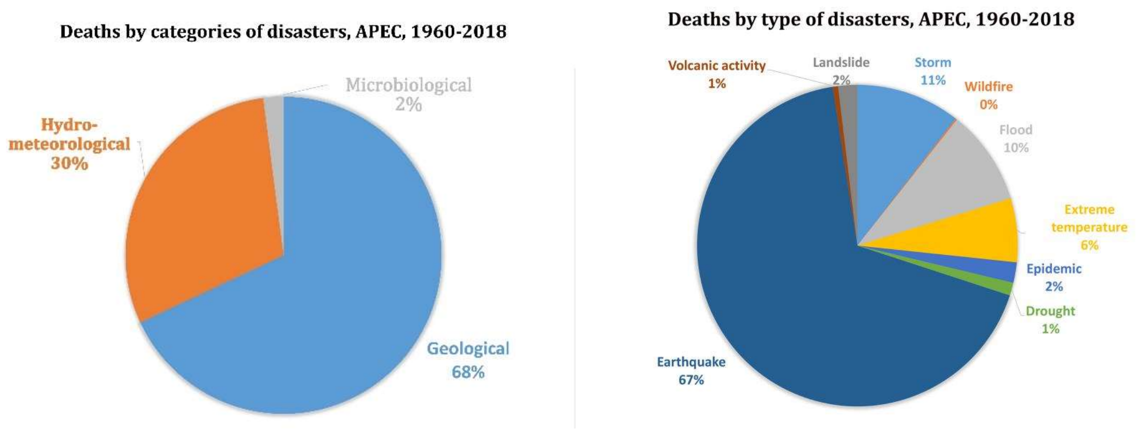


Figure 18: Deaths by categories and types of disasters, APEC, 1960 – 2018

Source: APSEC based on EM-DAT data

These three disaster categories were not analysed in their form of individual events, but rather as annual events. That means that all hydrometeorological events in APEC of the same year are added together and analysed as a single annual event, and the same was done for all geological and all microbiological events. The idea was simply to determine whether the number of deaths per year per disaster category in APEC shows a trend.

For deaths by disasters from geological origin, despite a decreasing trend that might be visible to the naked eye, this trend is too weak to be ascertained by regression analysis for both, the annual series and the 10-year moving average.

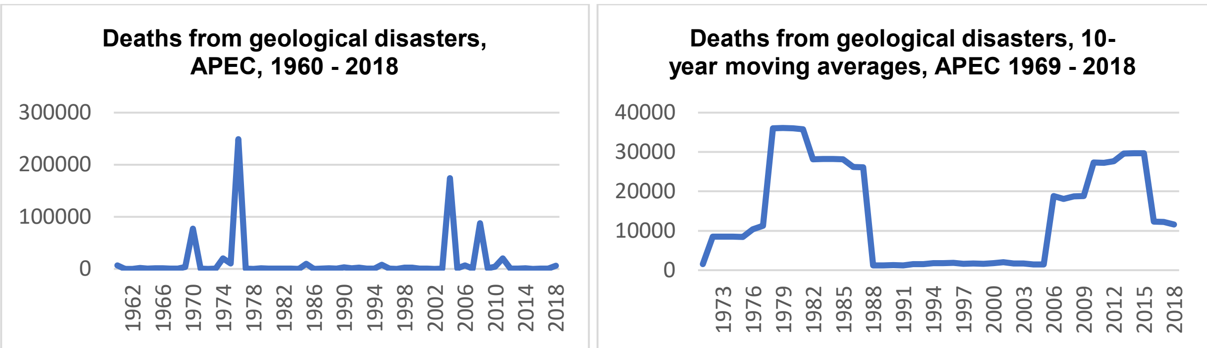
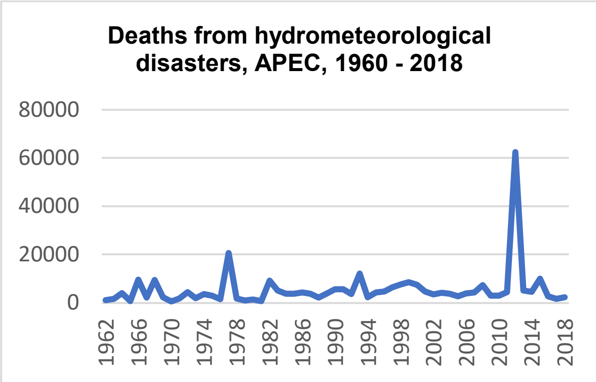


Figure 19: Deaths from geological disasters: Annual and 10-year moving average

Source: APSEC based on EM-DAT data

Concerning deaths by disasters of hydrometeorological origin, the increasing trend is visible to the naked eye in both cases. In the case of the annual series, the trend is too weak to be statistically significant. The large single event of 2010 is the heat wave over Western Russia in late July 2010. The 10-year moving average shows, however, a statistically significant increase of 2% per year.



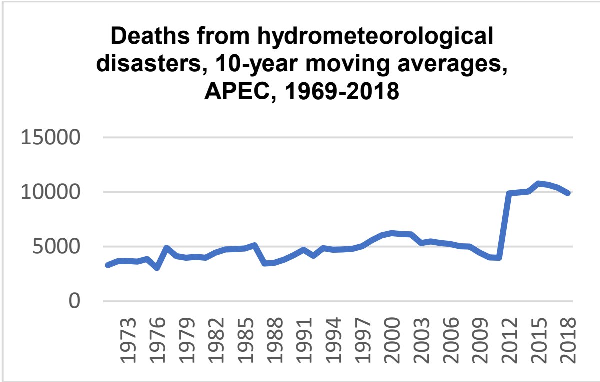


Figure 20: Deaths from hydrometeorological disasters: Annual and 10-year moving average

Source: APSEC based on EM-DAT data

The deaths caused by disasters from epidemics are determined by a peak in 1991. This peak does, however, not represent a single event, but is instead the result of the twelve events shown in the table below. The biggest component is the cholera epidemic of Peru which caused 9700 deaths during the period January to August 1991. It has been argued that this epidemic – as indeed most cholera epidemics – was the result of improper wastewater infrastructure[39].

Dates	APEC Economy	Region	Number of deaths	Type of epidemic
01/1991	Canada	Eastern Canada	18	Bacterial disease
13/06/1991	Chile		1	Cholera
07/1991	China	Anhui, Sichuan, Jiangsu provinces	1075	Cholera
03/1991	Indonesia	Aceh province (North Sumatra)	55	Cholera
04/1991	Indonesia	Aceh province (North Sumatra), Kalimatan	115	
01/1991	Indonesia		48	Cholera
15/01/1991	Indonesia	Java	41	Dengue fever
08/1991	Indonesia	Sumatra Centrale	35	Cholera
1991	Malaysia	Kuala Lumpur + other areas	263	Dengue fever
20/07/1991	Mexico	Tabasco, Chiapas, Guerrero, Yucatan, Tula Valley	52	Cholera
31/01/1991	Peru	La Libertad, Lambayeque, Ancash, Piura, Tumbes, Lima-Callao, Ica, Cajamarca, Arequipa, Puno, Apurimac, Huancavelica, Huanuco, Junin, Loreto, Moquegua, Tacna, Amazonas, San Martin, Ayacucho, Pasco, Ucayali departments	1726	Cholera
18/08/1991	Peru		8000	

Table 9: Components of the death peak by epidemics in APEC, 1991

Source: APSEC based on EM-DAT data

In comparison with the cholera epidemic in Peru of 1991, the number of deaths from epidemics in the year 2002 (SARS epidemic) was 1167, and in the year 2010 (H1N1 pandemic) it was 792 in all APEC economies cumulated. The latter events received much higher international attention because they were more successfully mitigated than the local Peruvian cholera epidemic.

Deaths from epidemics in APEC region show an increasing trend that is visible to the naked eye. The 10-year moving average shows a slight increasing trend. Both trends can be seen by regression, but none of them is statistically significant.

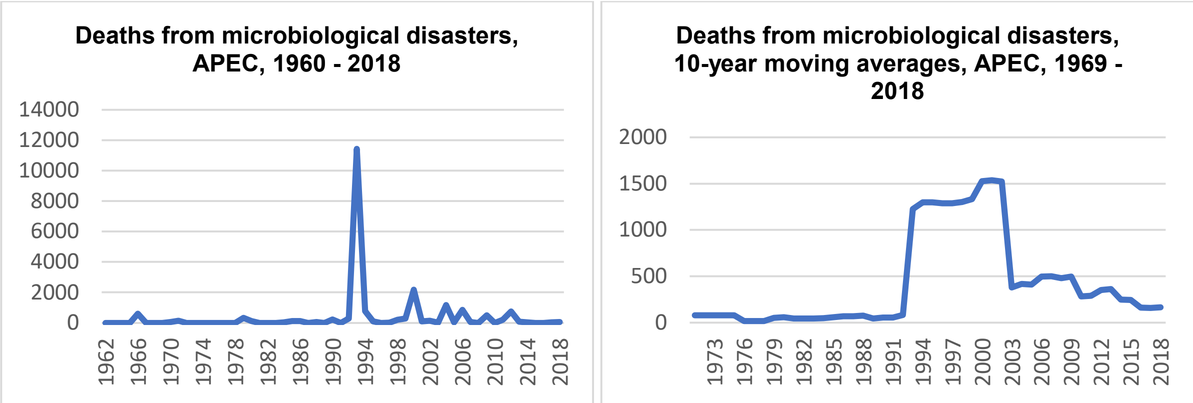


Figure 21: Deaths from microbiological disasters: Annual and 10-year moving average

Source: APSEC based on EM-DAT data

A technical guidance for monitoring and reporting on achieving the global targets of the *Sendai Framework* was released in 2017[40]. In the *Sendai Framework for Disaster Risk Reduction 2015 – 2030* the UN General Assembly sets seven global targets, the first of them has been quoted further above. It relates to the decade 2020 – 2030 compared to the period 2005 – 2015.

As a matter of fact, the base period 2005 – 2015 is an eleven-year period, just as the target period 2020 – 2030. To stick to the idea of comparing decades, as suggested in the *Sendai Framework*, the present report interprets the base period as being the most recent decade or 10-year period immediately preceding the adoption of the *Sendai Framework* in 2015. Hence the *Sendai Framework* base period referred to in the present report has been defined as the 2005 – 2014 period. The deaths by categories and types of disaster of the *Sendai Framework* base period 2005 – 2014 are shown in the figures below. Compared to the figures for the period 1960 – 2018 shown earlier, the composition has changed. The deaths attributable to geological disasters (i.e. essentially earthquakes) is down to 53%, whereas deaths due to extreme temperatures are now risen to 26%, followed by storms (11%). Floods still account for 6% of deaths from natural disasters.

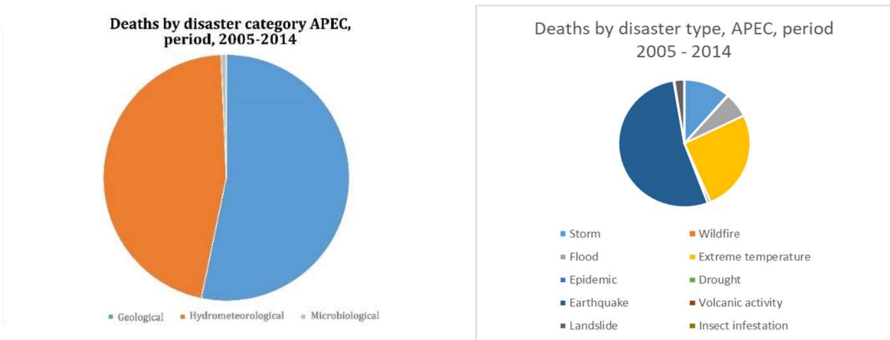
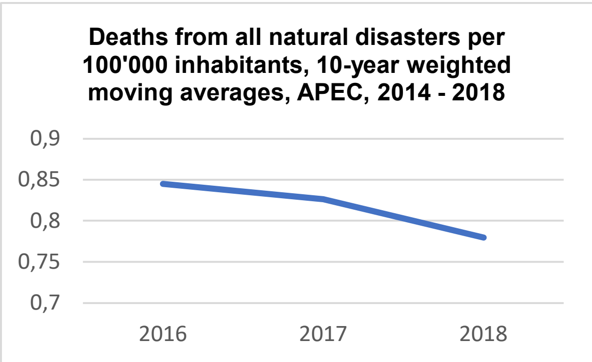


Figure 22: Deaths by disaster category and by disaster type, APEC 2005 – 2014

Source: APSEC based on EM-DAT data

The contribution by APEC to the *Sendai Framework* target is shown in the figures below which, however, still excludes deaths from technical disasters and accidents. As explained above, the target is expressed here in the form of 10-year weighted moving averages. Weighted moving averages allow to freely disaggregate and sum the scores of sub-entities. The left figure shows that the indicator of the decade 2005 to 2014 is decreasing for the subsequent decades, 2006 – 2015, 2007 – 2016, 2008 – 2017, and 2009 – 2018. The relative mortality rate due to natural disasters in APEC decreased from 0.86 per 100’000 to 0.47 per 100’000. Regression shows a statistically significant 11% decrease per year. For the time being, APEC is on track to achieve substantive improvement for natural disasters. However, the right figure shows how this indicator evolved since 1969. A lot depends, therefore, on large natural disasters that may (or may not) arrive by 2030 and cause important numbers of deaths.



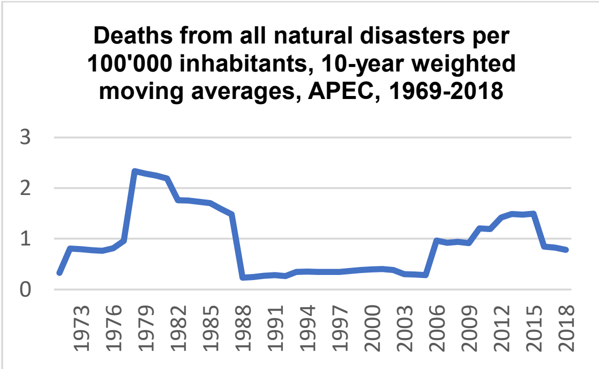


Figure 23: Deaths from natural disasters per 100'000 inhabitants APEC, 2014 – 2018, and 10-year weighted moving averages

The statistical regression analysis of the 10-year moving average of deaths from natural disasters per 100’000 inhabitants has been carried out not only for the five years shown in figure above, but also for the whole period 1960 to 2018. Taking the relative and weighted data of deaths per 100’000 inhabitants eliminates the possible increase of disaster deaths due to population increase. Once this has been eliminated, the risk figures are independent from the increase of population. The weighted relative data is a measure showing how many would have died if the population had remained stable. The analysis is based on 10-year weighted moving averages. In the 10-year weighted moving average, the effect of large events is still visible, albeit flattened. For deaths from all disasters as well as deaths from disasters of geological origin, the trend is slightly negative but statistically not significant.

For disasters of hydrometeorological origin, the growth trend of the weighted 10-year moving average data is statistically significant, as it was already the case for the unweighted series. That means that deaths by disasters of hydrometeorological origin in APEC do not only increase because the population increases, but due to increased hydrometeorological hazard. In APEC, disasters of hydrometeorological origin cause 0.8% additional deaths per 100’000 inhabitants per year over the whole period 1969 – 2018.

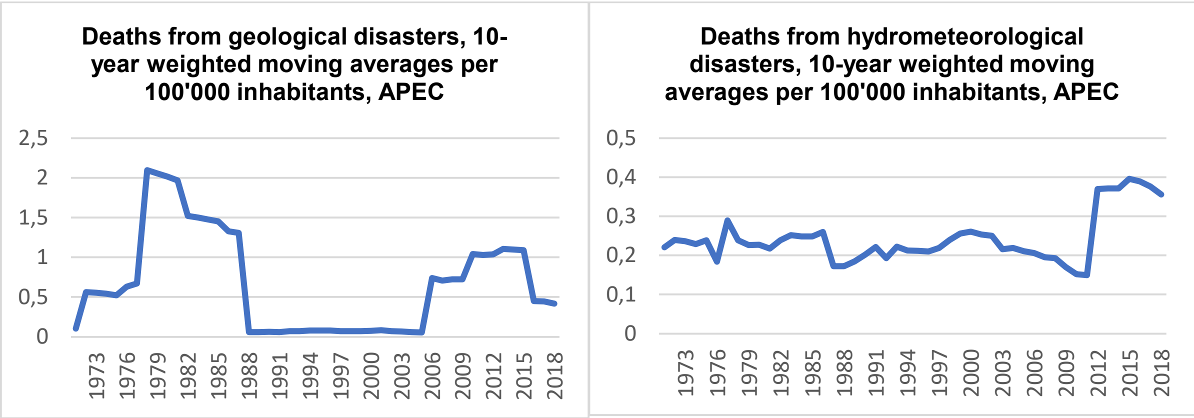


Figure 24: Weighted 10-year moving average of deaths from geological disasters and from hydrometeorological disasters in APEC

Source: APSEC based on EM-DAT data

For disasters from microbiological origin the plot of the 10-year moving average per 100’000 inhabitants may show a slight upward trend when seen with bare eyesight, but this trend is not statistically significant for the weighted 10-year moving average, just as it has not been for the unweighted one either. The various epidemics having hit APEC in the year 1991 (see table above) are still visible in the weighted 10-year moving average data.

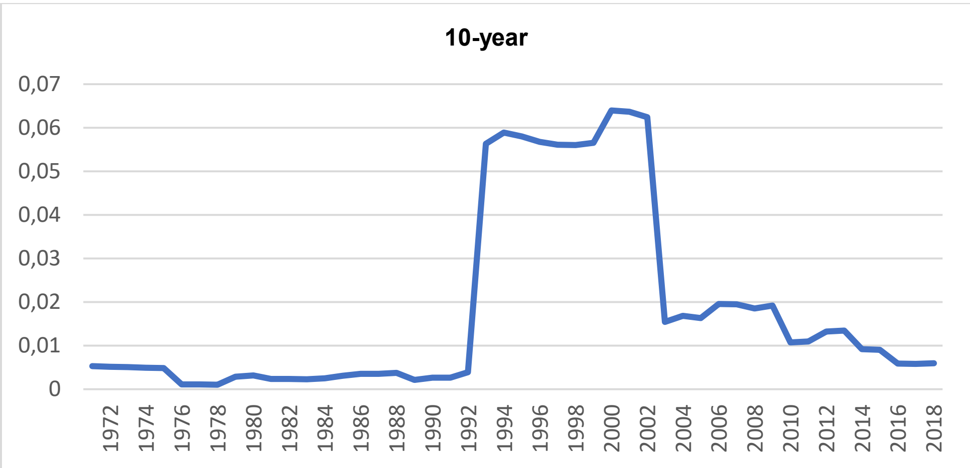


Figure 25: Weighted 10-year moving average of deaths from microbiological disasters in APEC

A cross-sectional analysis of disasters per 100’000 inhabitants was made for the base period 2005 – 2014 specified by the *Sendai Framework for Disaster Risk Reduction*. The analysis per disaster type shows the number of deaths per 100’000 inhabitants by disaster type for the whole APEC region during that decade (see figure below). Note that the weighted average has been computed as sum of disaster deaths in APEC during the period 2005 – 2014 divided by the sum of the APEC population over the years 2005 – 2014 times 100’000. This is mathematically equivalent to a weighted 10-year average of the period 2005 – 2014. The advantage of weighted averages is that they can be homogenously added and disaggregated.

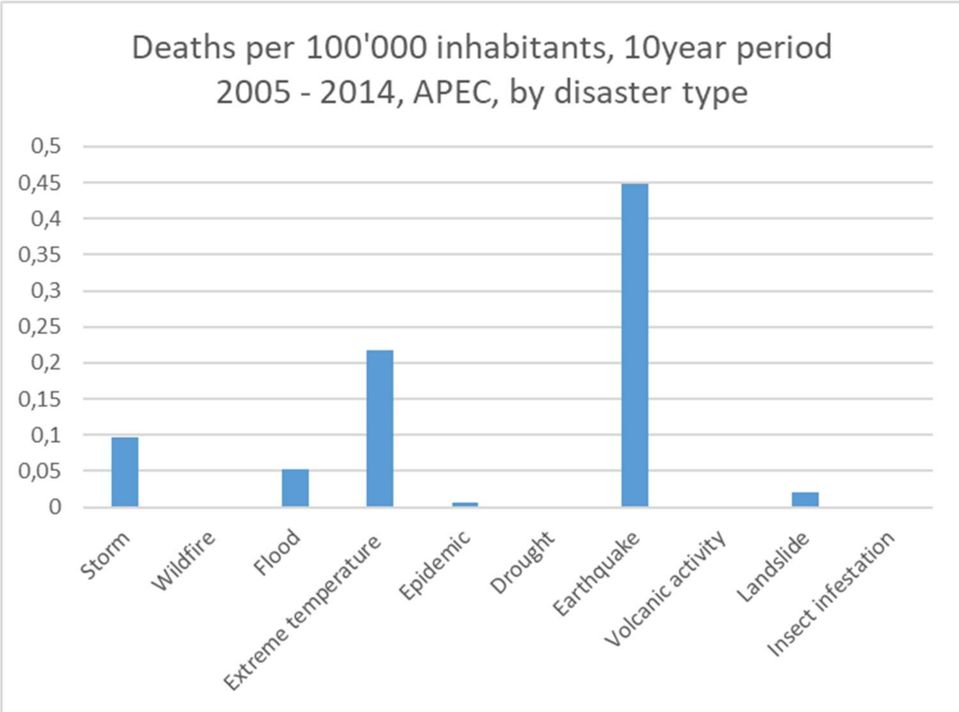


Figure 26: Deaths per 100’000 inhabitants, APEC, 10-year period 2005 – 2014

During the base decade 2005 – 2014 of the *Sendai Framework*, the largest threat to human lives in APEC originates from earthquakes which killed in average 0.45 persons per 100’000 inhabitants (53%), followed by extreme temperatures (0.22 per 100’000 or 26%), storms (0.10 per 100’000 or 11%), floods (0.05 per 100’000 or 6%), landslides (0.02 per 100’000), epidemics (0.01 per 100’000) and wildfires (0.006 per 100’000).

The relative and weighted disaster distribution of APEC during the *Sendai Framework* base period may be broken down to each APEC economy. The economy with the largest number of deaths from all disasters per 100’000 inhabitants during the period 2005 – 2014 was Russia (3.9 per 100’000), followed by the Philippines (2.0 per 100’000), Japan (1.7 per 100’000) and Peru (1.0 per 100’000). The other APEC economies were below APEC weighted average of 0.85 deaths per 100’000.

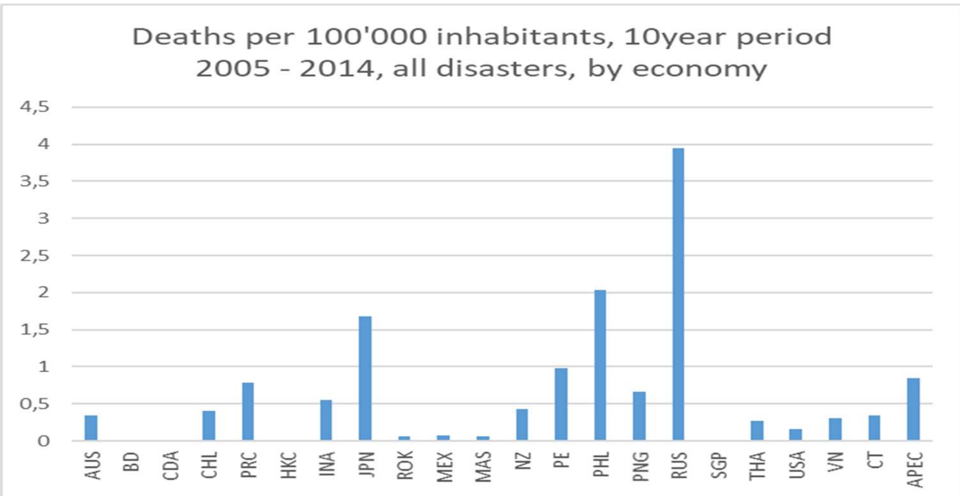


Figure 27: Deaths from all disasters per 100'000 inhabitants by APEC economy, 10-year period, 2005 - 2014

The disaster profile or relative importance of each disaster type for each APEC economy is shown in the table below. That table shows that APEC economies often have one specific dominant disaster type.

Earthquakes as main risk to life: New Zealand 98%, Japan 93%, China 87%, Chile 85% and Indonesia 72%. These economies are all above the APEC average of 53% for victims of earthquakes.

Extreme temperature (in this case always extreme heat) is the main risk to life in Russia (99%), Australia (64%), Peru (54%) and Canada (26%). These economies are all above APEC average of 26%. Canada's lethal extreme temperatures during the 2005 – 2014 period are all heat waves. The extreme cold waves such as the -48°C cold wave in January 2014 in Ontario, Manitoba and Saskatchewan provinces have not killed anybody.

Storms are the main risk to life in Hong Kong, China (100%), Chinese Taipei (96%), the Philippines (83%), the United States (82%), Mexico (51%), Viet Nam (51%). Storms are also above APEC average of 11% in Papua New Guinea (36%), Canada (29%), and Korea (29%).

Floods are a dominant risk to life in Thailand (93%), Malaysia (55%), Korea (51%). They still represent a risk to life above APEC average of 6% in most other APEC economies: Viet Nam (47%), Canada (40%), Mexico (31%), Indonesia (16%), Peru (15%), Australia (8%), China (7%), and the United States (6%).

In APEC average, landslides (2%) and epidemics (1%) are minor risks, but in Papua New Guinea, epidemics represent the largest type of disaster (40%).

	Storm	Wildfire	Flood	Extreme tempera-ture	Epidemic	Drought	Earthquake	Volcanic activity	Landslide
AUS	2	26	8	**64**	0	0	0	0	0
CDA	29	3	40	**29**	0	0	0	0	0
CHL	6	3	5	1	0	0	**85**	0	0
PRC	3	0	7	0	0	0	**87**	0	3
HKC	**100**	0	0	0	0	0	0	0	0
INA	0	0	16	0	3	0	**72**	3	5
JPN	3	0	0	3	0	0	**93**	0	1
ROK	29	0	**51**	0	0	0	0	0	19
MEX	**51**	0	31	1	0	0	1	0	16
MAS	0	0	**55**	0	35	0	0	0	10
NZ	2	0	0	0	0	0	**98**	0	0
PE	1	0	15	**54**	1	0	21	0	8
PHL	**83**	0	4	0	4	0	2	0	7
PNG	36	0	1	0	40	0	0	0	22
RUS	0	0	0	**99**	0	0	0	0	0
THA	2	0	**93**	3	2	0	0	0	0
USA	**82**	1	6	10	0	0	0	0	1
VN	**51**	0	47	0	2	0	0	0	0
CT	**96**	0	3	0	0	0	1	0	0
APEC	11	0	6	26	1	0	53	0	2

Table 10: Disaster deaths (%) per type of disaster for each economy, 10-year period 2005-2014

Source: APSEC based on EM-DAT data

Singapore and Brunei Darussalam have not recorded any deaths from disasters during the *Sendai Framework* base period; in Singapore, 33 deaths from SARS happened earlier, in the period February – May 2002, and a large forest fire in Brunei Darussalam between March and May 1998 did not kill anybody.

The UN is setting up its own data base for disaster risk management called Desinventar[41]. This data base was started in 2015 by the UNDRR. 89 governmental entities have notified disaster loss data. Among the notifying entities are not only UN member states but also some sub-state entities, e.g. the Indian provinces of Tamil Nadu and Uttarakhand. The following APEC economies are included in the data base: Chile, Indonesia, Mexico, Peru, Viet Nam. The data indicates tsunami and earthquakes as hazards causing the highest human mortality for the period 1970 – 2013, with combined share of 61%. The data base is still too narrow to allow for profound analytics and worldwide comparisons.

1.2.2. Economic Risk Profile of APEC Cities

The profile of overall risks affecting cities is difficult to measure. A comparative analysis of economic risks affecting cities worldwide has been elaborated annually since 2015 by the Centre for Risk Studies (CRS) of the Cambridge Judge Business School. In terms of the differentiation between human risks and economic risks, this analysis only addresses economic risks, i.e. the risks to lose GDP, which it falsely designates simply as “risks”. This economic risk is the same as the one addressed in SDG indicator 1.5.2, Direct economic loss attributed to disasters in relation to global gross domestic product (GDP). It is like SDG indicator 11.5.2. which, besides to loss of GDP, also includes loss to infrastructures. Historically, global economic growth over the past two centuries has not been linear but has gone through periods of growth and marked recession.

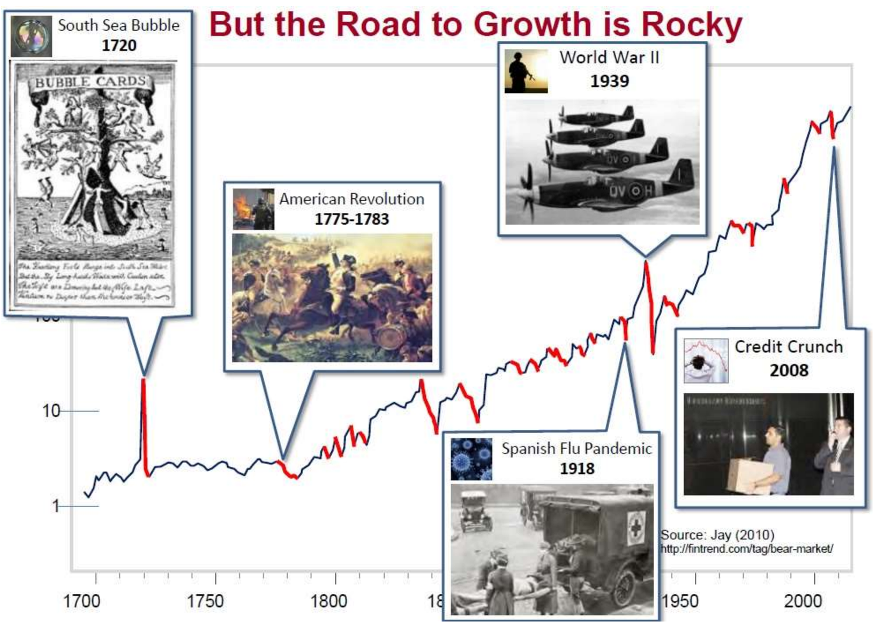


Figure 28: Periods of growth and recession since 1700

Source: Cambridge Centre for Risk Studies, 2014, based upon Elliott Wave International

The 2019 edition identifies 22 types of threats to 279 cities worldwide producing cumulated GDP of 36’745,22 bn $ equalling 41% of world GDP or 131,7 bn $ per city. In these cities, the overall GDP at risk is 577 bn$ or 1.57% of their total GDP or 2,068 bn$ per city. All these figures are expected annual GDP losses. The biggest risk categories are: Natural Catastrophes (174 bn$), followed by Financial, Economic and Trade (149 bn$), and Geopolitics and Security (140 bn$). Less important are Health risks (58 bn$) and Technological risks (56 bn$).

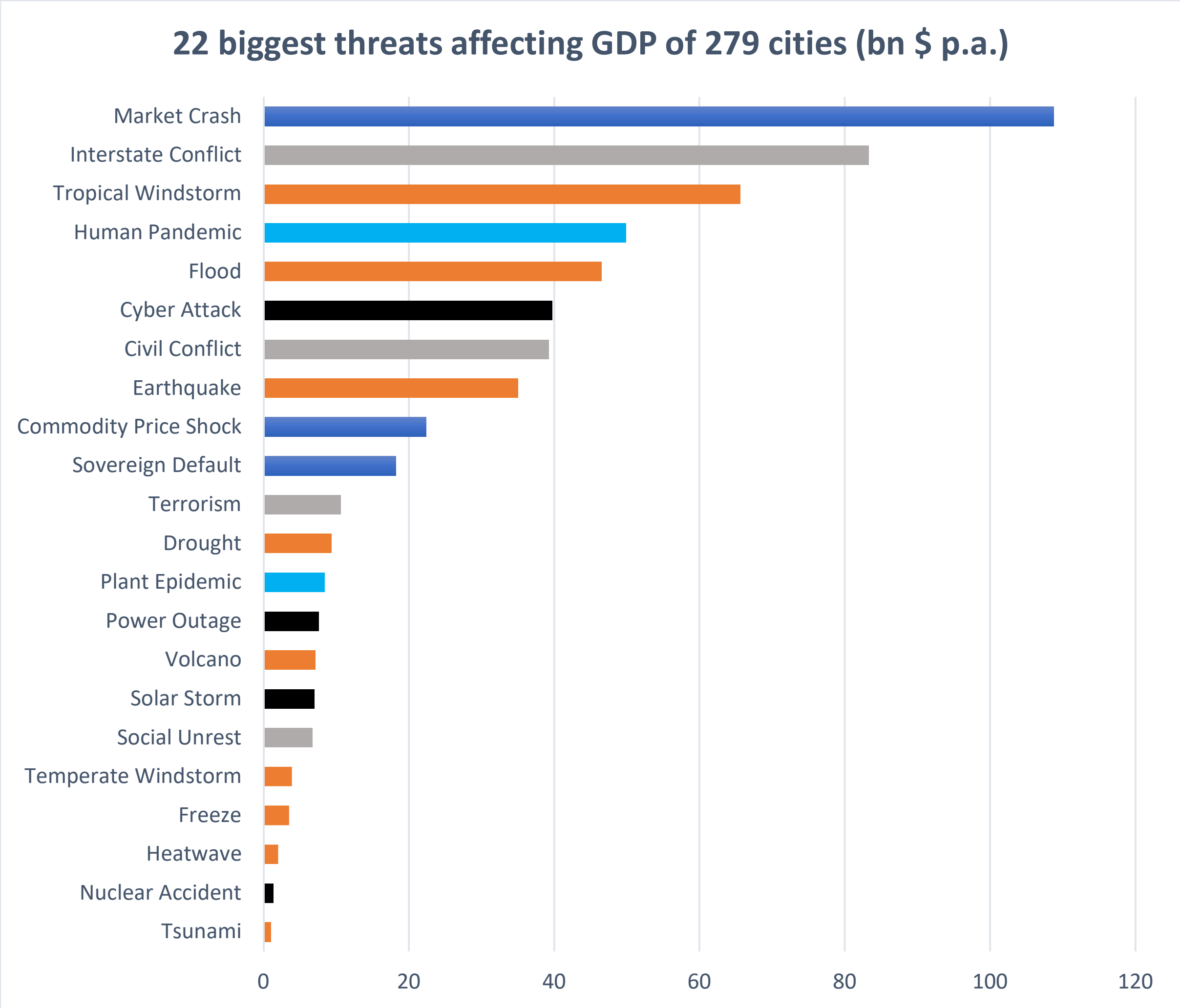


Figure 29: 22 biggest threats affecting GDP of 279 cities (expected annual GDP losses)

Source: APSEC using data of Cambridge Global Risk Index 2019 Executive Summary[42]

The threat of cyber-attack has increased by one position since 2018.

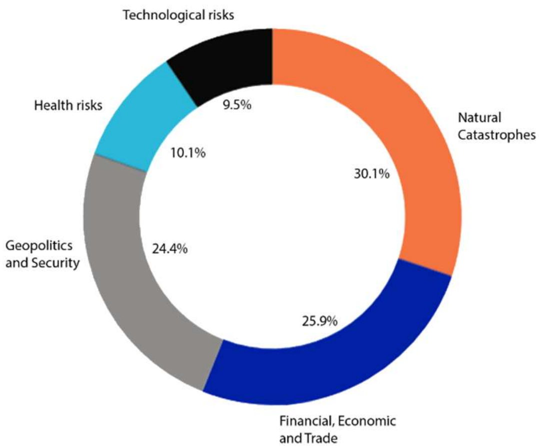
The three major threats affecting cities that can be related to climate change (tropical windstorm, flood, drought) take the third, fifth and twelfth position, respectively. The category of hydrometeorological threats identified in the previous section comprises all the natural catastrophes except earthquakes, tsunami and volcanos, which are bundled in the category of geological threats.

For the year 2018, the data can be taken from the Lloyds city risk index 2018, the predecessor of the CRS index. The Lloyds city risk index 2018 is available online[43]. The 279 cities have cumulated GDP of 35’404,22 bn$ equalling or 126,9 bn$ per city. In these cities, the overall GDP at risk is 546,5 bn$ or 1.54% of their total GDP or 1,959 bn$ per city. For the

279 sampled cities, the GDP at risk from hydrometeorological threats amounts to 130.8 bn$, three times as high as the GDP at risk from geological threats which amounts to 43.1 bn$.

For the year 2018, the above analysis can be refined and focused on APEC cities as a subset of the 279 cities that make up the total sample. The Lloyds city index 2018 includes 120 cities from 19 APEC economies. It does not include any city of Brunei Darussalam nor of Papua New Guinea. The total GDP of the 120 APEC cites is USD 24’085.34 bn or 200,711 bn $ per city, of which 335 bn$ or 1.39% or 2.79 bn$ per city is at risk.

This shows that APEC cities of the sample are economically almost twice as big (200 bn$ GDP per city) as the average global city (127 bn$ GDP per city). GDP at risk of APEC cities is at average less (1.39%) than global (1.54%) but in absolute terms higher (2,79 bn$ per city) than global average (1,959 bn$). These amounts are quite small for the global community, but enormously high for the affected local communities. The comparison per risk category (see below) based upon the last 50 years shows that APEC cites, compared to the global sample, have been more exposed to natural disaster risks and less exposed to geopolitical risks.



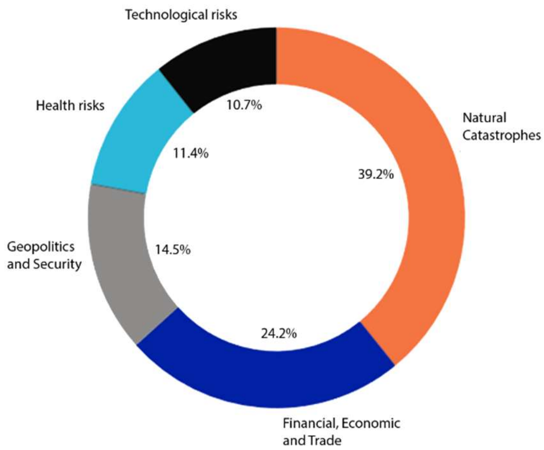


Figure 30: Risk categories affecting cities, comparison between global (left) and APEC cities (right)

Source: Lloyds city risk index[44]

Looking at the 22 specific threats having affected cities in the las 50 years (see below), APEC cities have more natural catastrophes (tropical windstorms) and less interstate conflicts than global average. They also have more earthquakes and less civil conflict than the rest of the world. Market crash remains, however, the biggest single threat for APEC cities as well as for the average global city. In the past 50 years, the world’s major cities have lost five times a third or more of their economic capital in average due to market crash. It does not come as a surprise that the biggest threat to the economy remains the economy itself. Economics is still a science in its embryonic stage of development, still lacking a clearly defined measurement unit linking it to the physical world and a measurement paradigm that defines what is being measured, and it is still is a science whose published forecasts (e.g. growth forecasts) cannot show the extent of their uncertainty or error margin, see as example the latest World Economic Outlook made by the IMF[45]. A natural value unit based on the human metabolism, combined with a hedonic measurement paradigm has been proposed in 2007[46]. The role of economic cycles in sustainability will be further discussed in section 2.2.4., the role of economics in resilience in section 3.1.4.

The figure below indicating total expected loss can be interpreted to show that each of the 120 sampled APEC cities loses every year in average around 500 M$ GDP (i.e. 60 bn$ divided by 120) due to market crash and about the same amount due to tropical windstorms. Both figures are averages of the sampled 120 APEC cities. Given that many APEC cities are not exposed to tropical windstorms at all, this means that for those APEC cities that are exposed to tropical windstorms, the loss due to tropical windstorms is unbearably large.

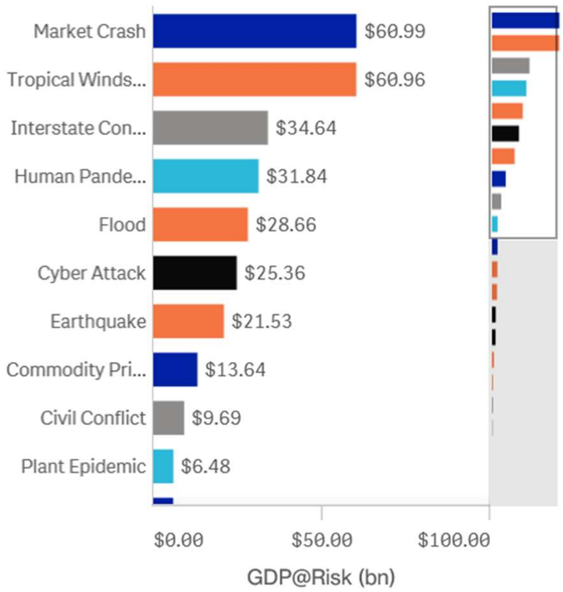


Figure 31: The ten most important treats of 120 APEC cities

Source: Lloyds city risk index

Even though market crash and tropical windstorms cause approximately the same level of risk to GDP (i.e. they cause expected losses of similar amount) in the 120 APEC cities, there is a striking difference between the two. Market crash happens with a high degree of uncertainty, whereas tropical windstorms occur with low degree of uncertainty[47]. Human behaviour is less predictable than meteorological behaviour. Degree of uncertainty is the opposite of the degree of confidence. These definitions are also used by the International Panel for Climate Change IPCC:

Confidence	Degree of confidence in being correct	Uncertainty
Very High Confidence	At least 9 out of 10 chance of being correct	Very Low Uncertainty
High Confidence	About 8 out of 10 chance of being correct	Low Uncertainty
Medium Confidence	About 5 out of 10 chance of being correct	Medium Uncertainty
Low Confidence	About 2 out of 10 chance of being correct	High Uncertainty
Very Low Confidence	Less than 1 out of 10 chance of being correct	Very High Uncertainty

Table 11: IPCC terminology on levels of confidence

Source: IPCC[48]

The level of uncertainty or, rather, the degree of confidence offered by the data for the 22 threats analysed above should therefore be represented graphically in an appropriate manner.

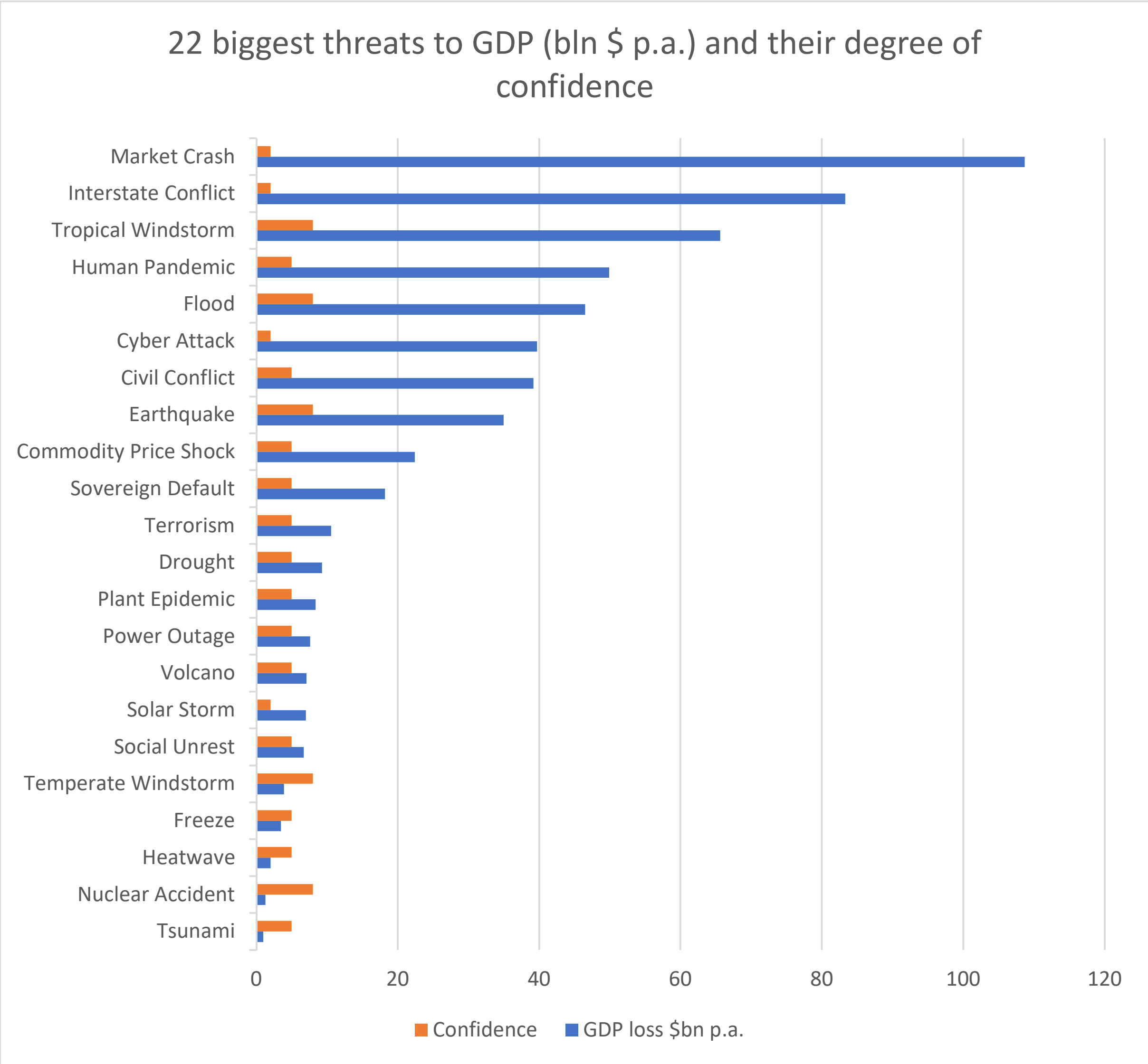


Figure 32: 22 biggest threats and their degree of confidence

Source: APEC using data from CRI

This raises the question, which of both, certain and uncertain threats, should receive more attention from public authorities. The answer is that both should receive the same attention if they have the same risk level, but the strategy to mitigate the risk might be different, depending on the level of uncertainty. Events like market crash can hardly be attributed to a single location like a city. Therefore, they should receive a global or economy-wide response in which cities fully participate according to their respective economic weight.

On the contrary, events like tropical windstorms that are relatively likely to occur at certain places – even though their exact date and place is not predictable – should receive a concrete response in city planning by implementing corresponding building standards. The places where tropical windstorms occur are, after all, relatively limited.

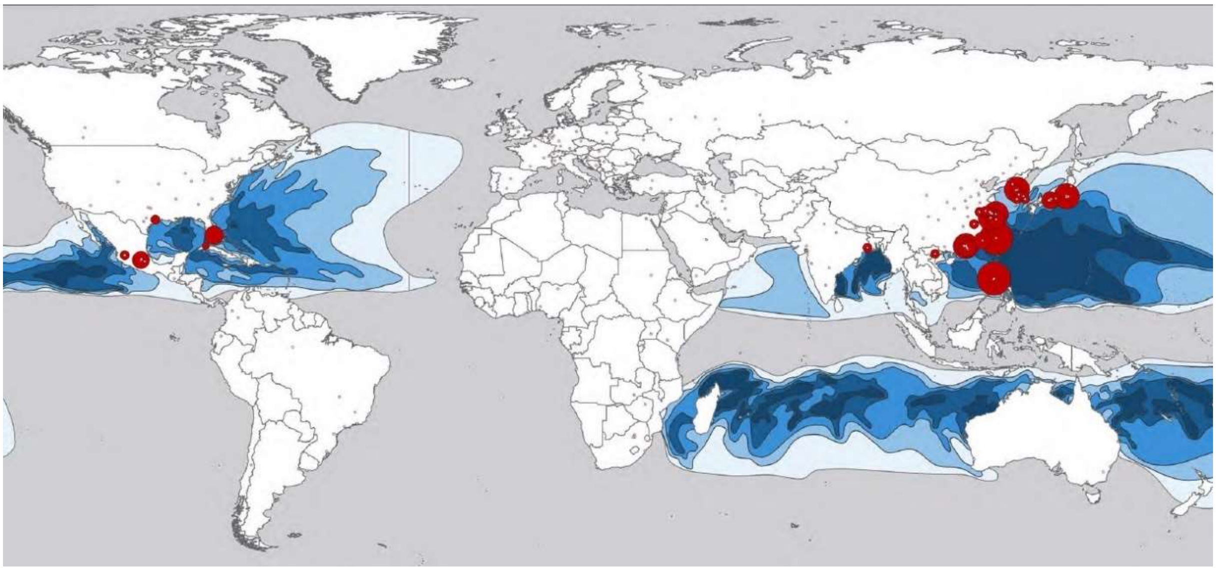


Figure 33: Geographic distribution of the five categories of tropical windstorms (wind speeds > 118 km/h)

Source: Centre for Risk Studies Cambridge, 2014

Cyclones, typhoons and hurricanes describe the same phenomenon of tropical windstorms around India and Australia, in the East Asian Pacific, and in the Caribbean and American Pacific, respectively. In the northern hemisphere, the tropical windstorm season is normally between June and November each year, in the southern hemisphere it is between November and April. In both hemispheres it is limited to the areas between 5° and 20° north and 5° and 20° south of the equator as only these areas create the conditions generating hurricanes. In the belt near the equator tropical windstorms do not occur. The conditions creating tropical windstorms are large amounts of warm (>27°C) surface water down to 50 meters deep, and light sea winds capable of transporting them over long distances.

Tropical windstorms are measured on the Saffir-Simpson scale, indicating values between 1 and 5[49]. This scale has originally been linked only to wind speed, to which later atmospheric pressure has been added. The problem is that wind speed does not adequately measure storm surge, the deadliest and most destructive effect of hurricanes. As example, hurricane Katrina of 2005 is considered as category 3 based on wind speeds, but in some areas in caused storm surges of more than 9 meters, corresponding to a pressure of 902 mbar, making it a category 5 hurricane. This type of mismatch between wind strength and storm surge is caused by the local topography. A shallow continental shelf and an estuary-type coastline both cause storm surge to be higher than a deep continental shelf and a straight coastline. The mismatch between wind strength and storm surge may cause residents to take insufficient protection measures, which aggravates the number of deaths. Cities should gauge the tropical windstorm warnings to take account of local topography and publish a local impact-related measure for the strength of tropical windstorms.

Category	Wind speed	Storm surge (height above normal)	Atmospheric pressure (millibars)	Damage
1	74–95 mph (119–153 kph)	4–5 ft (1.2–1.5 m)	>979	**Minimal**: No real damage to buildings. Damage to unanchored mobile homes. Some damage to poorly constructed signs. Some coastal flooding and minor pier damage.
Examples: Cindy and Ophelia (2005)				
2	96–110 mph (154–177 kph)	6–8 ft (1.8–2.4 m)	965–979	**Moderate**: Some damage to building roofs, doors, and windows. Considerable damage to mobile homes. Damage to piers from flooding. Small craft in unprotected moorings may break their moorings. Some trees blown down. Evacuation of some shoreline residences and low-lying areas required.
Example: The Perfect Storm (1991), Hurricane Isabel (2003)				
3	111–130 mph (178–209 kph)	9–12 ft (3–4 m)	945–964	**Extensive**: Some structural damage to small residences and utility buildings. Large trees blown down. Mobile homes and poorly built signs destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain may be flooded well inland. Evacuation of low-lying residences within several blocks of the shoreline may be required.
Examples: Dennis, Katrina, Rita, and Wilma (2005)				
4	131–155 mph (210–249 kph)	13–18 ft (4–5.5 m)	920–944	**Extreme**: More extensive failure on non-bearing, exterior walls with some complete roof structure failure on small residences. Major erosion of beach areas. Terrain may be flooded well inland. Massive evacuation of residential areas as far inland as 6 mi (10 km) may be required.
Example: Galveston Hurricane of 1900				
5	>155 mph (249 kph)	>18 ft (5.5 m)	<920	**Catastrophic**: Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Flooding causes major damage to lower floors of all structures near the shoreline. Massive evacuation of residential areas on low ground within 5 to10 mi (8 to 16 km) of the shoreline may be required.
Example: Andrew (1992)				

Table 12: Saffir-Simpson Hurricane Scale

In the long term, the impact of tropical windstorms is likely to worsen due to both, increase of strength of tropical windstorms and rising sea levels. Melting of Greenland ice would cause sea level rise by 7 meters[50], melting of the Antarctic ice a rise of 60 meters[51]. IPCC SROCC report projects that by 2100 the sea level may rise between 29cm and 110cm[52]. Resilience against tropical windstorms is presented in section 3.2.1. below.

Interstate conflicts have caused expected GDP losses of about half the magnitude of the losses of tropical windstorms in the sampled 120 APEC cities in the past 50 years. Since the 1970s, APEC region has been less exposed to interstate conflict than the world in average.

Human epidemics or pandemics, just like cybercrimes, do not destroy infrastructures and are, therefore, sometimes not listed under natural disasters. Human epidemics has caused expected losses of about half the magnitude of the losses of tropical windstorms (i.e. GDP loss of 250 M$ per year in average for each of the 120 APEC cities). These data do not yet contain the COVID-19 pandemic. Data about human epidemics is of medium confidence. In the past 50 years, five major human disease outbreaks have struck the world. Epidemics threaten the cities due to two pillar characteristics of cities, namely the high population density, and high mobility. Thus, transmissible diseases can rapidly spread to all the cities of the world. Cities might not necessarily have the capability to enact adequate border measures, except possibly at their local airports. Hence, they depend on measures taken at the level of their economies. COVID-19 has, however, shown an increased role of cities to fight the pandemic. With respect to understanding pandemics like the COVID-19, the most important questions are:

Firstly, is this pandemic a wave, or is it a persistent increase of the stationarity level (the equivalent of the sea level of the ocean)? Fortunately, the human immune system creates a response that destroys the virus. Cases of immunization are much more frequent than cases of reported exceptions or re-infection[53]. Therefore, the hypothesis of persistent increase of the stationarity level can be rejected at high level of confidence. Still, it is not yet known whether the recovered COVID-19 patients will suffer long term consequences of this disease.

The second question is: How frequently is such a wave going to happen? The given resilience response will be totally different if this an annual, decennial, or a hundred-year event. Above it was mentioned that the world has experienced an epidemic every 10 years during the past 50 years. The figure below goes even further back. It also shows that since 1920, nine epidemics appeared. Based on historical evidence, it is reasonable to assume that once every 10 years the world is facing an epidemic. To what extent this can be extrapolated into the future will be analysed in the fifth question below. The relatively low number of deaths of SARS (2002 – 2003) indicated in the figure below corresponds well with the data of the EM-DAT data base used in section 1.2.1. above, a number which contrasts with the high international attention SARS received. The high international attention was, lastly, the cause of the comparatively low number of deaths. The zika virus is not listed in figure below as it has never taken the dimension of an epidemic. Throughout human history epidemics or pandemics have been omnipresent. Each time they brought many deaths but those who survived were more numerous than those who died. World population has increased, and so has globalization and international intertwining. The nature of COVID-19 is not of a kind to fundamentally change this pattern.

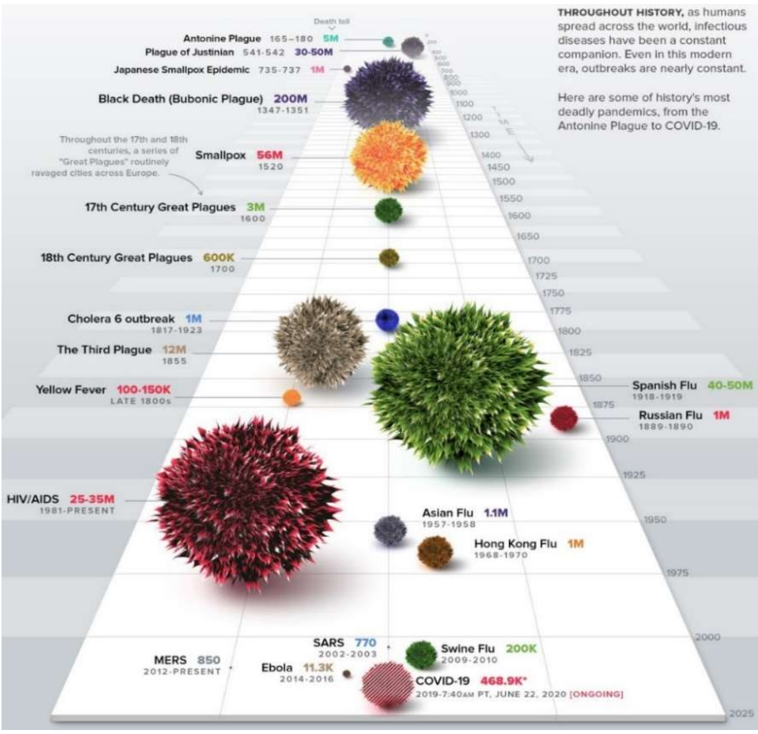


Figure 34: Comparison of past and present epidemics

Online source: https://www.visualcapitalist.com/history-of-pandemics-deadliest/ (updating)

The third question is: How quickly does this wave spread? The frightening factor of COVID-19 is its rapid spread, combined with mortality rate that is higher than the one of a simple influenza and the absence of vaccine and medical treatment. The HIV/AIDS is still endemic today and has killed almost as many people as the Spanish Flu, but its slow spread gives much more time for the health system to react and is, therefore, not restricting everyday life. Also MERS is still endemic today (i.e. could break out any time again) and has a case fatality rate of 30 to 40% which is certainly much higher than COVID-19, but as it spreads slowly it has not caused the disruption like COVID-19 either[54]. Conforming to expectations, COVID-19 has split into several strains. The online development of strains and their geographical spread can be seen on https://nextstrain.org/ncov/global. To date, two major groups exist, one spreading more rapidly than the other one. In Iceland, a patient has been infected by both major strains[55].

The fourth question is: How does this wave spread geographically? An epidemic is not spreading along geographic proximity, but along networks. Therefore, the basic mode of spread is the network mode. As cities are usually at the centre of networks, they play a key role in the transmission of epidemics. On a geographical map, the spread shows a spider-like dissemination which looks like an evolving fractal object. This explains why COVID-19, which originated in Wuhan, China, attained certain cities on other continents (e.g. northern Italy, US, or Brazil) faster than Chinese cities or regions that are relatively closer to Wuhan.

The fifth question is: Where do these epidemics all come from? Above it was mentioned that epidemics are a medium confidence type of disaster, meaning there is still only a 50% likelihood to have a correct prediction. SARS had its origin in civets, and MERS in camels, and COVID-19 most probably in bats[56]. Most of these pathogens are so-called zoonotic diseases that are found in wildlife[57]. A table of zoonotic diseases can be found in the Merck manual of zoonotic diseases[58]. The insufficient predictability originates from the impossibility to forecast when the next pathogen will cross the border between wildlife and humans and how much loss it will create. It is common knowledge that the destruction of wildlife habitat weakens wildlife in general, including by increased presence of wildlife disease which in turn increases the risk of crossing species-barriers and infecting humans. Increased monitoring of wildlife disease is the key to improving the existing early warning system of the FAO-OIE-WHO beyond the range of human society[59]. Note, however, that also animal farming can become a potential reservoir of zoonotic diseases. A group of Chinese scientists has drawn attention to a new type of swine fever originating from G4 EA H1N1 virus which has developed in the last ten years on Chinese pig farms and has the potential to cause a human pandemic[60]. The same causes might also favour the spread bacterial diseases. The discovery of antibiotics in 1928 gave way to efficient treatments against bacterial diseases. However, as almost half of the antibiotics are nowadays (mis)used in livestock production, antibiotic resistant bacteria have developed in the last decades. This becomes one of the greatest threats to human health[61].

The sixth question is: How tolerant is the society for accepting deaths due to epidemics? The social tolerance to accept deaths from any disaster has greatly decreased during the last hundred years. COVID-19 shows that epidemics make no exception in this regard. Contemporary society requires that the number of deaths from epidemics is constantly lowered, too.

The understanding of an epidemic requires also understanding of how it is being transmitted. Transmissible diseases are caused by invading pathogens: prions, viruses, bacteria, fungi, protozoans, or different types of worms and arthropods. Prions are supposedly the least known pathogens among non-specialists. Prions simple misfolded proteins that are in general not considered as living organisms, but still have the capacity to transmit their misfold to other proteins. Prions are unique in the sense that they do not create any response of the immune system. Prions have affected agriculture during the bovine spongiform encephalitis (BSE or mad cow disease) which is now largely believed to be under control[62]. Prions are also the pathogen of the Kuru disease found among the Fore people in Papua New Guinea before it had been eradicated[63]. The other pathogens (viruses, bacteria, fungi, protozoans, worms and arthropods) are better known among the public and need not be described in detail here.

Infectious diseases have several modes of transmission:

- Direct person-to-person contact, e.g. HIV
- Animal-to-person contact, e.g. rabies
- Contaminated objects incl. handrails, doors, elevator buttons, light switches, water taps, banknotes, coins etc.; e.g. COVID-19[64]. Transmissibility of infected objects depends on how long a specific micro-organism survives on their surfaces.
- Respiratory droplet of particle size >5μm, e.g. flu, COVID-19 and many other common transmissible diseases
- Airborne transmission by droplet nuclei and aerosols of particle size < 5μm, e.g. measles, COVID-19[65]
- Insect bites, e.g. malaria, zika
- Food and drinking water, e.g. cholera, salmonella
- Environment incl. warm water supply system and cooling towers, e.g. legionellosis

To understand the spread of transmissible diseases, it is necessary to know how many healthy (susceptible) people in average are infected by an infected person. Transmissibility is described by the base reproduction number R_0 of each disease. R_0 of a disease is defined as a measure of how transferable a disease is without any immunity nor vaccination[66]. R_0 differs from the effective reproduction number R_{eff} which measures the spread of the disease after vaccination or other measures, whereby $R_{eff} < R_0$. R_0 of a disease is, however, not a constant, as it depends on specific medical intervention parameters such as the average number of days to diagnosis (testing) and the mean degree of isolation of an infected person. The definition and role of R_0 and how it determines herd immunity are described in Annex 1. For the case of the Spanish flu, when viruses were barely known and when no vaccine nor treatment was available, the epidemic progressed until it was naturally stopped by herd immunity, i.e. after about one third of the world population had been affected of which 5% to 10% may have died. The eight genes of the Spanish flu virus have been reconstructed in the years 2001 – 2005[67]. For the three coronavirus diseases SARS, MERS, and COVID-19, the objective was each time to halt the progression well before herd immunity was attained. This was primarily motivated by decreased social tolerance to accept fatalities from these kinds of diseases, and the absence of vaccine or efficient medicine to treat them. Resilience against epidemics will be discussed in section 3.2.3.

Floods are the next largest type of disaster threatening GDP of APEC cities following epidemics. The threat of flood causes just a little less expected GDP loss to APEC cities than epidemics (i.e. around 238 M$ per annum in average for each of the 120 APEC cities). Globally, half of the analysed cities have suffered a serious flood during the past 50 years, a quarter have been flooded more than five times. Contrary to human epidemic, the data on floods are of high confidence. Floods are geographically localized and have three causes: 1) flooding due to coastal storms, 2) river flooding, i.e. heavy rainfall on possibly far away upstream locations, and 3) heavy rainfall (flash flood) on the urban drainage system itself. The three levels of flood intensity are low (>1m), medium (>3m) and high (>6m). Flooding is highly relevant for urban planning. The methodology underlying the city risk index differentiates between flooding as water damage and windstorm as wind damage [68], even though both often happen simultaneously. Resilience against floods will be presented in section 3.2.1. alongside with resilience against all types of climate threats.

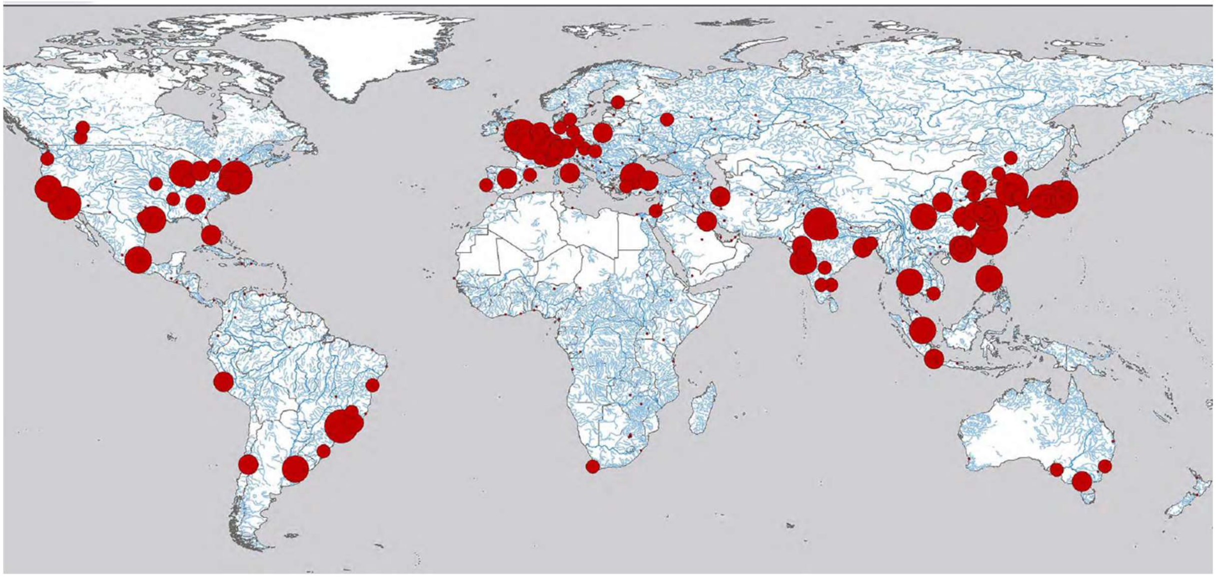


Figure 35: Map of flooding risk on cities

Source: Centre for Risk Studies Cambridge, 2014

Cyber-attacks are the next biggest threat affecting APEC cities by order of magnitude, causing around 211 M$ expected GDP loss per year to each of the 120 APEC cities in average. Data on cyber-attacks are of low confidence. Cyber-attacks are growing faster than all other threats. They are highly relevant for the new types of risks (e.g. systemic risk, cascading risk) described above. If there is one single type of threat that requires much stronger and deeper international cooperation it is cyber-threat. Cities can only protect their own administrations.

One of the most noteworthy recent examples of a cyber-attack on an APEC city happened on 22 March 2018 to the city of Atlanta. The city was hit by a ransomware that encrypted and locked files and requested users to pay a ransom. For five days, the attack significantly impacted online city services including critical services such as law enforcement, justice and online billing and online permitting services. As a precautionary measure, the Wi-Fi system at the Hartsfield-Jackson Atlanta International Airport was closed until 2 April[69]. The attack was caused by two individuals who created and deployed the “SamSam” software which requested the city to pay 0.8 bitcoin per computer, or around USD 51’000 for the 3789 computers connected to the city network to unblock the files[70]. Two months after the attack, still one third of the 424 software programs that the city runs remained offline or partially inoperable, of which one third were deemed “critical”[71]. In the months prior to the cyber-attack Atlanta had been warned in an internal audit report of long-standing severe deficits of its IT networks that made them vulnerable to threat[72].

The list of cyber threats and attacks comprises an ever-growing number of different types. A non-exhaustive list of cyber threats is given in Annex 3. Ransomware is the fastest developing type of cyber-threat. The figure below shows the development between 2012 and 2017.

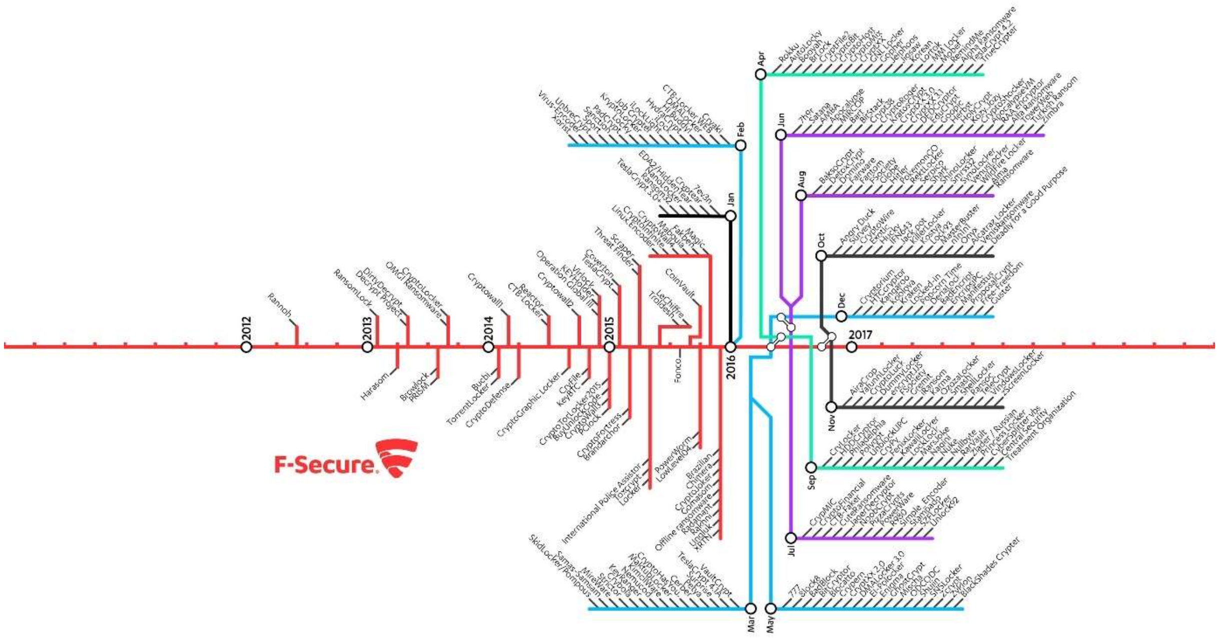


Figure 36: Ransomware-families 2012 - 2017

Source: F-Secure[73]

Cyber criminality can affect almost any other human activity. As an example, in 2015 a first type of medjacking emerged in the US. Medjacking is the name given to cyber-hijacking of medical equipment in hospitals. Medjacking is one of the possible consequences of the inadequate protection of devices connected to the internet of things IoT.

Box 2.1. Medjacking the infusion pump

Cyberattacks cascading into health systems and compromising patient lives through attacks on health-care monitoring devices ("medjacking") emerged in 2015. Security researchers discovered security flaws in the Hospira infusion pump that could remotely force multiple pumps to dose patients with potentially lethal amounts of drugs. In addition to insulin pumps, deadly vulnerabilities were found in dozens of devices, including X-ray systems, computerized tomography scanners, medical refrigerators and implantable defibrillators. After the discovery, regulators, including the United States Department of Homeland Security and Federal Drug Administration, began warning customers not to use the devices due to their vulnerability. The announcement was the first time the United States Government advised health-care providers to discontinue the use of a medical device.

(Source: World Economic Forum 2016)

Figure 37: The first case of medjacking discovered in 2015

Source: UN Global Assessment Report on Disaster Risk Reduction 2019

The biggest known cases of cyberattacks took place 2016. In March 2016 it was revealed that a group of hackers have stolen almost 1 billion USD from a group of 100 banks in 30 economies. To limit detection, the theft at each bank was limited to 10 million USD[74]. In March 2016, it became also known that a group of hackers had planned to heist 1 billion USD from the Central Bank of Bangladesh. Due to a spelling error, the system was stopped after only 81 million USD had been taken[75]. No link seems to exist between the two events. Banks are among the best secured entities against cyber-attacks. Resilience against cyber threats is discussed in section 3.2.4.

Earthquakes are the next biggest threat to APEC cities. They cause expected GDP loss of 179 M$ per year to each of the 120 APEC cities in average. In the past 50 years, the world's biggest cities have lost more than a million of their citizens to earthquakes. Earthquake data are of high confidence, i.e. low uncertainty. Earthquakes are distributed in specific places along geological fault structures. For the exposed cities, the damage can be extremely high. Urban planning has a central role to play in enacting and enforcing anti-seismic construction and in recovery planning.

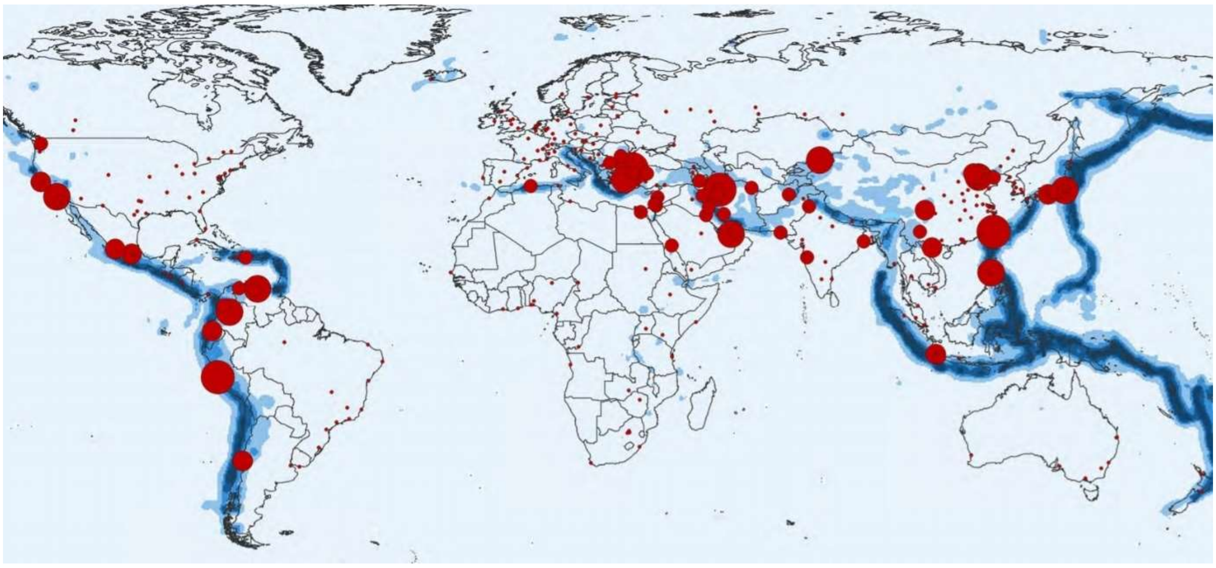


Figure 38: Geographical distribution of earthquakes

Source. Centre for Risk Studies Cambridge, 2014

The Pacific Ring of Fire is host to the world's 20 strongest ever measured earthquakes. As show above, earthquakes are today the disaster type causing the biggest number of deaths in APEC. Seismographs allowing to measure them have been used since 1906[76]. Except for the 1906 earthquake in Ecuador and Columbia, all the others are within today's APEC economies. It is, therefore, natural that urban planning within APEC context contains earthquakes as one of its topics.

	Mag	Location	Alternative Name	Date (UTC)	Time (UTC)	Latitude	Longitude
1.	9.5	Bio-Bio, Chile	Valdivia Earthquake	1960-05-22	19:11	38.14°S	73.41°W
2.	9.2	Southern Alaska	1964 Great Alaska Earthquake, Prince William Sound Earthquake, Good Friday Earthquake	1964-03-28	03:36	60.91°N	147.34°W
3.	9.1	Off the West Coast of Northern Sumatra	Sumatra-Andaman Islands Earthquake, 2004 Sumatra Earthquake and Tsunami, Indian Ocean Earthquake	2004-12-26	00:58	3.30°N	95.98°E

4.	9.1	Near the East Coast of Honshu, Japan	Tohoku Earthquake	2011-03-11	05:46	38.30°N	142.37°E
5.	9.0	Off the East Coast of the Kamchatka Peninsula, Russia	Kamchatka, Russia	1952-11-04	16:58	52.62°N	159.78°E
6.	8.8	Offshore Bio-Bio, Chile	Maule Earthquake	2010-02-27	06:34	36.12°S	72.90°W
7.	8.8	Near the Coast of Ecuador	1906 Ecuador–Colombia Earthquake	1906-01-31	15:36	0.96°N	79.37°W
8.	8.7	Rat Islands, Aleutian Islands, Alaska	Rat Islands Earthquake	1965-02-04	05:01	51.25°N	178.72°E
9.	8.6	Eastern Xizang-India border region	Assam, Tibet	1950-08-15	14:09	28.36°N	96.45°E
10.	8.6	Off the West Coast of Northern Sumatra		2012-04-11	08:39	2.33°N	93.06°E
11.	8.6	Northern Sumatra, Indonesia	Nias Earthquake	2005-03-28	16:10	2.09°N	97.11°E
12.	8.6	Andrean of Islands, Aleutian Islands, Alaska		1957-03-09	14:23	51.50°N	175.63°W
13.	8.6	South of Alaska	Unimak Island Earthquake, Alaska	1946-04-01	12:29	53.49°N	162.83°W
14.	8.5	Banda Sea		1938-02-01	19:04	5.05°S	131.61°E
15.	8.5	Atacama, Chile	Chile-Argentina Border	1922-11-11	04:33	28.29°S	69.85°W
16.	8.5	Kuril Islands		1963-10-13	05:18	44.87°N	149.48°E
17.	8.4	Near the East Coast of Kamchatka Peninsula, Russia	Kamchatka, Russia	1923-02-03	16:02	54.49°N	160.47°E
18.	8.4	Southern Sumatra, Indonesia	Bengkulu	2007-09-12	11:10	4.44°S	101.37°E

19.	8.4	Near the Coast of Southern Peru	Arequipa, Peru Earthquake	2001-06-23	20:33	16.27°S	73.64°W
20.	8.4	Off the East Coast of Honshu, Japan	Sanriku, Japan	1933-03-02	17:31	39.21°N	144.59°E

Table 13: The 20 largest ever measured earthquakes

Source: USGS[77]

The largest ever recorded earthquake has taken place in Valdivia, Chile, on 21 or 22 May 1960 (depending on whether UTC or local Chilean time is used). The magnitude 9.5 event combined earthquakes, tsunamis, landslides, land subsidence and fires. At this magnitude, sandy soils become like a liquid or quicksand in which solid objects may disappear. Houses tossed downhill like slides. One of the reasons this event has not created the highest number of deaths in Chile was that it has been preceded by four foreshocks of magnitude 7 or higher[78], so that many people had left buildings. These people were then struck by the tsunami which first hit the region and thereafter spread out over the whole Pacific within about 24 hours. Some regions were struck by several waves. Up to 2 million people in Chile may have become homeless. In Hawaii, one wave plucked 20-ton rocks from the sea wall and carried them 180m inland. The tsunami caused 6000 deaths in Chile, 138 deaths in Onagawa, Honshu Island, Japan, and 32 deaths on the Philippines[79].

The Valdivia earthquake accounts for 20% the total global seismic moment release between 1906 and 2005. The three largest recorded earthquakes above account for almost half the total global seismic moment release between 1906 and 2005[80].

The recording of earlier earthquakes depends on the quality of historic records. The deadliest earthquake recorded in history took place on 23 January 1556 in the Shaanxi Province in China. It may have caused 830'000 victims or 60% of local population[81].

The most common way of measuring the size or strength of earthquakes is by their magnitude which is approximately related to the size of released seismic energy. The Richter scale developed in 1935 is a magnitude scale[82]. Subsequently developed magnitude scales are harmonized by the International Association of Seismology and Physics of the Earth's Interior (IASPEI) and share the basic characteristics of the Richter scale:

- They are logarithmic scales of the amplitude of seismic waves. An increase of 1 point on the Richter scale means a 10times increase of the amplitude of seismic waves. As the energy of a wave is $10^{1.5}$ times its amplitude, an increase of 1 point on the Richter scale means a 31.6fold increase of energy or strength of an earthquake.
- They are calibrated to be approximately equal to the Richter scale around magnitude 6.0.
- They do not take account of the duration of the earthquake, meaning that they underestimate the destructive capacity of strong earthquakes (>7).
- They are all so-called "local" scales measured at the surface above the epicentre. They are relevant for urban planning, but for the geophysicist, they underestimate the actual strength of earthquakes taking place far away (horizontally or vertically) from the seismograph. The actual strength of an earthquake is the seismic moment (i.e. the amount of physical work) done by the earthquake in sliding one tectonic plate against the other. It is estimated from the amount of the slip, the area of the surface slipped, and a resistance factor. Seismic moment is expressed in Nm.

Magnitude is different from intensity which refers to the strength or force of shaking or peak velocity at a given point. As intensity is greatest at the epicentre but otherwise varies from point to point, intensities of earthquakes must be indicated in so-called isoseismal maps of observed intensities. The Mercalli scale is an intensity scale. Resilience against earthquakes will be presented in section 3.2.2., alongside with resilience against all disasters of geological origin.

The next biggest threat to GDP of APEC cities is the sudden increase of commodity prices, especially fossil energy prices (oil, coal, gas), on international markets. The energy intensity of GDP is only an indicator of medium confidence, i.e. medium uncertainty to predict actual shock. Such so-called commodity price shock creates losers (cities in oil importing economies) and winners (cities in oil exporting economies). For the 120 APEC cities, the total amount of expected annual GDP loss due to energy price shocks amounts to 113 M$ per city. More details can be seen from the Cambridge World City Risk Atlas[83].

Among the disasters of microbiological origin are also plant and animal epidemics. The plant epidemics are a considerable risk to GDP in APEC region. They cause expected GDP loss of around 54 M$ per year in each of the sampled 120 APEC cities. As a major cause for crop failure they affect food security of cities, a risk that should not be underestimated.

Lesser threats affecting the GDP of 120 APEC cities are shown in the figure below.

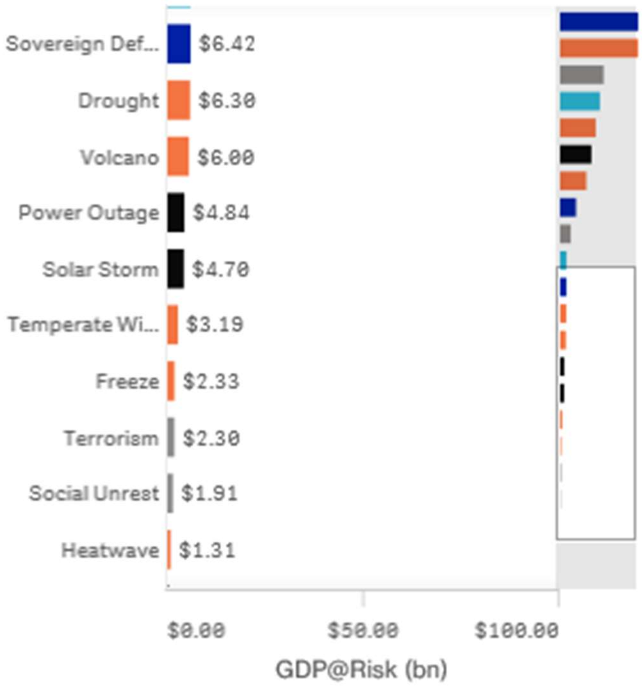


Figure 39: 11th to 20th largest threat affecting APEC cities

Source: Lloyds city risk index

Sovereign default of government affects GDP of cities. The risk depends on the credit rating of their government. Low credit rating is only a medium confidence indicator for default as default is often avoided by appropriate countermeasures taken in time. The Paris Club is the informal institution where rescheduling of government debt takes place. In the past 50 years, the world has seen more than 50 occasions of government defaulting. The threat of sovereign default causes expected GDP losses of 53.5 M$ per year to each of the 120 APEC cities.

Four lesser hydrometeorological threats (drought, temperate windstorm, freeze, and heat wave) cause together expected annual GDP loss of 13.13 bn$ to the 120 APEC cities, i.e. 109 M$ per city per year. Except for temperate windstorm for which data are of high confidence, data of the other three threats are of medium confidence. Furthermore, climate change is likely to influence the future risk of these threats. Cities that experience draught might need to restrict water consumption by means of rationing or otherwise. Freeze and heat wave cause problems in those regions where they are usually not expected or where large groups of the population are especially vulnerable. The above figure also shows that freeze is in average almost twice as destructive for the GDP of APEC cities as heat waves. This contrasts with the effect of heat waves on deaths in APEC economies which is stronger than the effect of cold waves, as shown in section 1.2.1. above. Resilience against these hydrometeorological threats is presented in section 3.2.1., alongside with resilience against all climate-related threats.

Volcanic eruptions are threatening APEC cities and cause annual expected GDP loss of 50 M$ in average for each city. However, most eruptions are of small scale (Volcanic Explosivity Index VEI 1 to 3), their impact is mostly limited to 500 km neighbourhood of cities. The VEI is a logarithmic scale for volcanic explosivity that was developed in 1982[84] and indicates the volume of ejected substance in m^3. Between VEI 1 and 2, there is, however, a factor of 100 instead of a factor 10.

VEI 5 corresponds to ejected material of over 1 km^3 (e.g. the Vesuvian eruption that destroyed the Roman city of Pompei in the year 79 AD).

VEI 6 corresponds to 10km^3 (e.g. Okmok II in 43 BC that may have accelerated the end of the Roman Republic[85], Krakatoa in 1883 and Mt. Pinatubo, the Philippines, in 1991).

VEI 7 corresponds to 100 km^3 (e.g. the eruption of Thera/Santorini around 1613 BC[86] that destroyed the Minoan civilization on Crete and may have contributed to the fall of the Xia Dynasty in China; the 1257 eruption of Samalas, Indonesia[87]; the latest eruption of Tambora, Indonesia, 1815, that created the global year without summer and extensive famine in 1816).

VEI 8 is the highest known level and corresponds to 1000 km^3 ejected material (e.g. the most recent Oruanui eruption of Lake Taupo, New Zealand, around 26’500 years ago that might have prolonged the ice age)[88]. Volcanic activity is still difficult to predict; hence risk estimates are of medium confidence. The figure shows the heavy concentration of volcanic activity around the Pacific Coast (Ring of Fire).

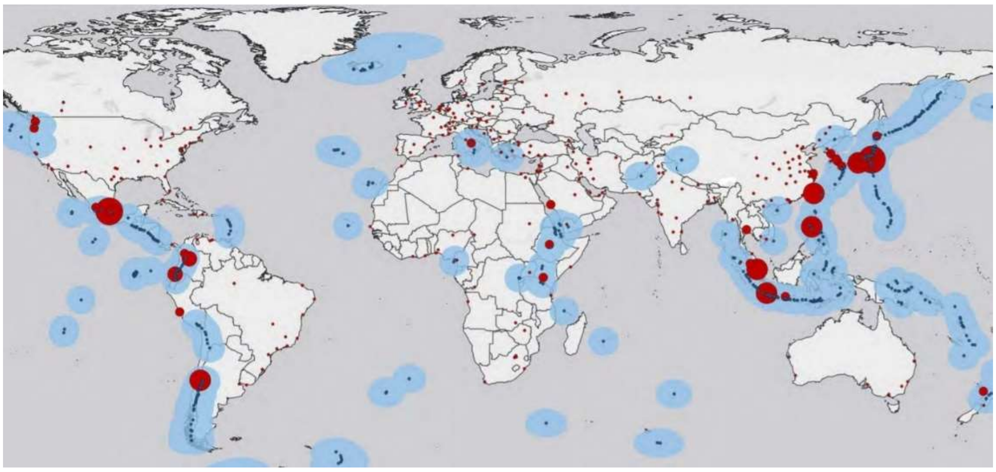


Figure 40: Volcanic eruptions since 1900 and threatened cities.

Source: Centre for Risk Studies Cambridge, 2014

The table illustrates the meaning of each level of the VEI scale.

VEI	Ejecta volume	Eruption Classification	Description	Plume Height	Frequency of Eruption	Examples	Occurrences in last 10,000 years*
0	< 10,000 m³	Hawaiian	Effusive An outpouring of lava on the ground (as compared with eruptions of ash into the air)	< 100 m	Persistent	Kilauea, Piton de la Fournaise	Many
1	> 10,000 m³	Hawaiian / Strombolian	Gentle Low-level, small to medium volume	100–1000 m	Daily	Nyiragongo (2002)	Many
2	> 1,000,000 m³	Strombolian / Vulcanian	Explosive Dense cloud of ash and gases with volcanic bombs (2-3 meters in diameter)	1–5 km	Weekly	Ruapehu, New Zealand (1971), Mount Sinabung (2010)	3,477
3	> 10,000,000 m³	Vulcanian / Pelean	Severe Glowing avalanche of hot ash and pyroclastic flows	3–15 km	Few months	Soufriere Hills (1995), Nevado del Ruiz, Colombia (1985)	868
4	> 0.1 km³	Pelean / Plinian	Cataclysmic Columns of gas and ash Extends to stratosphere	10–25 km	≥ 1 yr	Mount Pelee, West Indies (1902), Eyjafyallajokull (2010)	421
5	> 1 km³	Plinian	Paroxysmal	20–35 km	≥ 10 yrs	Mount Vesuvius, Mount St. Helens (1980)	166
6	> 10 km³	Plinian / Ultra-Plinian	Colossal	> 30 km	≥ 100 yrs	Krakatoa, Indonesia (1883), Mount Pinatubo, Philippines (1991)	51
7	> 100 km³	Ultra-Plinian	Super-colossal	> 40 km	≥ 1,000 yrs	Tambora (1815)	5 (+2 suspected)
8	> 1,000 km³	Supervolcanic	Mega-colossal	> 50 km	≥ 10,000 yrs	Yellowstone (Pleistocene)	0

Table 14: Volcanic eruption index VEI

Source: ETE[89]

Resilience measures related to local volcanic eruptions up to VEI 6 are discussed further in section 3.2.2. The larger volcanic events of VEI 7 and VEI 8 are global and extremely rare events which affect the global climate. If measures are to be taken one day, they should be at global level.

The next lower threat of expected GDP loss in the order of magnitude are power outages. They cause expected GDP loss of annually by 40 M$ per city for each of the 120 APEC cities. The predictability of power outages and of their impacts can in general only be made with medium confidence. Power outages of cities may heavily depend on the policies of their economies. Highly affected economies have more than 50 outages per year, little affected economies less than one outage per year. No APEC economy is in the highest risk group with more than 50 outages per year. Mexico, Viet Nam, Malaysia and Papua New Guinea are shown in the second group with 10 to 50 outages a year. Among the 120 analysed APEC cities, Mexico is the city that is most affected by power outages in terms of percentage of GDP loss, followed by Taipei, Ho Chi Minh City and Ha Noi. The least affected APEC cities are in Japan (Osaka, Sapporo, Hiroshima, Tokyo, Fukuoka, Nagoya, Sendai).

The next lower threats affecting APEC cities by order of magnitude are temperate windstorms. Temperate windstorms cause expected annual GDP loss of 26 M$ per city. They are high confidence data (i.e. they are of low uncertainty).

Nuclear meltdown causes expected annual GDP losses of 15 M$ per city, corresponding to 1.8 bn$ per year for all 120 APEC cities taken together. Nuclear meltdown is also a low uncertainty risk where the available data have comparatively high confidence.

The analysis of the city risk index can also be complemented by considering the risks by cities. The most threatened cities of the world for all 22 threats combined, if measured in terms of GDP percentage, are all war-torn (Kabul 17%, Tripoli 16%, Saana 15%, Baghdad 15%, Khartoum 13%, Kinshasa 11%, Beirut 10%). Manila is worldwide the most threatened city that is not war-torn, with 9.68% GDP at risk. The figure below shows the 10 most threatened APEC cities. This is the ranking in terms of local GDP percentage which is more important for comparing cities. The ranking in terms of absolute GDP would give a very different order as cities with large GDP have automatically higher absolute GDP that is at risk.

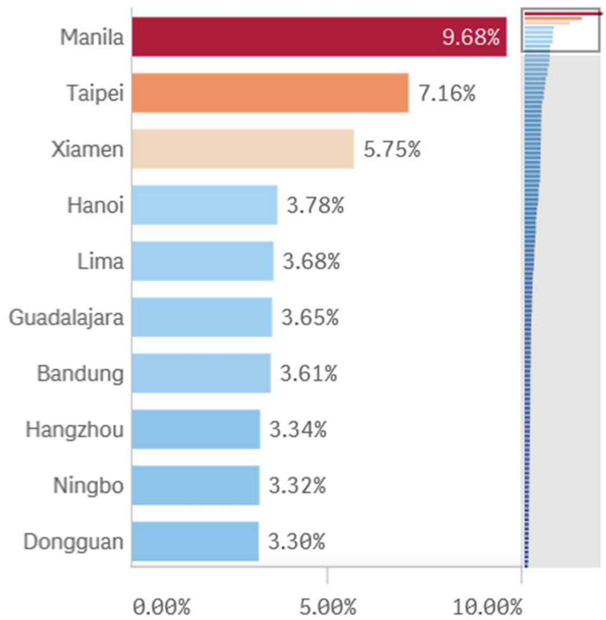


Figure 41: Ten most threatened APEC cities (all threats combined)

Source: Lloyds city risk index

For the three most affected APEC cities Manila, Taipei and Xiamen (all 22 threats combined), the dominant threat is the tropical windstorm.

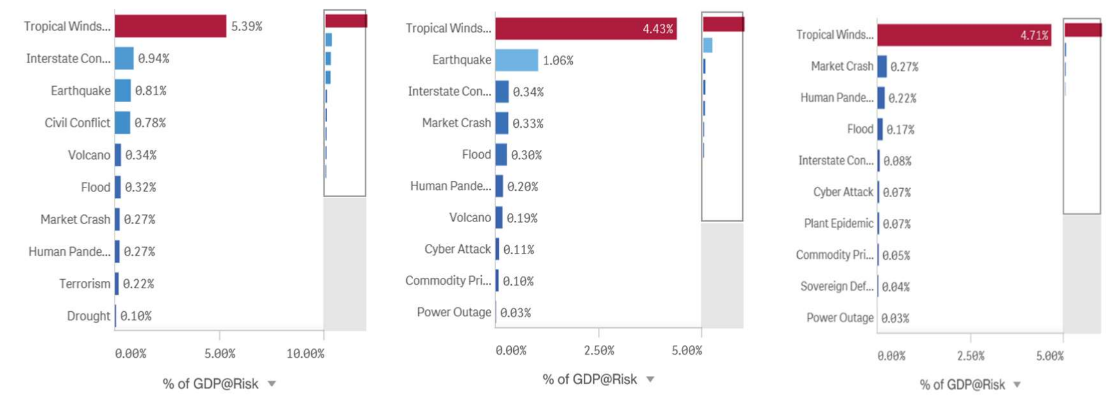


Figure 42: Risk profile of Manila (left), Taipei (centre), Xiamen (right)

Source: Lloyds city risk index

For the next three APEC cities by order of magnitude (all threats combined), Ha Noi, Lima and Guadalajara, the risk profile is more diversified:

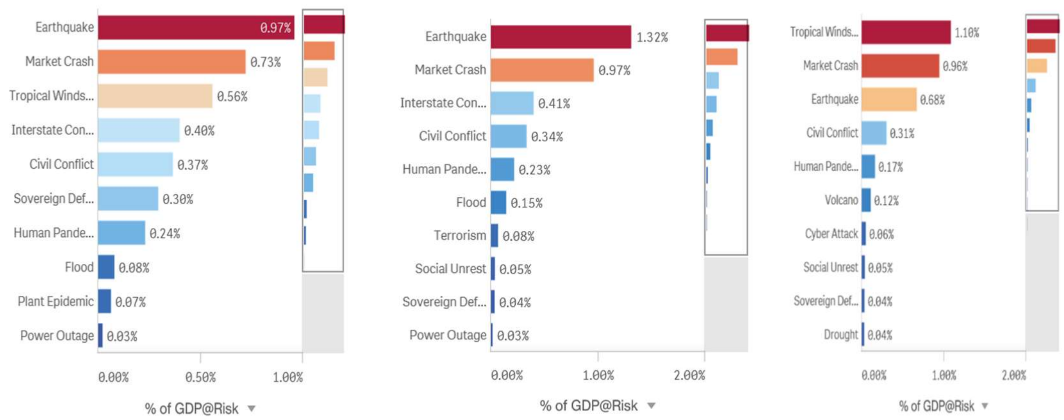


Figure 43: Risk profile of Ha Noi (left), Lima (centre), Guadalajara (right)

Source: Lloyds city risk index

The risk profiles of next three most affected APEC cities (Bandung, Hangzhou, Ningbo) are shown hereafter, Bandung having four major threats (earthquake, civil conflict, market crash, volcano), whereas Hangzhou and Ningbo have the tropical windstorm as main threat.

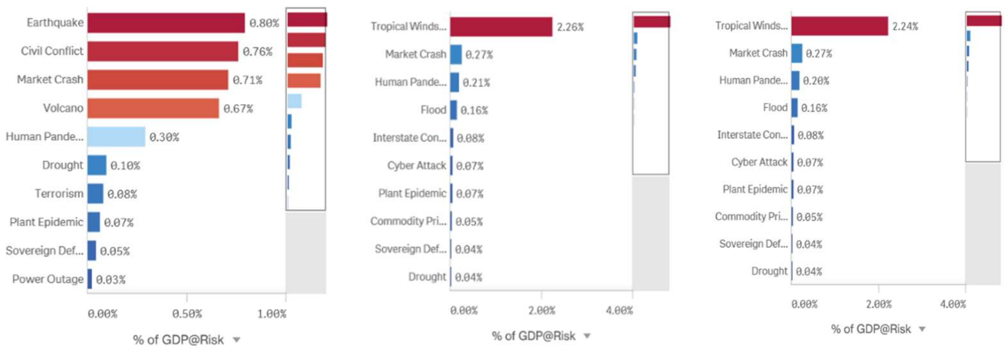


Figure 44: Risk profile of Bandung (left), Hangzhou (centre), Ningbo (right)

Source: Lloyds city risk index

As for the exact interpretation of these figures, it must be noted that the authors of the study have considered each city's ability to limit the impact (or to protect itself against shocks) as well as the ability of each city to recover from shocks. Between 2018 and 2019, the GDP at risk of the selected 279 cities has increased by 5.6%. Of this increase, 4.0% stems from an increase in GDP, 0.2% stems from a change (i.e. deterioration) of the recovery capacity, and 1.3% stems from an increase of the hazard level[90].

2. From Sectoral to Integrated Urban Planning

Urban planning has been a tool for shaping cities since the most ancient times. Many APEC cities or capitals have been planned and built according to a masterplan. The report shows how industrial revolution favoured urban monocultures, individual housing and car mobility, but excluded the vulnerable. Facing sustainability issues such as a general lack of circularity, insufficient disaster resilience, rising CO_2 emissions, the danger of slum formation and insufficient local data, cities are advised to overcome sectoral planning and management of their urban infrastructures, namely transport, energy, water, waste and social infrastructures, in view of developing integrated long-term planning. Integrated planning also includes cooperation with the private sector in a vast array of possible public-private partnerships, most often in view of securing the most advanced technologies. Budget planning is presented as part of integrated urban planning.

Successful integrated urban planning builds upon certain theoretical concepts which are borrowed not only from urbanization theory in the strict sense, but also from optimal geographic location theory, from management cycle theory, or from public policies against economic cycles. Essential elements of the modern theoretical planning toolbox are adaptive cycles borrowed from the theory of complex adaptive systems (CAS), the post-Maslow panarchy of psychological needs, and the theory of constraints (TOC).

The Sustainable Development Goals and their indicators offer useful guidelines for urban planning targets in the context of integrated urban planning. The report relates the SDGs back to the original pillars of environment, society, and economy, to which it adds governance as a fourth pillar, and it shows why these four pillars should be shown as concentric circles. The concentric SDG model allows identifying three thematic clusters, namely food and biodiversity, green urban economy, and social inclusion. While integrated urban planning can address the latter two clusters, it largely fails to address the first cluster. A systems-theoretic look on SDGs shows that if sustainability is the goal, then disaster resilience may deliver the necessary instruments, hence the two are like Siamese twins. A comprehensive form of integrated urban planning is Transit-Oriented Development (TOD) combined with Land-Value Capture, which allows implementing the UN Habitat's five principles of sustainable neighbourhood planning. Two best-practice TOD examples, Hong Kong and Tokyo, are presented.

2.1. Traditional Urban Planning and Urban Tasks

2.1.1. Land Planning as Traditional Urban Task

Urban planning is probably as old as the cities themselves. Since the emergence of larger urbanized settlements and early cities some ten thousand years ago, urban planning has been the prime instrument used for administering the scarce resource *land*. Land in cities becomes scarce because of the concentration which characterizes most cities. The dictionary defines the urban planner as the one whose job is to develop comprehensive plans and designs for the use of space within cities, towns, developments[91]. The continuous competition for space among residential, industrial, recreational, agricultural space, as well as for mobility, creates the main challenges to the urban planner. Urban planning is also defined as the branch of architecture dealing with the design and organization of urban space and activities[92].

In the understanding of the French urbanist Alfred Agache[93], urban planning is a science, an art, and a philosophy. A science because it proceeds from the systematic review of the facts based on a detailed study of the pasts of cities and their characteristics. Observation, classification, analysis and synthesis are all required characteristics of a scientific study. But if science alone could solve the problems of city planning, urbanization could undoubtedly be reduced to a few formulae. It is not so. Urbanism is also an art because the intuition, imagination and composition play an important role in its application: The planner must translate into proportion, volumes, perspectives, silhouettes, the various proposals suggested by engineers, economists, public health concerns and financial constraints. Urbanism is also part of social philosophy. The city, in fact, seeks to achieve plastically the appropriate framework for the existence of an organized community.

Cities are often built according to specific design patterns. In Ancient China, where the tradition of urban planning of the Longshan culture dates to about 10'000 BC, urban planning was influenced by harmony between man, state, nature and heaven[94]. Ancient Chinese cities were built mostly along a square or orthogonal pattern which, moreover, was perfectly oriented along the north-south and east-west axes. From the Zhou Dynasty (11th century BC) onwards, Chinese cities were often built in square form. This has been codified during the Han Dynasty (ending in the 3rd century AD) in the so-called Artificers Record (Kaogong Ji) specifying that cities were built as an aggregate of nine squares, each of which had a specific function[95]. The city of Daxing, built during the Sui Dynasty (6th century AD), renamed Chang'an during the Tang Dynasty (7th century AD), the core of present-day Xi'an, can best illustrate this pattern. In a world full of curves and irregularities, the straight line and the orientation in the north-south east-west directions was felt to be a sign of progress and a mark of civilization.

The Kaogong Ji philosophy that inspired Chang'an in China has also inspired other cities in East Asia, notably the predecessor cities of Beijing, the first of which was created around the 10th century BC (West Zhou Dynasty) and moved in the 8th century BC (East Zhou Dynasty) to the Ji city, i.e. more or less to its present location. It became politically important after the 10th century AD (Liao Dynasty) and became the capital city of China in the 12th century AD (Jin Dynasty)[96]. The same philosophy also inspired the creation of Kyoto in Japan, built in the year 794 AD as the new imperial capital, having kept this function until 1868, when the capital was moved to Tokyo[97].

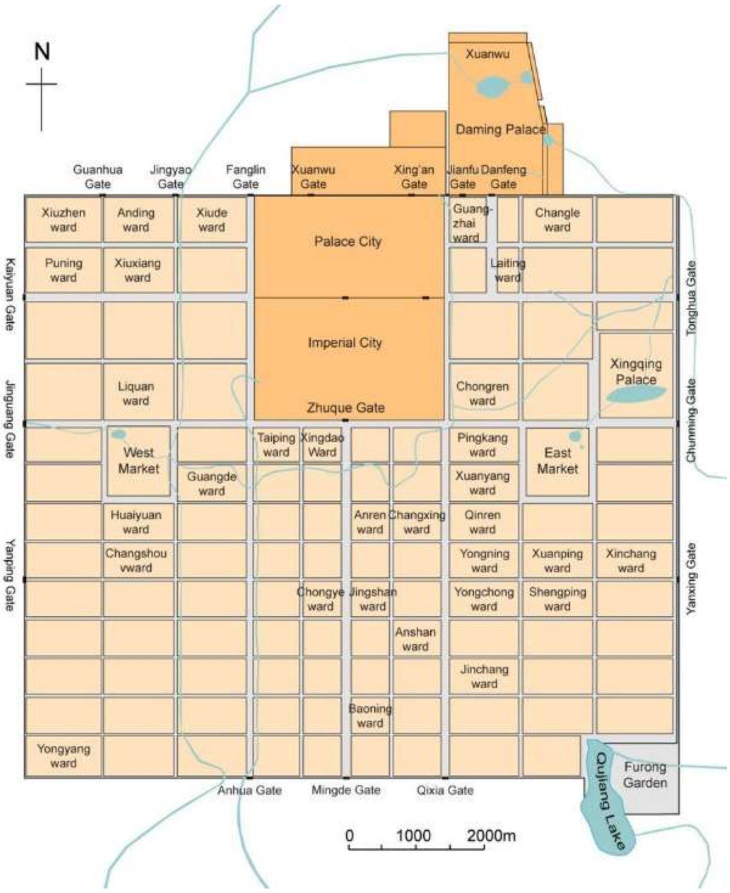


Figure 45: City of Daxing, renamed Chang’an, today’s core of Xi’an

Source: Chaz[98]

In Ancient Mesopotamia, cities were less often planned from scratch, but often grew in a natural, partially planned manner. Still, orthogonal patterns were the usual design elements, but alignment in cardinal directions was not the rule. The example of the city of Uruk, one of the most flourishing cities of the 4th millenary BC, can illustrate this:

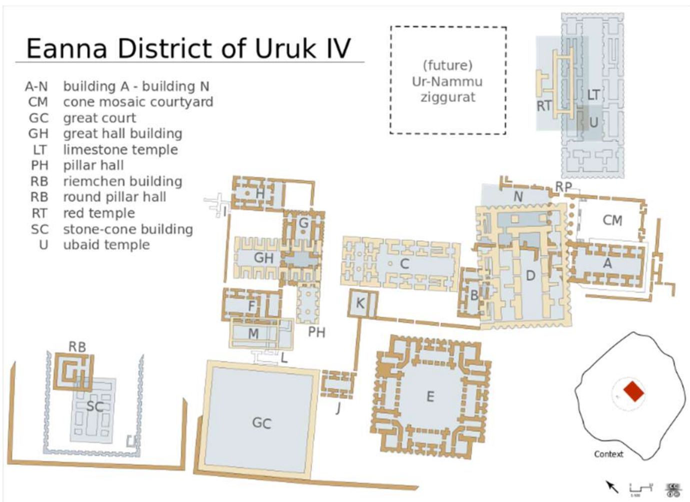


Figure 46: The central district of the ancient city of Uruk, 4th millenary BC

Source: Lamassu Design Gurdjieff[99]

The Fertile Crescent of the Middle Eastern region was probably the first one where the climatic conditions allowed generating an agricultural surplus that favoured the development of urban life with all its non-agricultural activities. The presence of abundant water carried by the two rivers Tigris and Euphrates was thereby essential. The Fertile Crescent was also exposed to migrations and invasions. Cities then started to protect themselves by city walls. Jericho is reported to have been the first walled city[100].

Urbanization spread from Ancient Mesopotamia to Ancient Egypt, where it took a different form. Water, coming from the Nile river, played a similar role in Ancient Egyptian civilization as in Mesopotamia. Ancient Egypt is known for its pyramids, temples and other outstanding monuments, however, contrary to Mesopotamia, where city-states played the dominant role between the 4th to the 2nd millenary BC, there were no big cities in Ancient Egypt. Rather, Ancient Egypt had a more dispersed model of urbanization, characterized by smaller, more specialized settlements[101][102]. The famous 13th century BC pharaoh Ramesses II built an important capital city, named Pi-Ramesses after him. Most of the important monuments such as the Giza pyramids, the temple of Amun at Karnak as well as the temple of Abu Simbel are well aligned to cardinal directions.

In Ancient Greece, the philosopher Hippodamus of Miletus (5th century BC) is being regarded as the father of city planning. He promulgated the construction or re-modelling of cities according to a grid plan with orthogonal layout (so-called Hippodamian plan) that assigned different functions and social classes to different parts of the city[103]. Greek cities were by and large aligned to cardinal directions, but often adapted themselves to the local geography[104]. This is the case with the city and port of Miletus oriented north-northeast.

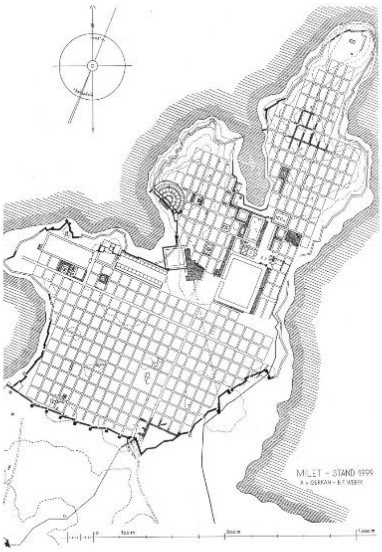


Figure 47: City and port of Miletus

Source: Andrew Boyd[105]

The question what type of resilience ancient cities were built for may be pertinent for understanding the development of resilient cities in a historical dimension. Before the age of industrialization, the main motivation for creating cities was defence against all kinds of dangers. The biggest danger may have been war. To defend themselves with architectural means against wars and other unwanted intruders, cities started building fortifications in form of walls, as mentioned above in the case of Jericho. The usefulness of city walls as protection against intruders decreased gradually with the development and use of gun powder after the year 1500. Since the end of World War II and the start of the nuclear age, the modern military-grade firepower is way stronger than the best possible fortifications.

Besides wars, another known danger looming on ancient cities was fire. The list of ancient cities having burned during history is long. As wood was widely used for construction in cities, urban fires could easily unleash to destroy entire cities. The technologies of fire prevention and firefighting were not up to the dangers caused by fires. One of the early architectural features was to firewall the kitchens from the rest of the building. This was not always successful as the example of the burning of the city of London in 1666 shows. This fire is said to have originated from a bakery. Small fires were common in London in those times. In 1666 the reaction of the city Mayor was, however, too slow to allow getting control of the fire. As England was at war with the Dutch and the French the attention of authorities may have been focused on military matters. The effect of the fire was to boost the early development of fire insurance in the decades after the fire.

Figure 48: Burning of London in 1666

Source: Museum of London[106]

Besides fires, also epidemics were a major danger to ancient cities. As the microbiological origin of epidemics was not known, the only measure was to separate the sick from the rest of the population and bury the dead or place them in mass graves.

Among other dangers, floods affected ancient cities. Ancient Egypt managed to live in harmony with the annual flood of the Nile which was used as beneficial phenomenon for agriculture and social life. These floods may have prevented the creation of bigger cities in Ancient Egypt. Besides Ancient Egypt, no other example is known where floods were beneficial for the affected communities.

Disasters of geological origin such as earthquakes and volcanic eruptions have also affected ancient cities. The Vesuvian destruction of Pompeii may stand as a well-known example. The dissemination of earthquake-resistant construction methods to threated communities remains a challenge until today.

2.1.2. Examples of Planned APEC Cities

In the history of APEC economies, the creation of cities as so-called planned cities on previously scarcely inhabited territory is a common phenomenon. The most recent example may be Indonesia. The Indonesian President announced in 2019 that the Indonesian capital will be moved from Java to East Kalimantan[107]. The construction is planned to start in 2020. The elaboration of the masterplan will be made by three companies McKinsey, Nikken Sekkei and AECOM. Already the present-day Indonesian capital Jakarta was created in 1619 as a planned city named Batavia.

In the Philippines, Quezon city was created in 1939 under the impulsion of the Philippine President Manuel L. Quezon. In 1941, the masterplan for the city was approved. In 1948, Quezon city officially became the capital of the Philippines until the decision was cancelled in 1976 when Manila was formally re-instated capital. With the strong urbanization of Metro Manila, Quezon city and Manila are today among the sixteen parts forming Metro Manila. Metro Manila has a rapidly developing subway transit system. The capital city is also linked by the Bicol Express train line to Legaspi, operated by the Philippine National Railway Company (PNR)[108]. However, the line has been interrupted over a large part and cut into two parts since 2012 when a hurricane caused severe damage which has not yet been repaired.

Malaysia decided in the mid-1990s to move its federal administrative capital to a new city called Putrajaya, situated between Kuala-Lumpur and the Kuala Lumpur International Airport, and linked to the Malaysian railway system. As important federal institutions continue to remain in Kuala-Lumpur, Putrajaya is in fact an administrative city rather than a full-fledged capital.

Korea has been planning since 2003 to move its capital from Seoul to Sejong. The plan had to be amended in 2005 due to constitutional obstacles to move the entire capital. It was then decided to create a smart administrative city instead. Sejong is advertising its advantages of offering luxury living at a fraction of the cost, with shiny state-of-the-art condominiums, ample public green space and smart and sustainable city tech, like automated trash collection and zero-waste food disposal, electric car charging and sharing stations, solar-powered buildings, interactive digital signage, closed-circuit television security and fine dust emergency alerts[109]. However, the Sejong public transport is limited to local buses, bus rapid transit (BRT), taxis, and public bikes[110]; Sejong has no subway transport system and the Osong KTX high speed train station linking high speed trains to Seoul is well outside the territory of Sejong. The transfer of Ministries and other agencies from Seoul to Sejong is planned as a long-term process to be completed by 2030.

Australia has created the capital city Canberra as a planned city in 1913. Its planners, W.B. and M.M. Griffin, were inspired by the garden city movement. Design focussed on the so-called Parliamentary Triangle, comprising the Parliament House, the Defence Headquarters, and the City Hill. In 1927 the Provisional Parliament House, now known as Old Parliament House, opened in Canberra, marking a milestone in the development of the city. Construction of major works, including the artificial Lake Burley Griffin, were only started after the creation of the National Capital Development Commission in 1957. The permanent Parliament House was opened in 1988, during the bicentenary festivities of Australia, marking the end of the construction of the originally planned elements of the city. Canberra has no subway transport system and is linked by a railway line to Sydney. Besides Canberra, also Adelaide and Melbourne are planned cities of Australia.

Figure 49: The main design elements of the city of Canberra

Source: Martyman[111]

The foundation of Washington DC, capital city of the United States, was decided in 1790 by the US Congress who authorized President George Washington to choose a plot of 100 square miles for the creation of the capital. The President then commissioned to design the city on the northeast bank of the Potomac river. The part of the city situated southwest of the Potomac river was neglected. In the 1840s their inhabitants requested their part of the territory to be retroceded to the state of Virginia who had originally given the territory to the capital city. This request was accepted by Congress in 1847 and the southwestern part was retroceded to Virginia. The design of the city as it presents itself today is centred around the Capitol which divides the city into four unequal parts (northwest, northeast, southwest, southeast). The Capitol, the National Mall (a landscaped park), the Washington Monument, the World War II Memorial and the Lincoln Memorial are all on an exact East-West axis. The White House is to the north of the Lincoln Memorial. Due to its small administrative area, Washington DC has today less than a million inhabitants or only about one tenth of the population of the Washington Metropolitan agglomeration. The Washington Metro follows a radial design and reaches beyond the District of Columbia. It serves the inner ring of the Washington Metropolitan agglomeration. Extension to the Dulles International Airport is underway. Washington has also an important railway station within walking distance from the Capitol.

Figure 50: Washington: Original size(l), after the retrocession (c), design revised by Ellicott (r)

Sources: http://www.boundarystones.org/ (l), USGS satellite image, Public Domain (c)[112], Thackara & Vallance sc., Philadelphia 1792 - Library of Congress, Public Domain (r)[113]

In Russia, the city of St. Petersburg has been founded in 1703 by Tsar Peter the Great who moved the Russian capital from Moscow to St. Petersburg. He commissioned the design of a masterplan of the city in 1716, but due to the premature death of its chief architect J.-B. Alexandre Le Blond in 1719 the city was not built according to the original elliptic masterplan. A subway system has been built since 1955 and interconnects today the four main railway stations of St. Petersburg.

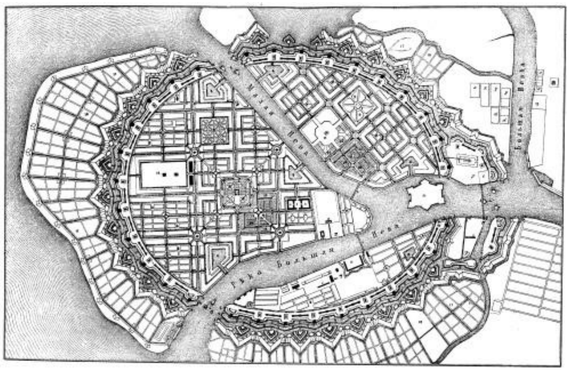


Figure 51: Masterplan of St. Petersburg by Le Blond

Source: Renzo Dubbini[114]

2.1.3. Industrial Monoculture and Sprawl

As mentioned above, with the rise of gun powder and canons, the exterior city walls gradually lost importance. The beginning of industrialization and specialization changed the motivation of city planning: the main asset of a city were no longer its protective city walls, but the capacity of the city to become engine of economic growth. Economic growth in most of the cases meant growth of industrial enterprises accompanied by rapid growth of population. This required geographical extension beyond the city walls. In the second half of the 19th century, cities were confronted with the need of setting up railways, improved roads and port facilities allowing them to handle increased freight. In communication, the telegraph started to become of use. In the 20th century, the development of the car has exaggerated this geographical growth process of cities to such an extent that many newly built cities have been designed as car cities, degrading the pedestrian or cyclist to a vulnerable or marginal population group.

The process of industrialization has developed new technologies which required corresponding development of land law (e.g. the right to extract minerals, or the use of airspace above the land). Land rights have become quite diverse, and the analysis of this topic would go beyond the scope of this report. Land rights do not exist in all APEC economies in the same manner. Some economies allow different types of land use but do not allow buying land for indefinite time periods. Land use can be conceived as a bundle of rights composing one, or possibly several, of the following elements[115]:

- The right to reside on the land forever (in fee) or for a specified term (for the life of widow, or for a predefined period)
- The right to hunt or fish on the land (a hereditament)
- The right to harvest crops or timber on the land
- The right to use water while it passed over the land
- The right to sublease one’s rights on the land
- The right to extract minerals
- The right to dam the flow of water (which would by necessity involve the downstream owner too)
- The right to subdivide the land into smaller parcels
- The right to use the airspace above the land
- The right to use the subsurface area (e.g. for the placement of drainpipes)
- The right to passage by foot, horse or vehicle (an easement)
- The right to leave the rights to one’s heirs

Modern technologies would require adding the right to collect solar and wind energy as essential rights for moving towards more sustainability. Land rights are essential to manage transit-oriented development (TOD, see sections 2.3.4 to 2.3.7 below).

During the industrial age, urban zoning basically started by assigning dedicated uses to specific city areas thereby creating single-use zones. This practice is said to have originated in Prussia after 1870s[116]. It was brought to the USA in the late 19th and early 20th century. It has originated as a bottom-up process created by estate developers desirous to give their projects specific characteristics or ensuring high property value[117]. Towards the beginning of the 20th century, some developers in Kansas City fixed the orientation of their buildings to the street and set minimum construction costs[118]. The first zoning ordinance in the US is known to be the 1916 New York Zoning Resolution[119]. As zoning is by nature an infringement into private property of landowners, it has been challenged in court. In 1926 the US Supreme Court in a landmark ruling approved the zoning rules of the village of Euclid, Ohio[120]. Since then, the concept of so-called Euclidean zoning became a basic concept of modern urban planning in the US, describing a system of height and use restrictions on different city areas having the effect of segregating specific land areas for specific land uses such as housing, shops and factories. This system has been widely applied in US city planning.

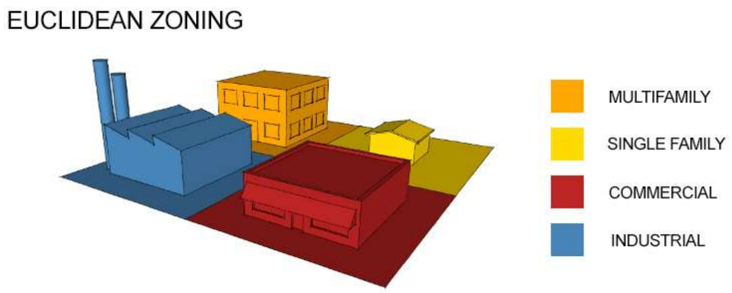


Figure 52: Euclidean zoning

Source: Los Angeles Department of City Planning.

Urban zoning has been a primary prerogative of local governments, as central governments would normally not care for what they consider as specifically local affairs. As a matter of practice, spatial zones have henceforth been classified in several types of constructible zones, e.g. residential, commercial, industrial, institutional, or built-up open space. Outside the urban area-proper, there were non-constructible zones such as, e.g., agricultural lands, forests, waters and lakes, and mountain areas.

Euclidean zoning in its original version is characterized by single-use zones that are separated by minimal distances among each other. Given the growth of cities and the corresponding geographical expansion, the effect of this type of zoning has been to favour the two major achievements of the 20th century middle class, namely the private single-family housing and the private car. Both these achievements are at the root of urban or suburban sprawl.

Figure 53: Suburban sprawl in a single-family zone

Source: Urban kchoze[121]

In growing cities, the strict application of Euclidean zoning has the – presumably – unwanted consequence of requiring more and more residents to use cars to go from their housing zone to other zones. In particular, the car is required to go to work, but also to go for shopping. The sprawl is so large that each household of a single-family residential area needs two cars. As a result, cities need a car-friendly design, with broad, multi-lane streets and ample parking spaces around factories and commercial centres. Besides the single-family dwelling suburbs shown in the figure above, the multi-lane highways and huge parking areas are the other elements that characterize the visual aspect of cities planned and built along these lines (see figures below).

Figure 54: Placing the car into the centre of urban planning

Sources: Getty Images[122], AP[123]

In our era of growing greenhouse gas emissions and climate change, this form of pure Euclidean zoning has become the symbol of the unecological city due to the kind of spatial monoculture and sprawl it implies.

Furthermore, Euclidean zoning establishes a kind of informal hierarchy among the zones: On the one side of the spectrum emerges the single-family zone as the most appreciated living zone, whereas on the other side of the spectrum remains the dumped zone containing e.g. prisons, sewage plants or landfills. In between these extremes are all the other zones, such as the multi-family zone as well as commercial and industrial zones. As the separation between single-family and multifamily houses often correlates with social or racial stratification, Euclidean zoning is also sometimes considered as source of the social divide.

Figure 55: Land zoning categories in Euclid today

Source: City of Euclid, Ohio

The effects of this kind of zoning, has led Jane Jacobs, one of the most influential urban planners of the 20th century, to publish a widely read book in 1961 bearing the title *The Death and Life of Great American Cities*[124]. Therein she asserted that American cities were at demise and that one of the main causes was the exclusively car-friendly manner of urban planning. These rationalist or modernist approaches focusing city planning on private cars, private homes, factories and shopping malls had the side-effect to create urban sprawl, income segregation and social isolation, so that they needed to be opposed by other approaches focusing more on pedestrians, sidewalks, cultural diversity, redundancy, and vibrant local communities.

> "Automobiles are often conveniently tagged as the villains responsible for the ills of cities and the disappointments and futilities of city planning. But the destructive effects of automobiles are much less a cause than a symptom of our incompetence at city building."
>
> *Source:* Jacobs (1961: 16).

Figure 56: Quotation by Jane Jacobs

Source: Jacobs

Similar criticism was echoed by other authors throughout the second half of the 20th century until recently[125].

To address this issue, zoning concepts have developed towards less restrictive zoning methods, such as impact zoning, performance zoning or incentive zoning[126]. Basically, these three types all use Euclidean zoning, but provide for a set of exceptions. Such exceptions can be based on limiting impacts of non-conforming activities by specific standards, or by allowing non-conforming activities if they satisfy public interests such as affordable housing. An even further development is the so-called form-based zoning[127], which regulates spatial development by focusing on scale, design and placement of buildings. Form-based zoning is particularly useful in protecting urban cultural heritage. The specificities of local construction patterns and styles can best be described and protected in a form-based zoning code. To implement these codes, practitioners may be required to use 3D design tools allowing visualization of all aspects of form of buildings and other amenities.

The claim that urban zoning improves public health is questionable. While cities without any form of planning (e.g. slums) clearly favour the development of diseases such as cholera, dengue fever, hepatitis or intestinal parasites, the effective fight against these diseases is not due to spatial zoning, but due to infrastructure planning such as adequate freshwater supply and sanitation.

2.1.4. Infrastructure Management as Urban Task

Besides urban zoning as described in the preceding sections, infrastructure planning and development has become an important task of urban planning. The following will help to identify what is sometimes meant in the term *infrastructure*.

The American Society of Civil Engineers (ASCE) identifies sixteen different types of infrastructures[128]. For the present analysis, it is convenient to place these infrastructures into five different categories: Transportation, Energy, Water, Waste, and Social.

This allows identifying infrastructures that the ASCE does not consider as being part of their sixteen infrastructures, but which play nonetheless the role of infrastructures in the context of sustainability and disaster resilience. These are added in brackets.

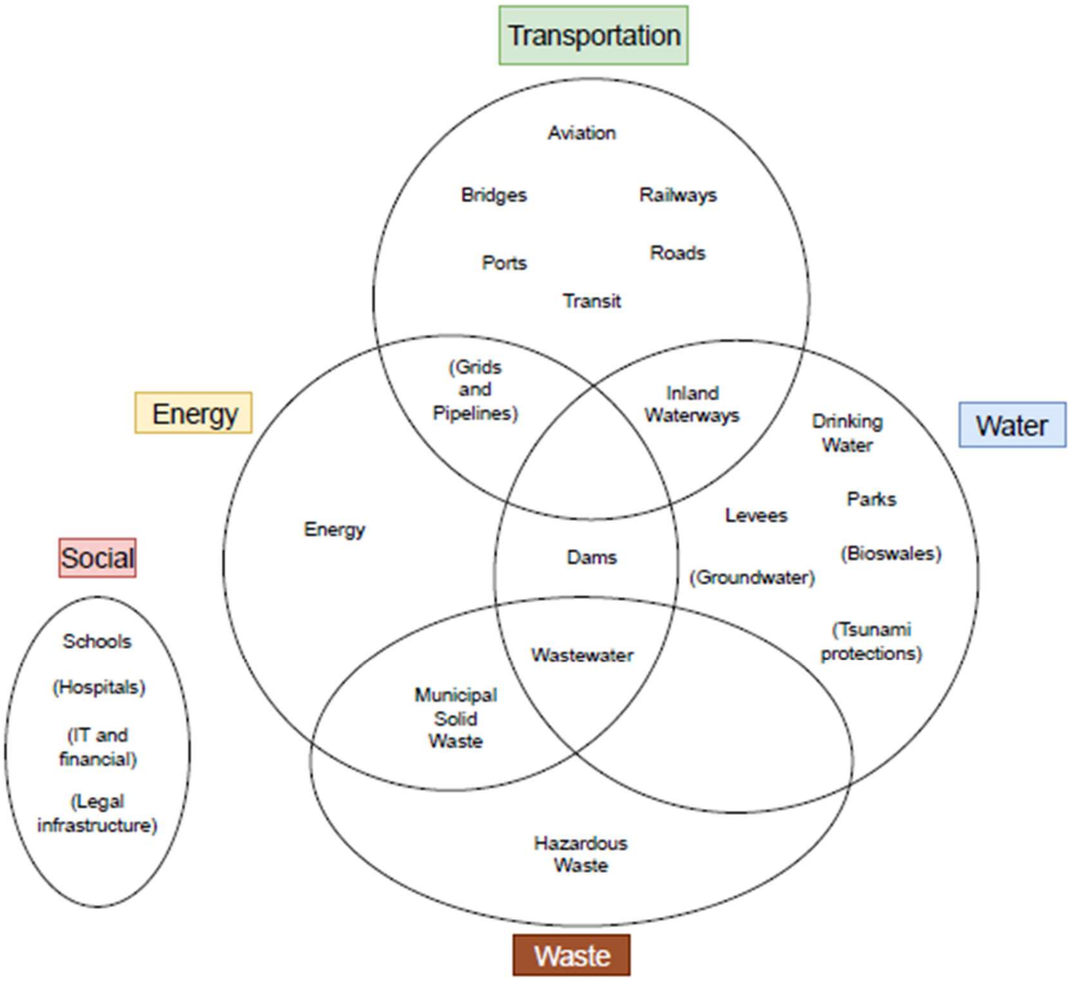


Figure 57: Typology of infrastructures

Source: APSEC, based on ASCE typology

The biggest number of infrastructures can be found in the category of transportation. This includes not only aviation, bridges, railways, roads, ports and transit infrastructures as purely transportation oriented, but also inland waterways making the nexus between transportation and water. The ASCE typology does not consider electricity grids and pipelines as separate infrastructures but lists them under energy infrastructures. For the present analysis it is convenient to list electricity grids and pipelines in the nexus between energy and transport.

Another important category of infrastructures is given by energy infrastructures. These contain all infrastructures related in the broadest sense to electricity, gas and petroleum. Dams are at the nexus of energy and water, municipal solid waste is at the nexus of waste and energy, and wastewater is at the triple nexus between energy, water and waste. *APSEC (2018)*[129] has pointed out how energy can be produced from waste and from wastewater.

The next category of infrastructures is related to water. It contains drinking water infrastructures as well as levees. The ASCE typology describes levees as earthen embankments or concrete floodwalls, which have been designed and constructed to contain, control, or divert the flow of water to reduce the risk of temporary flooding. Vertical concrete floodwalls may be erected in urban areas where there is insufficient land for an earthen levee[130]. The above figure also places parks among water infrastructures as they regulate the water cycle, besides bringing recreational benefits. Besides the water-related infrastructures identified in the ASCE typology, some APEC economies have other water-related infrastructures. In Japan, special infrastructures exist for protection against tsunami. In the above figure, these have been added as specific infrastructures and placed between brackets as they are not specifically mentioned in ASCE. Equally, the above figure includes bioswales and places them in the category of water-related infrastructures. Bioswales are destined to accelerate the filtering and absorption of rainwater into groundwater. Bioswales are used in some APEC economies, e.g. in China, as part of so-called sponge cities. Finally, groundwater is added as infrastructure. It may not be perceived as an infrastructure by everyone yet, but the discussion about disaster resilience of cities includes an increased focus on so-called natural buffers or green and blue infrastructures into city policy and projects, to which groundwater belongs.

The category waste contains as special infrastructure all those facilities treating hazardous waste. As already mentioned, municipal solid waste is at the nexus of waste and energy, and wastewater is at the triple nexus of energy, water and waste.

The above-described infrastructures (Transportation, Energy, Water, Waste) can be called technical infrastructures, as opposed to the social infrastructures described hereafter.

ASCE typology includes schools as infrastructures. For the present analysis, schools are placed into the category of social infrastructures. There are, however, also other social infrastructures that need to be mentioned. The above figure adds hospitals to the same category. Apparently, hospitals are not considered as infrastructures by the ASCE, but other APEC economies may consider them as infrastructures. The COVID-19 pandemic has shown the importance of hospitals as infrastructures. Equally missing in the ASCE typology are the IT and financial infrastructures. The role of IT and finance is known to be crucial for promoting sustainable development and resilience. And finally, this analysis adds the legal infrastructure (i.e. laws, decrees, decisions, good governance etc.) as being part of the social infrastructures.

Social infrastructures have no nexus to other infrastructures in the sense as e.g. waterways are at a nexus between water and transportation. Social infrastructures have, however, very important links to all other categories of infrastructures as they are instrumental to develop other infrastructures. Social infrastructures could, therefore, also be called instrumental infrastructures.

Infrastructure panning involves two distinct aspects: the build-up or investment phase, meaning the phase during which infrastructures are being planned, approved, built, and made ready for use. Infrastructures can be among the most expensive and capital-intensive entities of a city or an economy. They may be big land-users and hence may require long-term land planning. A second aspect of infrastructure planning is the management phase, during which infrastructures are run as economic enterprises contributing in one way or another to their own financial sustainability. When run successfully, infrastructures may have a very high impact on the economic performance of the city or economy. Infrastructures are, therefore, key elements of any city or economy.

Further down (section 2.1.6.) investment policies will be introduced within budget management as instrument of local planning and policies. As infrastructures often involve considerable investment, there is an obvious link between infrastructure planning and investment planning.

2.1.5. Public Private Partnerships as Means to Accede to Technology

Integrated urban planning does not only consist of linking the planning and the management of different urban infrastructures into a coherent plan. It also means involving the private sector in investing and managing the infrastructures. A very common manner to involve the private sector is by public-private partnerships (PPPs). There is a large choice of possibilities of different PPPs.

Public-Private Partnerships (PPPs) are widely used in cities for practically any area of urban activity. They are indispensable to make cities sustainable and disaster resilient. The key factor for successful infrastructure PPPs is to balance the relative interests and strengths of the involved public and private partners to give long term satisfaction to both sides. The comparative advantages of the public sector are its capacity to set rules and regulations and the relatively easier access to capital. The relatively easier access to capital applies for the central government level. For the local government level there can be greater obstacles to access capital, depending on the circumstances. The comparative advantage of the private sector is to develop and provide new technologies and to be able to take risks if appropriately rewarded.

To mould these comparative advantages into a concrete infrastructure project, local governments as well a regional or central government have for long time been using one or several forms of public private partnerships (PPP). In the broadest definition of PPP, a PPP designates any form of joint or cooperation enterprise between a public and a private entity. In this broad sense there is a large variety of different PPP. One simple way to illustrate the variety of PPP is to map them according to the depth of engagement of both sides, the public and the private side. On the one end of the spectrum, there are those PPP forms where the public sector plays the dominant role, whereas on the other end are those forms where the private sector plays the dominant role. In well-designed PPPs the burden share between both sides, public and private, is equilibrated, meaning that the sharing of risks and obligations will correspond to the corresponding sharing of benefits of the project. The higher the investment (and hence the associated risk), the longer will be the duration of the project. In the figure below, PPP projects that respect the burden share between both parties are all on the straight equilibrium line.

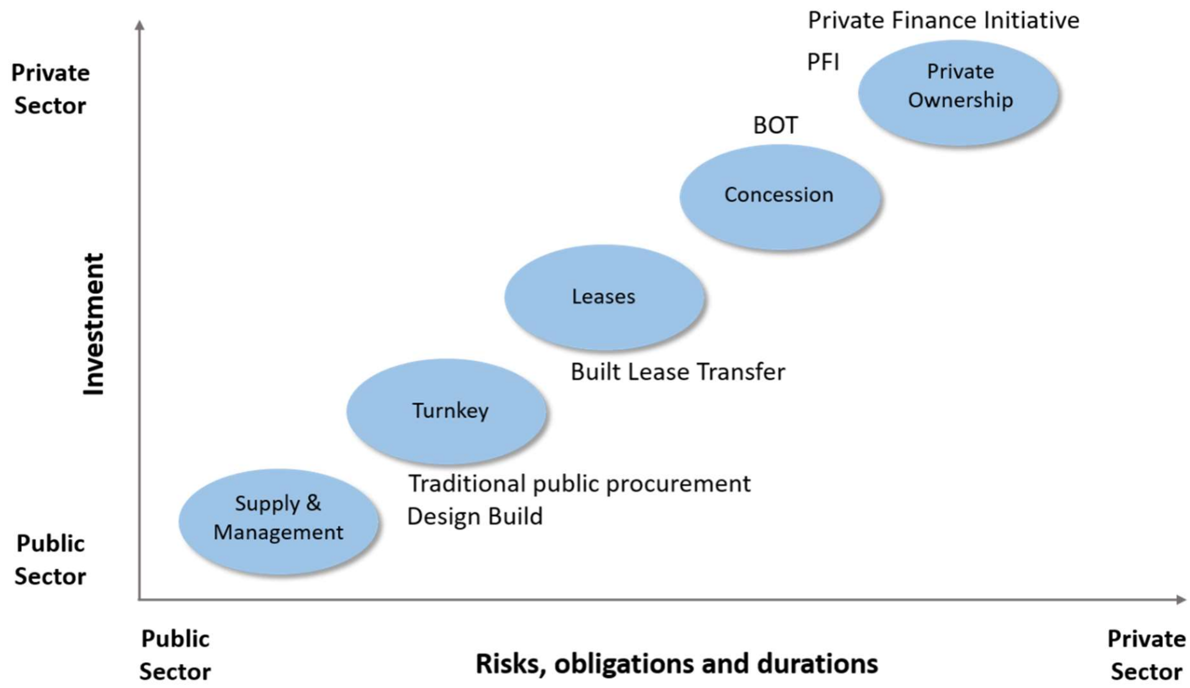


Figure 58: Models of public private partnerships PPP

Source: APSEC based on UNESCAP[131]

The Supply and Management model shown at the bottom left is a PPP model in which the public sector makes the totality of the investment, but then calls for the private sector to manage it. The private sector has no investment responsibility. This PPP model could, e.g. be used in a scheme of affordable housing where the local authorities retain ownership but require a private partner or property manager to run the scheme. It can also be proposed for the management for an electricity transmission grid in case the public sector wishes to retain grid ownership but chooses to hand over grid operation to a specialized firm with necessary expertise in the complex issues this requires.

Turnkey is the PPP model where the public sector gives more choice to the private partner than in the Supply and Management model above. In Turnkey projects the public sector tasks a private constructor to design and build an infrastructure. The responsibility of the private firm is limited to the design and construction.

In the Build-Lease-Transfer model the private sector has yet higher responsibility as compared with the Turnkey model. In the Build-Lease-Transfer model, the private sector not only builds the infrastructure, but after completion it leases it during an agreed period after which it is being returned to the public sector. During the lease period, the private firm acts, however, only as leaseholder and does not make any subsequent investment.

The Concession model as compared to the Build-Lease-Transfer model gives the private party not only the task of building and running the infrastructure during a fixed period, but usually also allows the concessionaire to make all the subsequent investments during the concession time. There are different types of concession models, such as Build-Operate-Transfer (BOT), Build-Rehabilitate-Operate-Transfer (BROT), Build-Lease-Transfer (BLT), and Built-Transfer-Operate (BTO). Many others exist or are being developed for suiting specific circumstances. They all have in common that the private party receives the mandate to build and operate the infrastructure during a certain time whereby accessory conditions may determine specific rights and obligations of both sides, and that at some stage, the ownership is transferred back to the public party which owns it.

Under the Private Finance Initiative model, the private party may receive responsibilities for design, construction and operation of an infrastructure, and the public sector buys services from the private firm, often at predetermined rates. In some cases, private ownership of the infrastructure may result at the end of the period, like in a Build-Own-Operate (BOO) model.

In sum, making cities sustainable and disaster resilient may involve deployment of new technologies, public-private partnerships offer an important tool for local communities to implement sustainable development.

Another way to plan an urban infrastructure is by means of cooperation with neighbouring communities. This will diminish the cost for each participating community. Take as example a waste combustion plant. This is an infrastructure that cannot always be kept at local level but can easier be realized by a group of local communities. Other examples are hospitals offering specialized treatments. These facilities are expensive and will sometimes better serve in a group of local communities.

The budgets of local communities might often be integrated into regional or central government's budgets. This gives the local communities more flexibility to be integrated into large-scale projects, but on the other hand local communities will have to contribute to central government policies of all kinds. One type of central government policy that matters in this regard is anti-cyclical fiscal policy. The lessons learnt from the Great Depression of the 1930s by John Maynard Keynes[132] stated that government should do anti-cyclic fiscal policies. In times of economic growth, they should increase taxes and accumulate budget surplus, in case of economic depression they should lower taxes, use the accumulated budget surplus and make investment projects to stimulate the economy. The New Deal of the 1930s is seen as a stimulating policy of this type. Government, in this sense refers to all levels of government, including local government. Obviously, anti-cyclic policies perform better if also the local government level is participating in this effort. This is the economic justification for integrating economic policies of all levels.

The explanations given above on local budgets and the different ways to cover the deficit do not, however, exhaust all the possibilities. The problem of financing costly infrastructures for development has in some cities of the world become so acute that the local communities have been forced to create innovative financing and cost-covering schemes in order to assure development which their citizens require. The so-called transit-oriented development or TOD provided the land value capture (LVC) as financing instrument, which implements the "beneficiary pays" principle. TOD and LVC are explained further down (sections 2.3.4. to 2.3.7). In the discussion about disaster resilience, financial resilience plays an important role, see section 3.1.4.

2.1.6. Urban Budget as Planning Task

Cities are important entities of the local government level. Throughout history, the role and degree of local budget has evolved, depending on the degree of centralization of the overarching economy. Since the era of industrialization, cities have rapidly grown everywhere in both, population and tasks, and hence their budgets have also increased. Receipts have not always kept up with spending; in some cases, the state of local public finance has become a predicament[133].

Spending is divided into the major categories of current spending (e.g. wages of local agents) and investment spending made to build and maintain the infrastructures described above. At local level, transfer payments (i.e. purely redistributive payments satisfying social objectives) may be rather exceptional.

Urban budget planning basically involves matching the expenses with the revenues. The budgets are usually expense driven. Each new task that is attributed to the local government, either by desire of its own citizens or by directives from central government, entails new expenditure. In the ideal (i.e. rare) case, the entity asking for a new task also allocates the corresponding budget. Usually, however, this is not the case, because current receipts are not adapted, meaning that the local government must find some form of deficit cover by appropriate means.

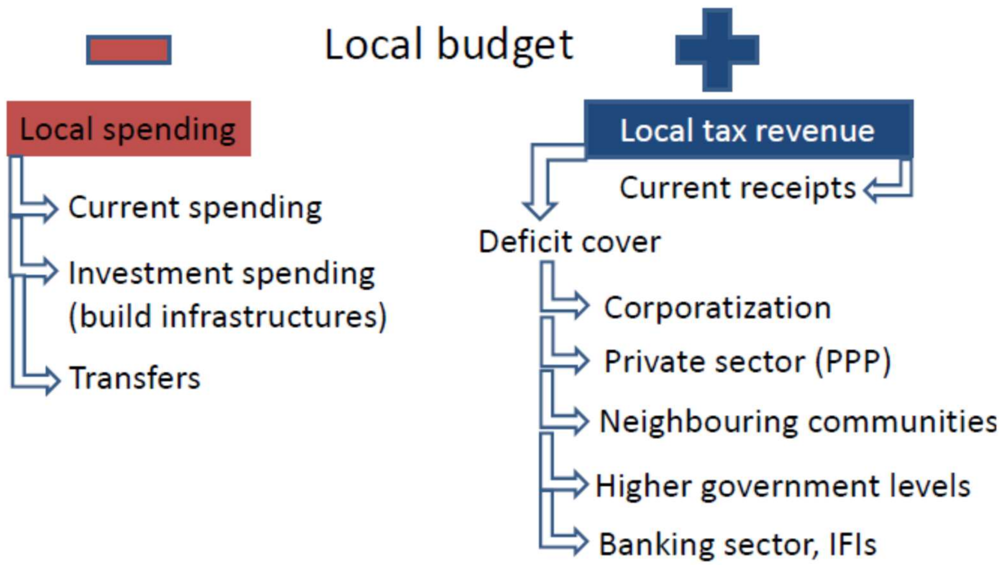


Figure 59: Simplified local budget

Source: APSEC

One of the tasks of cities is to run infrastructures of the type described further above. For doing so, local communities, but also regional or central government, use the method called corporatization. Corporatization is the process by which a government unit is reorganized in such a manner that such a unit can behave like a publicly owned enterprise. Typical examples of corporatized municipal enterprises may be the local electricity distribution company or the local subway company. Corporatization means that the company will be able to receive income from the sale of services. Corporatization usually also implies separate accounting of the income and spending of corporatized enterprises. Income received from sale of services is not counted as tax income but still enters the local budget at large.

Decisions to build infrastructures are investment decisions, i.e. decisions whose effects will spread in the future over the medium or even the long term. The key objective of managing local investment spending should be to ensure sustainability and disaster resilience of the local community. Given the high cost of investments, local communities are obliged to make tradeoffs between different alternative projects that cannot be realized simultaneously due to lack of funds. Some typical questions with which local authorities are being confronted are e.g.: Should local budget be spent on building a new subway line or on extending the research facilities of the local university? Should a waste incineration plant be built together with a private investor or together with other neighbouring communities? Should the local government participate in a large-scale solar plant to be built in another province against guarantees of receiving cheaper electricity for local consumers or should it provide electricity for its city on the regular electricity wholesale market?

More precisely, local governments are constantly facing the decision of what type of investments they should make, and whether to make them on their own, or together with neighbouring communities, or with the higher level of government, or together with private partners in public private partnerships. Investment is the part of budget spending which accumulates capital so that it produces effects in future years.

For large investment projects, cities will usually require substantive sums which are raised by all possible stakeholder categories. An important category are the infrastructure users who will contribute to the financial viability of infrastructures through payment for their services (e.g. farebox revenue for urban transit enterprises). Another stakeholder category are local taxpayers who contribute to public budgets. But these two categories would by far not allow raising the required financial sums for large infrastructures. The local authorities will most often need additional means such as grants, concessional loans, equity, guarantees, and other specialized instruments stemming often from the financial sector, including commercial banks, equity providers, venture capital providers or foundations. Complementary to these sources, the public sector may be called to provide complementary funding or blended funding. This comprises not only the central government, but also the international financial institutions such as the Green Climate Fund (GCF) which is the financing institution of the *Paris Climate Agreement*, the Global Environmental Facility (GEF) which is the global institution financing other environmental areas than climate, the Adaptation Fund (AF) which was established under the Kyoto Protocol of the UNFCCC to support climate adaptation and resilience activities, the Climate Investment Funds (CIF) which are hosted by the World Bank and have four programmes under their management funding climate mitigation and adaptation activities.

Some of these funds, such as the Green Climate Fund, cannot be reached by cities or other project owners directly, but should be acceded through specific accredited institutions preparing the requests. The figure below summarizes the financial architecture for urban climate-related projects.

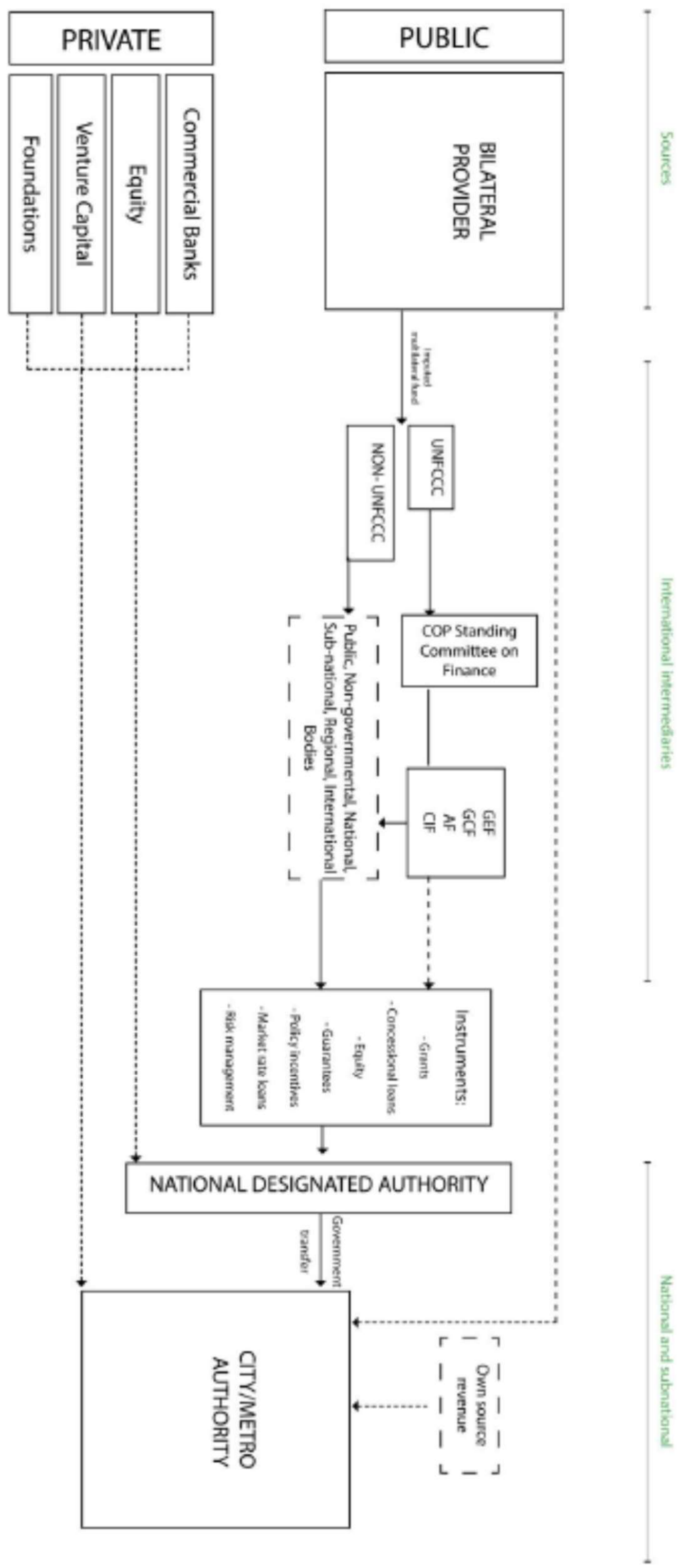


Figure 60: Global urban climate finance architecture

Source: Green Climate Fund[134]

2.2. Theoretical Elements of Integrated Urban Planning

2.2.1. Theory of Urbanization

The term *urbanization* has been created by the Catalan engineer and Spanish MP Ildefons Cerdà in his *General Theory of Urbanization* written in 1867[135]. Therein he defined urbanization as the set of principles, doctrines and rules that should be applied so that buildings and their conglomerations, as opposed to constricting, distorting and corrupting the physical, moral and intellectual faculties of social humans, can help promote their development and vitality, thereby improving individual wellbeing, the sum total of which constitutes public prosperity.

Ildefons Cerdà has tried to implement his ideas in his design of the Eixample neighbourhood of Barcelona. The grid-based neighbourhood is made of a great number of basic building blocks of 113m side length each (or 1.2ha area) and shaved-off 45° angles originally designed for allowing the tramway to make right-angle turns. Originally it was planned to have each block built only on 2 or 3 sides with ample open space and greenery inside each block. The lack of density of this design has, however, led the town government to gradually increase the floor-to-area-ratio FAR to 4.7 and allow not only to build up the 3rd and the 4th side, but also to increase the original 16m height of most blocks to 24m, to create some super-blocks of 3x3 size, and to transform some interior open green space to parking space or similar public facilities with the effect that, paradoxically, the neighbourhood today lacks greenery.

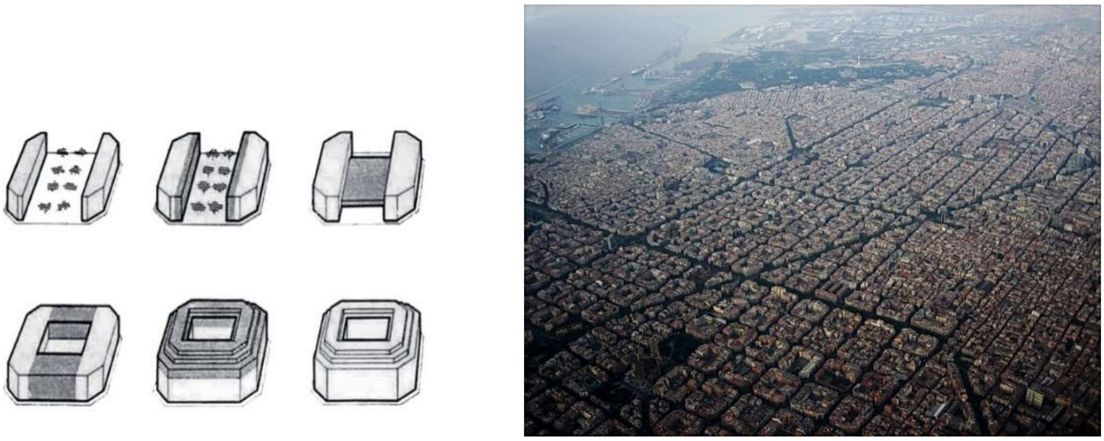


Figure 61: Block wise development and aerial view of Eixample, Barcelona

Source: Failed Architecture[136] and Flickr[137]

Ildefons Cerdà's approach to urbanization is by today's standards remarkably progressive, integrating not only the elements of walkable cities, but also sunlight, ventilation in homes, sanitary installations, sewage, waste disposal, flood prevention, greenery, movement of people, goods, information, and most up to date technologies. In the Eixample neighbourhood, it is possible to find food stores, schools, banks, or recreational areas within 5 to 10 minutes' walking distance. Cerdà recognized that every transit trip starts and finishes with a walking trip. Transit oriented development (TOD) or walkable cities differ from car-friendly cities notably in the size of their building blocks. The size of building blocks of car-friendly cities reaches up to 14ha each (350m to 400m side length) [138], whereas it is much smaller for walkable cities (1.2ha in the case of Eixample). Cerdà also integrated the city perfectly well into the southwest-northeast direction which is naturally given by the sea border and the hills of the hinterland. He recognized that by choosing this orientation and setting the street width at minimum 20m, he optimized the effect of sunshine.

Modern walkable cities are designed in such a manner that the pedestrians are given a proper reason to walk, that they can walk safely and comfortably and experience interesting interactions with people while walking. Besides diminishing the necessity to use cars and thereby contributing to less CO_2 emissions, walkable cities may have several side-benefits, such as allowing higher population density, diminishing pedestrian casualties by car crashes and fighting obesity[139]. Cerdà's design of Barcelona's Eixample neighbourhood with its well-integrated rail transit still serves as a model for urban design, land use, transportation planning, and pedestrian-scaled streets working in synergy to produce accessibility. For this reason, the Barcelona model has recently been used for proposing e.g. a new rail transit system for Honolulu[140].

APSEC (2018) makes a comparison between the sprawled city of Atlanta and the roughly 25 times more densely built city of Barcelona. These differences reflect the role of land which is relatively abundant in Atlanta and relatively scarce in Barcelona, whose area is somewhat limited on a stripe between the sea and the hilly hinterland. The density difference may also be attributed to the fact that this neighbourhood has been built according to a masterplan. It is important to note those elements of the masterplan that have been maintained – essentially the street grid – and the elements that have been adapted to changing requirements – especially the height and density of each building block. This illustrates that the key role of urban planning is not so much to plan individual buildings of cities, but rather more to design the city's infrastructures, present and future, above all the streets and transport infrastructures. Where design is implemented, the required land is being made available for these infrastructures. The space allocation made by Cerdà between the streets and the building blocks has proven to be a fruitful allocation on which the city has evolved during the industrial age. This has also allowed to start introducing sustainable mobility and thus making the city fit for some future challenges.

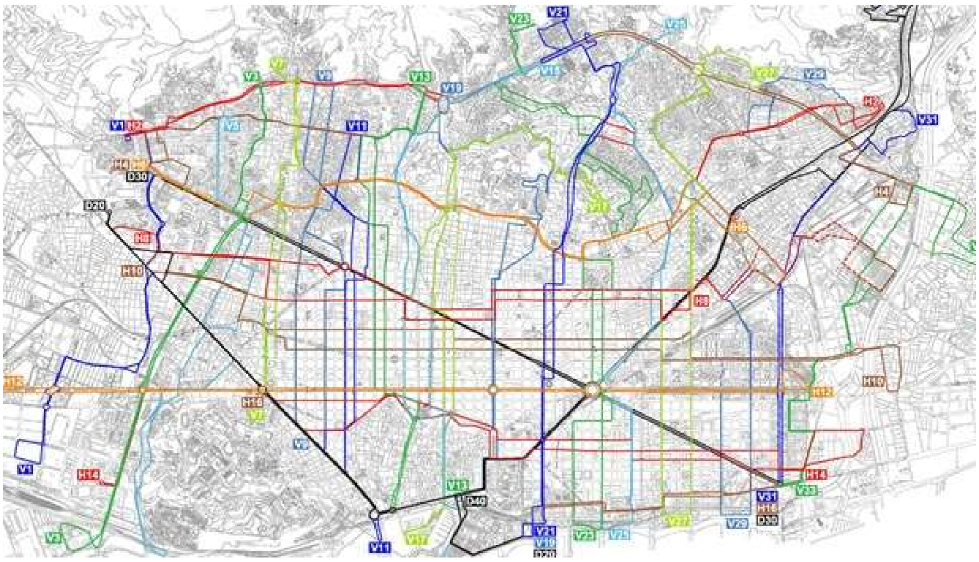


Figure 62: Sustainable urban mobility plan of Barcelona

Source: Agència d'Ecologia Urbana de Barcelona[141]

According to Bertaud[142], role of the urban planner is not so much to shape the function of buildings which should more efficiently be let to the market to decide. Rather, urban planning should focus on planning the various urban infrastructures, the examples of which are set out in section 2.1.4. above. Barcelona illustrates this quite well: During times of economic growth, market forces call for higher density and for an equilibrium between the different kinds of spatial utilization (e.g. residential, commercial, transport, recreation). In the case of Barcelona, market forces have driven upward the height and density of the buildings. Urban planning, on the other hand, implements specific public policy objectives (e.g. efficient transport, sustainable energy, health and sanitary protection, fire protection, environmental protection, public security, protection of cultural heritage). In the case of Barcelona, limiting the building height to 24m not only maintains uniformity of the visual aspect of the neighbourhood and thus preserves its cultural heritage, but also allows everybody to have sunshine in winter, a right that some people would lose if high-rise buildings were allowed.

Another example of a city that has been designed along a masterplan is Manhattan district of New York. Squeezed on a land strip bound on three sides by the water, the scarcity of land may have driven the planning commission of 1811 to design a grid with relatively small block size. The grid is based upon rectangular blocks of 183m x 76m dimension (having an area just under 1.4ha) and street width of 17.6m[143]. Originally this grid was designed for single-storey houses, but then the need for a denser habitat grew rapidly. Contrary to Eixample, height restrictions have been lifted in Manhattan to allow denser habitat. Manhattan is being considered as one of the most walkable cities[144] as the number of amenities that can be attained within a few minutes walking is nearly unequalled. The masterplan of Manhattan has been called the single most important document in New York city development[145] and has proven to be resistant to techno-economic development of unprecedented extent. Remains to be seen how walkable cities like the Eixample neighbourhood or Manhattan will manage the transformation towards sustainable energy and disaster resilience.

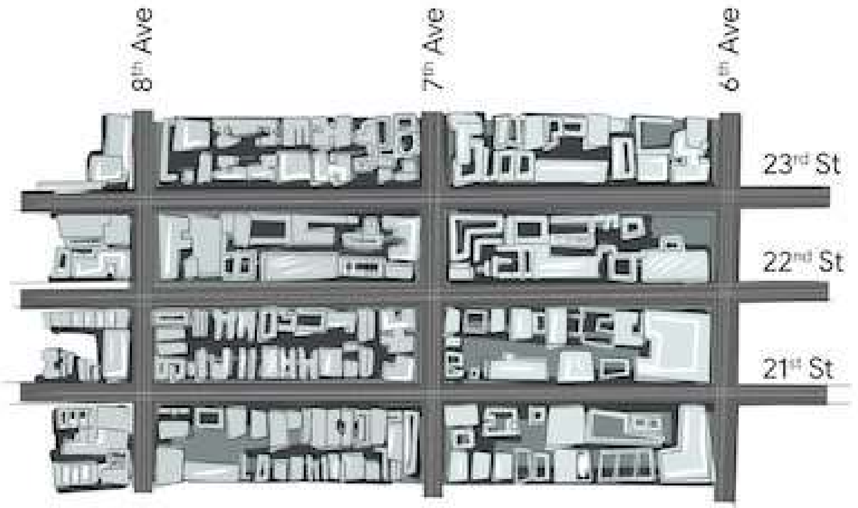


Figure 63: Grid design of Manhattan, New York

Source: NYC Subwayguide[146]

2.2.2. Theory of Economic Location

The various elements of urban planning described above are all sectoral in nature, either focusing on land planning or on infrastructure planning. Further down under the discussion on disaster resilience, elements addressing specific emergencies will be added. The role of local communities in spatial or financial planning is more cross-sectoral in nature. This role will be described hereafter.

Spatial planning of economic activities has been formulated in spatial economics, i.e. theory that explains where activities locate around given economic centres as a function of transport cost or other explanatory variables. In the 19th century cities have for the first time been described as economic entities in a geographic space. The German economist Johann Heinrich von Thünen (1826)[147] developed a concentric city model which explains the way different rural activities locate as a function of transport cost around a city which is seen as the central marketplace. Production of perishable goods (fruit, vegetables, dairy products) or intensive activities locates more closely to the city than production of less perishable goods such as crops or extensive farming. This establishes a space hierarchy of concentric circles, so-called von Thünen circles, around the city.

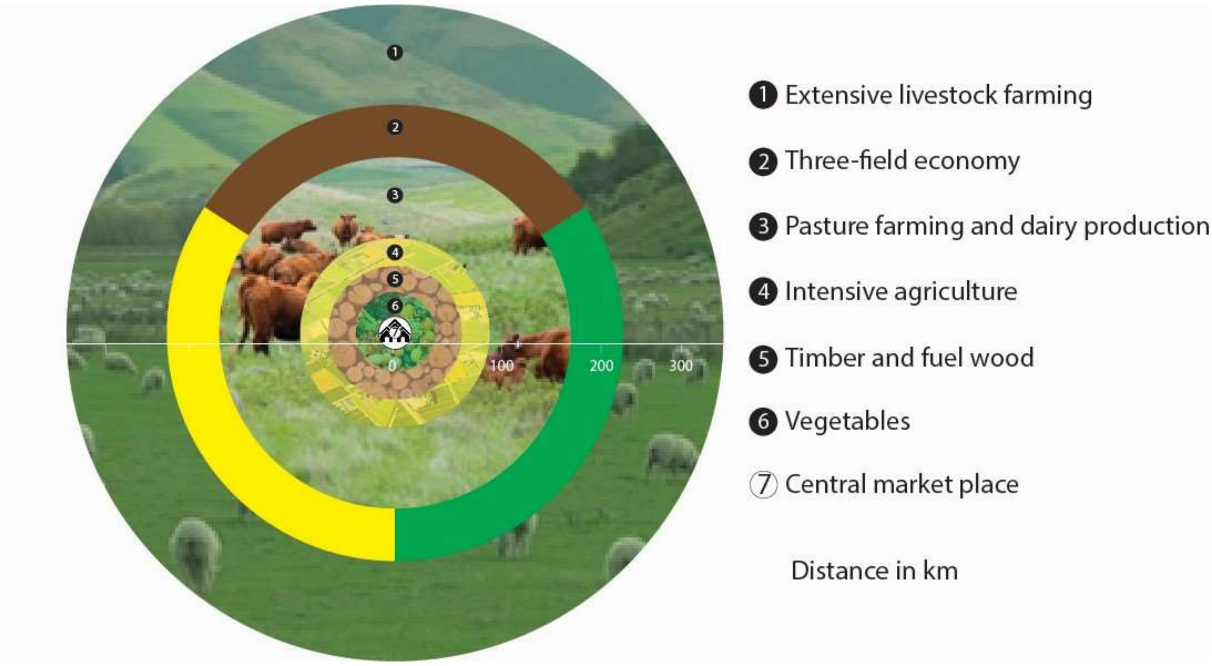


Figure 64: The concentric city model by von Thünen

Source: APSEC

The proximity to the city also allows explaining how the land rent decreases with increasing distance from the city. Note the relative proximity of timber and fuel wood whose higher transport cost requires location relatively close to the city. According to the calculations of von Thünen, cities require large areas of hinterland. The relationship between transport and land rent is used in modern Transit Oriented Development (TOD) approaches, see below section 2.3.4.

In 1909[148], the German economist Alfred Weber formulated a theory of industrial location in which the problem of optimal location of industrial production activity is calculated by minimizing the transport cost, considering location of the three factors: raw materials, workers and clients (so-called Weber triangle). He also noted the difference in considering transport cost for materials whose weight is conserved during transport (raw materials and products) and the materials whose weight diminishes during transport (energy materials). In case there is no loss of weight during production, the production would be located close to the clients, whereas in case of loss of weight during production, it is advantageous to locate production closer to raw materials.

In 1933, Walter Christaller proposed the so-called central place theory[149]. In this theory he described the relationship between bigger cities (which he called central places) and neighbouring smaller cities. Today a structure composed of one or several big cities surrounded by smaller cities is called a cluster of cities. Clusters of cities play an important role in promoting regional development.

Spatial economics has been further theorized by August Lösch (1940)[150] who is considered as founder of regional economics. Loesch's proposed model is a model of market equilibrium of the territorial self-organization of society and its economic life. He showed that the optimal spatial organization is a network of hexagonal cells with cities at their edges. If the zoning is carried out in squares, there will be fewer transport routes (eight), which means that the cost of transportation will be higher than in hexagonal zones (twelve roads). Loesch also notes that with hexagonal zones in cities such as Berlin, Paris, London, there are 12 highways emanating from the city. Loesch proposed an equilibrium model for the location of production, where two forces create an equilibrium: The interest of the state as a whole (i.e. the maximum number of economically independent facilities), and the interest of the entrepreneur, whose objective is the profit maximum, are both considered. The actual point of equilibrium was determined by studying many factors, including state regulation and state boundaries.

In 1964, William Alonso[151] described demographic migration movements of the city by focusing on the question how households choose their location as a function of distance to points of interest (CBD, workplaces) and space rent. The result is a concentric city model with CBD and shopping areas at the centre, surrounded by office space and, further out, by residential zones. From this he formulated a theory of rental formation in urban spaces.

The main trends of economic literature on spatial economy since the 1970s can be found in the World Development Report 2009 bearing the subtitle: Reshaping Economic Geography. The main research results are summarized below.

Cities evolve on a dynamic equilibrium path between centripetal forces, i.e. attractive forces that increase concentration, and centrifugal forces, i.e. those forces that disperse economic activity away from agglomerations. The most important centripetal force – indeed the only one – is increasing returns to scale, meaning that when all inputs into the production process are, e.g. doubled, the returns are more than doubled. In a techno-economic environment having these characteristics, cities will grow. Centripetal forces originate primarily from increased cost. In an increasing cost scenario, doubling all the inputs into production processes will result in total cost rising to more than the double. Cities will see their economic activities delocalizing and quitting them in an increasing cost scenario. Hence, one of the main tasks of city authorities to maintain the competitiveness of their cities is to find ways to keep costs low. One way to keep costs low is to monitor competitiveness of local infrastructures and to abolish local monopolies by increasing diversity of supply wherever this is possible.

When mentioning cost in the above analysis, this is not limited to internalized cost, but includes also external costs, i.e. costs which are not supported by those who cause them, but by those who are being affected by them. In cities, important external costs are e.g. the costs of congestion (lost waiting time), and cost of air pollution (increased health cost and death rate). External benefits are the contrary of external costs and include e.g. the spill overs of research, meaning that an enterprise can benefit from human capital that has been formed elsewhere. External benefits have centripetal effects.

Subject	Main insights	Key publications
Industrial organization, 1970s	Increasing returns to scale and imperfect competition can be incorporated into formal economic models	Spence 1976; Dixit and Stiglitz 1977
Urban economics, 1970s	External economies within cities and systems of cities; different levels of agglomerations are related to city functions	Mills 1972; Diamond and Mirrless 1973; and Henderson 1974
International trade, 1980s	Increasing returns and imperfect competition explain intraindustry trade between countries with similar endowments; initial endowments may, through trade and specialization, influence the long-run rate of growth; trade unleashes forces of both convergence and divergence	Krugman 1980, 1981; Ethier 1982; Helpman and Krugman 1985; Grossman and Helpman 1995
Economic geography, 1990s	Increasing returns-to-scale activities are characterized by agglomeration and imperfect competition, while constant returns-to-scale activities remain dispersed and competitive, helping to explain spatial distribution of economic activity and growth of cities	Krugman 1991; Fujita, Krugman, and Venables 1999; Henderson 1999
Endogenous growth, 1980s	Perfect competition and knowledge-related or human capital–related externalities imply aggregate increasing returns and explain why growth rates may not fall over time and why wealth levels across countries do not converge	Romer 1986; Lucas Jr. 1988
Endogenous growth, 1990s	Imperfect competition explains why the incentive to spend on R&D does not fall, and knowledge spillovers explain why R&D costs fall over time, resulting in more and better products that fuel growth	Romer 1990; Grossman and Helpman 1991; Aghion and Howitt 1992
Endogenous growth, 2000s	Imperfect competition and Schumpeterian entry and exit of firms, with entrants bringing new technologies, explain how a country's growth and optimal policies vary with distance to the technology frontier; knowledge accumulation in cities leads to growth	Aghion and Howitt 2005; Rossi-Hansberg and Wright 2007; Duranton 2007

Table 15: Research topics of spatial economics since the 1970s

Source: World Development Report 2009, The World Bank

2.2.3. Management Cycles in Urban Planning

Planning is part of the more general activity of management of a system or a project. Planning is the activity that structures the relation between a managing and a managed system. A planning cycle is a tool that helps the planner to describe the sequence of events or decisions the managed system will undergo. The fact of describing planning as a cycle and not as a straight line reflects the idea that planning is in a way a cyclical activity having no beginning and no end, but with a certain number of steps that are gone through. The cycle expresses the idea of feed-back where an outcome is used to influence the future input.

Management cycles are widely used in project management. As cities structure numerous activities around projects, cycles are important to understand the process of planning and implementation. They are also important to inform the constituents and the public about how a process is proceeding. The planning cycle of urban projects describes the phases that a project is undergoing, considering administrative, technical and legal factors. While there is no one-size-fits all, some similarities can be found for projects of similar nature.

The project cycle below is designed to illustrate the different steps a city will undergo for planning and implementing a policy aiming at modernizing energy infrastructures and wishing to evaluate the improvement that has been achieved. The core of the project is making an investment and replacing older run-out equipment with modern and more efficient equipment. Before the investment, several steps will be gone through. Preparation, analysis and priority setting are normally done in close cooperation with stakeholders. The priority setting may be coarse, but it might also consist of precise targets that are agreed in this phase. The action starts with the action plan. Action might lead to feasibility studies and include cost forecast that result therefrom. The investment or building phase is the core of the cycle, involving building hardware and setting up the equipment. After the start of operation, monitoring will ensure that data is collected on the performance of the new system. After sufficient data has been collected, or after the first phase of operation is over, the evaluation can start, whereby not only the hardware is evaluated, but also legislation and policies are assessed, and conclusions drawn. From there, a new cycle can start.

Figure 65: Policy cycle for improving urban energy efficiency

Source: APSEC

In urban planning, projects play a large role. However, some issues need to be addressed in a different manner than the above-specified policy cycle that relates to making an investment and assessing its efficiency as compared with prior set goals.

In urban planning, projects play a large role. However, some issues need to be addressed in a different manner than the above-specified policy cycle that relates to making an investment and assessing its efficiency as compared with prior set goals. The above cycle is relatively simple and straightforward. A more elaborate cycle applies to management of emergencies or disasters. The management of disasters in the broad sense can be split into two phases, one consisting of disaster management in the narrow sense and one in improving disaster preparedness. Immediately after an extreme event, the most important measures are providing relief and necessities to the affected people and installing urgent communication and emergency infrastructures. In a second phase, the reconstruction takes place. Only after the reconstruction, there is time for making in depth risk analysis and improving preparedness by strengthening hardware (buildings and materials) and software (early warning systems, training).

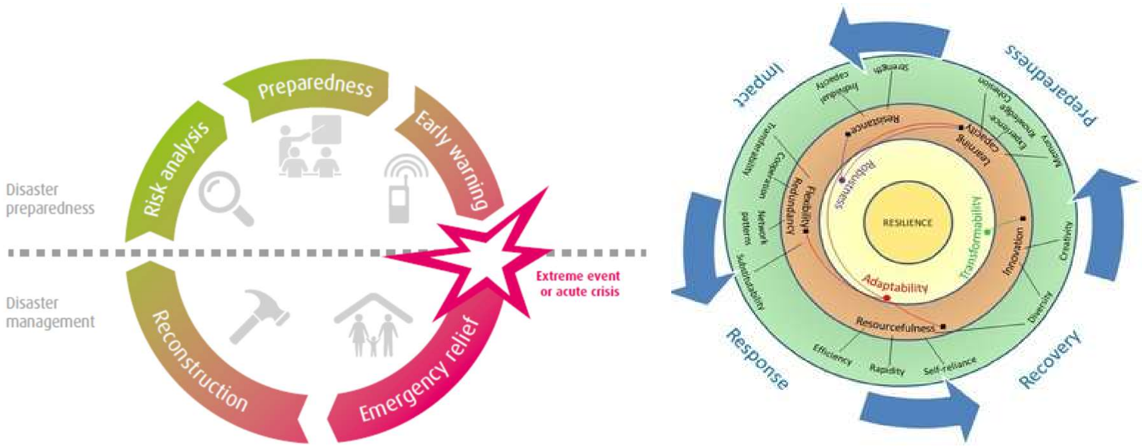


Figure 66: Disaster management and resilience cycle

Sources: World Risk Report 2016 and UK Department for Environment, Food and Rural Affairs[152]

The above disaster management cycle on the left side reflects a reality often found in disaster management. After emergency measures have been taken, the priority is to build back the lost infrastructure. In the ideal case, e.g. in the APEC Disaster Risk Reduction Framework (2015)[153], this phase is called “build back better”. The problem, evidenced by many disasters, is that in that precise moment, there is not enough time to make improved and forward-looking planning. People affected by disasters want to go back to normal life as quickly as possible. “Normal life” means adding only the strictly necessary improvement, e.g. protection against the disaster just experienced. As example, buildings that did not survive an earthquake should be built according to higher seismic norms. The above resilience cycle on the right side shows the same process from the resilience perspective. The difference is that the disaster itself disappears. The resilience discussion tends to focus on characteristics of the social system. Resilience of social systems will be further discussed in section 3.1.3.

The usual emergency management cycle assumes that disasters are returning after an average number of years. However, this pattern might change under the influence of climate change. Local communities and cities can become affected by disasters that are entirely new or have never been recorded in that specific place. The likelihood of such new types of disasters can be determined with climate modelling whose result is fed into the risk assessment and planning phase of the cycle. The cycle below shows such a possibility. This cycle is not disaster management cycle but an improved planning cycle for climate change impact.

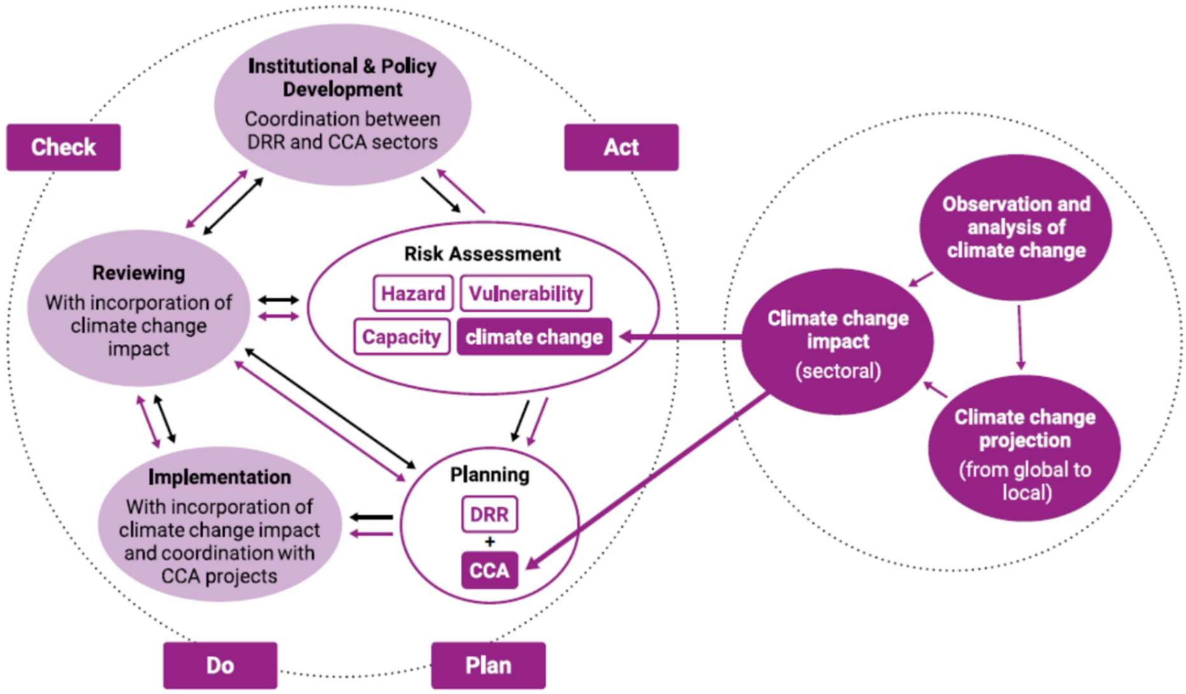


Figure 67: Climate change impact assessment cycle

Source: Japan International Cooperation Agency 2017

2.2.4. Economic Cycles

The analysis of theoretical aspects would not be complete without a brief look at the role of business cycles in economic activity. As has been shown above (section 1.2.2.) economic cycles cause large economic losses to APEC cities. For this reason, they have received special attention by economists. Anti-cyclical policies are today part of the standard economic policy mix. They can alleviate but not eliminate them. 160 years after the discovery of economic cycles by Clément Juglar, his understanding still holds: it appears that crises, like diseases, are of the condition of the existence of those societies where trade and industry are prevalent. One can predict them, alleviate them, delay them up to a certain moment, one can facilitate the recovery of economic activity, but it has turned to be impossible to eliminate them notwithstanding all the possible methods that have been applied[154].

The most regular cycle is the Juglar (or J-) or investment cycle, discovered in 1860 by the French physician and statistician Clément Juglar who set the beginning of a cycle at the moment of crisis that causes a downturn to start. Pursuant to this definition, there have been 21 cycles between 1817 and 2008/10 with length between 7 and 11 years. The 22nd cycle is expected to finish around 2020.

The J-cycles can be explained by the combination of a multiplier and an accelerator effect. The multiplier effect means that investment spending of the public sector acts in such a way that each money unit of investment spent by the public sector (cities, regions, central governments) generates more than the same amount of consumption spending by those who are paid to build the investment, because their spending is income for others. This multiplier effect is combined with the accelerator effect, meaning that incremental demand of a good will accelerate the investment into production capacities of that good. In anti-cyclic policies the public sector slows down its investment during economic upturn to avoid overheating and steps up investments during periods of economic downturn to mitigate the severity or the trough of the cycle.

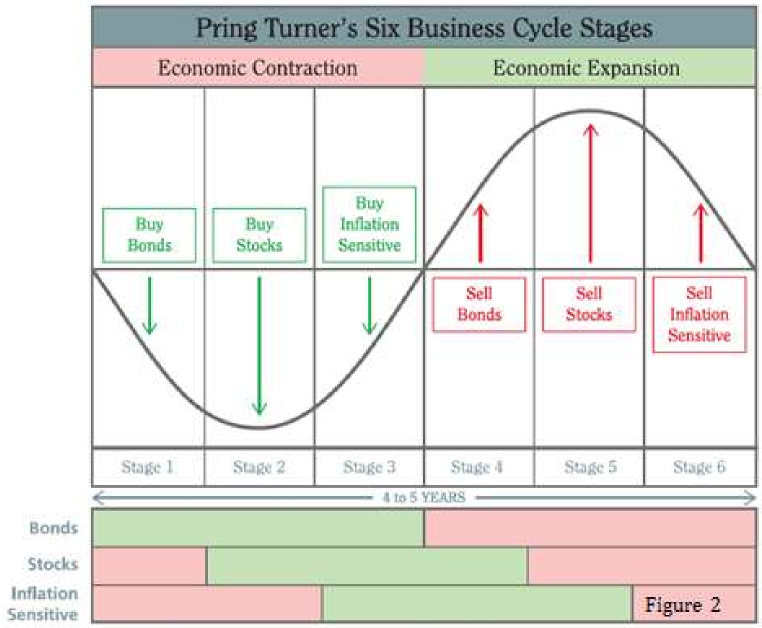
The J-cycles have been shown to be correlated to long-term Kondratief (or K-) technological swings. Each K-swing contains 4 to 6 J-cycles. Between 1785 and 2020, four and a half K-swings have been noted with length between 40 and 60 years. The first swing, driven by textile, iron and waterpower, had its expansion phase (1785 – 1817) followed by contraction phase (1815 – 1847). The second swing, driven by steel, railway and steam engines, had expansion (1850 – 1873) followed by contraction (1874 – 1896). The third swing driven by the internal combustion cars, chemistry and electricity, had expansion (1896 – 1920) followed by contraction (1920 – 1940). The fourth swing driven by petrochemicals, electronics and aviation had expansion (1940 – 1970) followed by contraction (1970 – 1993). The fifth swing driven by digital networks, software and new media is expanding since 1993, with a peak expected around 2020, after which a contraction of two to three decades is expected.

Serial numbers of K-waves	*Long waves' phases and their dates*	*Serial numbers and dates of J-cycles*	*Number of J-cycles per the respective K-wave phase*
I	B (downswing): 1817–1847	J1: 1817–1825	3
		J2: 1825–1836/7	
		J3: 1836/7–1847	
II	A (upswing): 1847–1873	J4: 1847–1857	3
		J5: 1857–1866	
		J6: 1866–1873	
	B (downswing): 1873–1890/3	J7: 1873–1882	2
		J8: 1882–1890/3	
III	A(upswing): 1890–1929/33	J9: 1890/3–1900/3	4
		J10: 1900/3–1907	
		J11: 1907–1920	
		J12: 1920–1929/33	
	B(downswing): 1929/33–1948/9	J13: 1929/33–1937/8	2
		J14: 1937/8–1948/9	
IV	A(upswing): 1948/9–1966/7	J15: 1948/9–1957/8	2[30]
		J16: 1957/8–1966/7	
	B(downswing): 1966/7–1979/82	J17: 1966/7–1974/5	2
		J18: 1974/5–1979/82	
V	A(upswing): 1979/82–2008/10	J19: 1979/82–1990/3	3
		J20: 1990/3–2001/2	
		J21: 2001/2–2008/10	

Figure 68: Relationship between J-cycles and K-swings

Source: Grinin and Korotayev[155]

Besides these two types of cycles, there exists also a 15-to-20-year (infrastructure or Kuznets) cycle, which is important for housing and real estate development, whereby usually 2 to 3 Kuznets cycles fit into a K-swing. Finally, the 4-to-6-year inventory or financial (or Kitchin) short term cycle is the one that matters most for portfolio-investors trading in stocks, bonds and commodities. These short-term cycles can be considered as the seasons that are relevant to the financial market, just as the meteorological seasons are relevant to the farmer.

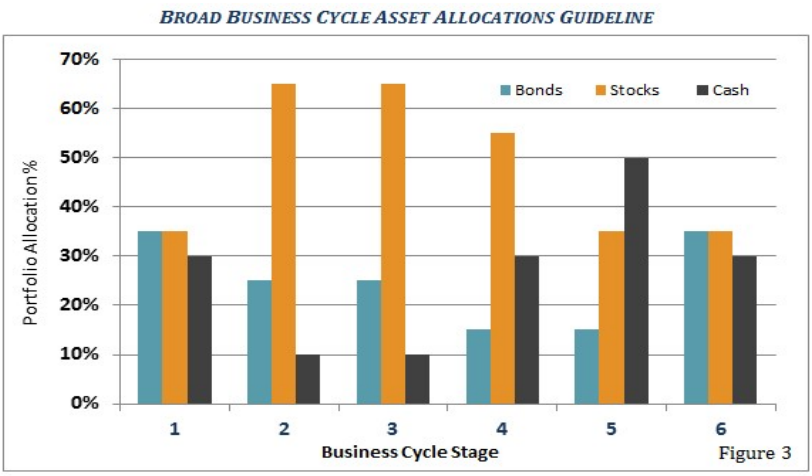


The six-stage model can help investors dynamically adjust asset allocations around the typical business cycle sequence. Certain asset classes are favored (green) or de-emphasized (red) during specific times in the cycle.

Figure 69: Phases of the inventory cycle

Source: Pring Turner[156]

It is important to note that the duration of these four types of cycles is not stable and that the economy is not a mechanical engine, but rather a variable organic entity. The irregularity of these cycles in length and amplitude has up to now prevented anyone from finding a perfect model that would link all these cycles together. Any attempt claiming to be able to determine the exact position of the present economy within these cycles should itself be taken with precaution.



This broad asset allocation guideline can serve as an important starting point for actively managing portfolios throughout the business cycle. The graph serves as a general guideline but should not be mistaken as a precise model, simply an illustration.

Figure 70: Broad business cycle asset allocations guideline

Source: Pring Turner

The question whether local communities – or indeed any public sector entity – should be allowed – or even encouraged – to use the inventory cycle as a means for additional revenue generation is controversial. It is widely recognized that anti-cyclical fiscal and infrastructure policies of the public sector help limiting the negative impact of business cycles. Acting anti-cyclically means acting to a certain degree against the sense of short-term business interests. If the public sector does not act in an anti-cyclical manner, the social losses, especially in terms of business failures and unemployment occurring during the trough or depression phase, are larger than with anti-cyclical policies. The negative consequences of depressions will inevitably have to be borne by the public sector, mostly by local communities who will face lower tax income and higher social spending. It is not known, however, whether the portfolio investments of public sector entities are to be regarded as investments that amplify the swing movements of the traded items – stocks, bonds, commodities – or whether the public sector's influence on prices of these items is negligible.

For sustainability analysis, economic cycles are important as they tend to illustrate that the economy is not a body regulated by homeostasis, but a complex adaptive system (CAS) with numerous partial feedbacks of the type that is described further down in section 3.1.1. The reality of business cycles has been described for more than 160 years now. Still, much economic thinking takes place in terms of general equilibrium which might seem to be the anti-thesis of cycles. Equilibrium has been described by Adam Smith (1776)[157] postulating the effect of an invisible hand. A century later, Leon Walras's (1874/77)[158] added a precise mathematical formulation of the general equilibrium. He inspired his disciple V. Pareto (1919)[159]. Similarly, Irving Fisher (1892)[160] was heavily inspired by physical equilibrium that had been formulated by the physicist and chemist J. W. Gibbs (1876)[161]. In the 20th century, the economic equilibrium has again received attention by K. J. Arrow and G. Debreu (1954)[162] and later by G. Debreu's fundamental work Theory of value – an axiomatic analysis of economic equilibrium (1959)[163] for which he was awarded the Nobel Prize in 1983.

Equilibrium and cyclical behaviour are not incompatible among each other. Rather, it must be recalled that economic equilibrium is created under a series of restrictive hypotheses which demonstrate that equilibrium is an optimum, not a reality. These hypotheses are referred to as conditions for Pareto efficient markets. They can be summarized as follows:

- perfect competition (i.e. have an infinitely large number of players),
- perfect information (no information advantage of sellers over buyers)
- no cost for entry or exit of any market player
- absence of transaction costs
- consumers have individual preferences for substituting goods among each other
- perfect mobility of production factors (capital and labour) between producers
- perfect substitution of all firms among each other
- internalization of all external effects (costs and profits)
- no economic growth
- no technological progress

These conditions are restrictive and rarely apply to the real economy. Some of the above conditions can be integrated into more sophisticated general equilibrium models. Changes in consumer preferences between goods produced in different industries can cause economic stress in those industries whose products are affected by falling demand. This is the heart of the problem area of industrial risk. Local communities where ailing industries are located (e.g. coal and steel) are constantly confronted with the question how to deal with this problem.

The above being said, an important lesson should be borne in mind when attempting to make the economy more sustainable and more disaster resilient. Any development towards more sustainability or disaster resilience should ideally be a process driven by well-informed consumers. Well-informed consumers can become trend-setters and influence the market and hence the producers. Producers will then ask for better regulations that bring about more sustainability and disaster resilience of the economy.

In cases this process is not led by well-informed consumers, it can still happen in form of a producer-driven process, but this requires an almost unrealistically high level of cooperation and like-mindedness among producers.

In principle this process can also happen as regulatory-driven process. In this case, it requires that regulations provide for sufficiently high levels of economic incentives and disincentives to producers and correspondingly tight controls so that producers have effective advantages of follow the rules. Otherwise, the regulatory action taken in favour of sustainability and disaster resilience might be perceived as obstacle to trade and become unpopular among both, producers and consumers.

2.2.5. Adaptive Cycles

Looking at cycles can be a way to reducing the complexity of a system and better understanding it. Very special and complex cycles can be found in the ecological environment. Environmental systems undergo cyclical or quasi-cyclical evolution patterns that have been described as adaptive cycles. Adaptive cycles are being analysed and identified in different areas of interest by the Resilience Alliance[164].

As its name indicates, adaptive cycles are cycles, whose endpoint is not identical to its departure point. Adaptive cycles can be understood like spirals. After one cycle, some form of change has intervened. This change is a learning effect or evolution. This is a general pattern seen in living systems which undergo evolution in small steps. Often, this evolution is being pushed by disasters or environmental pressures, and the evolution is the response of the system to these events. In a certain way, the “build back better” cycle mentioned above denotes an adaptive cycle in its simplest form.

The mere evolution after each cycle is, however, not sufficient to characterize the adaptive cycle as it is being described and depicted by its main proponents[165]. Rather, the adaptive cycle contains four very distinct phases which are grouped into two half-cycles each, after which the system is close to the starting point, which is, however not identical to the starting point due to the evolutionary shift forward.

The four phases of the adaptive cycle are usually shown in the shape of a Moebius-strip on two axes designating connectedness of the system (i.e. the number and intensity of relations between the elements of the system, indicating e.g. the organizational and complexity level of the system) and a potential of the system (expressing the size of the system in a scalar number of something that is accumulated during growth, e.g. biomass, wealth, energy). The two foreloop phases are conventionally named r and K and symbolize growth (r) and accumulation (K). At the end of accumulation, there is a disaster or similar striking event which causes major parts of the system to collapse (end, omega), from where it slowly recovers again by reorganizing itself and approaching the starting zone (alpha). Every new cycle is different from the preceding one.

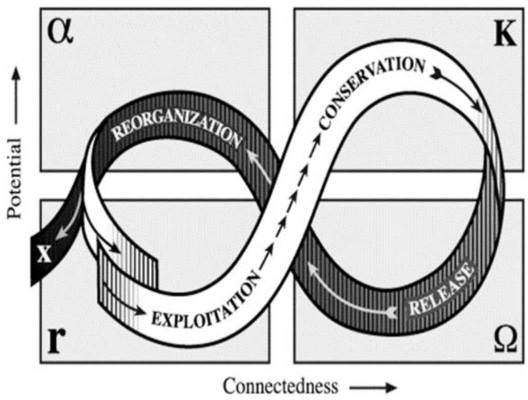


Figure 71: Adaptive cycle of ecosystems and socio-ecological systems

Source: Resilience Alliance[166]

An example from ecology might illustrate the meaning of the four phases of the adaptive cycle[167]. If forest fires happen at a small scale, they help to clear out dead wood and other materials that would otherwise have taken much longer to break down and provide soil nutrition for the next generation of trees and plants living in that forest. This process helps to keep a forest ecosystem healthy. The cycle takes place in four phases.

Phase 1: Burned forests serve as important habitat for many species, such as the Black-backed Woodpecker, *Picoides arcticus*, that is specialized to live and thrive in forests that have experienced severe burning. Only few species have the capability to exploit the specific environment of burned forests. For a new forest, this is the exploitation phase during which both, the quantity of biomass as well as the degree of organization of the ecosystem are low and start growing.

Phase 2: The first plant species that recolonize a previously empty or fallow space are pioneer herbaceous species, such as fast-growing grasses and weeds. Next, slower-growing and taller types of plants come in. Later, early successional tree species, such as small pine trees come in, and then larger pine trees become established. Eventually, long-lived hardwood tree species like oak and hickory become established, giving rise to a mature climax forest. This process can take a long time, ranging from several decades to even hundreds of years to move from early pioneer to climax stage habitat. This is the conservation phase, during which both, biomass and connectedness, are already high and grow further.

Phase 3: A biomass-rich forest is vulnerable to disasters such as forest fires. When such a disaster occurs, the biomass is rapidly released. This is the release phase, during which not only the trees burn, but with them also the established interaction patterns, i.e. the connectedness among the species and other elements of the forest.

Phase 4: After the forest fire occurs, a process called *ecological succession* takes place, where the ecosystem goes through a series of changes and eventually might develop into a mature forest again. The phase following immediately the forest fire is the reorganisation phase during which the forest restarts the process of reorganization, usually by self-organization, allowing at first development of species that are specialized in living in burned forests. A new forest will usually be somewhat different from the previous one.

As already mentioned, these four phases have some similarity with the disaster management cycle described above (section 2.2.3.). Furthermore, there are also similarities to the economic cycle described in the preceding section. More precisely, the question of equilibrium plays an important role in adaptive cycles. The analysis of adaptive cycles goes much further than the analysis of equilibrium and of business cycles in economic theory. Economic theory pretends that there is one single overall equilibrium which can be attained under ideal circumstances called Pareto optimality conditions (see above). Adaptive cycle analysis, on the other hand, distinguishes between different kinds of equilibrium and makes the postulate that different types of equilibria not only co-exist in nature, but that the topological landscape that created these different equilibria is itself evolving over time. Adaptive cycles describe a multi-equilibrium world with evolving topological space. What this exactly means can be illustrated by the figure hereafter[168]:

Case A describes a so-called flat world. This means that no force exists to pull the system in any given direction. In this case, all points metaphorically shown on the stability landscape equilibrium points. The system makes a pure random walk whose direction and end points are purely random.

Case B describes a system with a stable unique equilibrium. This can be called a balanced world. Its equilibrium corresponds to the general economic equilibrium. The underlying stability landscape is such that the system will necessarily converge to one single point in a finite length of time. This equilibrium is a stable equilibrium. If the system is affected by any random disturbance it will eventually reach its equilibrium position again.

Case C describes a globally unstable and unpredictable equilibrium. This can also be called anarchic world. If by chance the system is in equilibrium, any disturbance affecting it will cause the system to lose the equilibrium and to start a random walk whose direction and distance is purely random.

Case D describes a multi-equilibrium world which contains all the previously described equilibria at the same time. More precisely, these multiple equilibria are in a stationary non-linear stability landscape. This world is called resilient world.

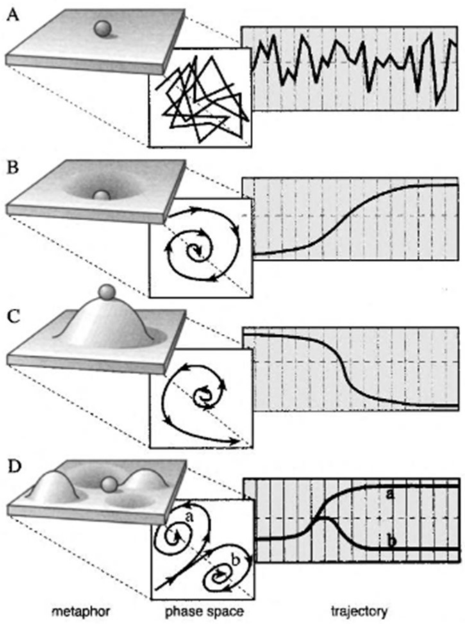


Figure 72: Stability landscape, phase diagram and trajectory of different types of equilibrium

Source: Holling, Gunderson, Ludwig (2002)

What is important for understanding adaptive cycles is to realize that the world they describe is neither flat (without equilibrium, A), nor balanced (having exactly one static equilibrium point in a dynamic environment, B), nor anarchic (globally unstable and unpredictable, C), nor resilient (multiple equilibria in a stationary non-linear landscape, D).

Instead, the world described in adaptive cycles is evolving, meaning that it can have any or all the equilibrium points described in D, but that the stability landscape is non-stationary and non-linear, i.e. it may undergo topological transformation over time. Topological transformation describes the kind of "rubber sheet geometry" produced by stretching, bending, shrinking, twisting the stability landscape without tearing it apart or gluing it.

The ecological systems described by adaptive cycles also have some further characteristics that are not usually found in economic analysis but apply to ecological systems:

- Multiplicity of scales: nature may behave differently in different scales. Some phenomena may be visible at micro-scale but may disappear at macro-scale, or vice-versa. It is then said that the macro-scale has emerging properties. The classical example of an emerging property is temperature. At atomic scale, there exists no temperature, only movement of particles. An example of an emerging property in economics is inflation. Inflation cannot be observed for individual prices, but only at the macroeconomic level. Note that in urban planning, four scales are currently used: the city (or regional scale), the corridor scale, the station scale, and the site scale.

- Self-organization and capability of learning: Systems described by adaptive cycles are self-organizing and have the capability of learning. This is expressed by the fact that the end point of a cycle is slightly different from the starting point.

The figure below shows what this means for stability, processes and policies of systems that are described by adaptive cycles.

	Stability	**Processes**	**Policies**	**Consequence**
Nature Flat	none	stochastic	random	trial and error
Nature Balanced	globally stable	negative feedback	optimize or return to equilibrium	pathology of surprise
Nature Anarchic	globally unstable	positive feedback	precautionary principle	status quo
Nature Resilient	multiple stable states	exogenous input and internal feedback	maintain variability	recovery at local scales or adaptation; structural surprise
Nature Evolving	shifting stability landscape	multiple scales and discontinuous structures	flexible and actively adaptive, probing	active learning and new institutions

Figure 73: Five types of nature

Source: Holling, Gunderson, Ludwig (2002)

The consequences for policies of the fact that Nature is evolving in the way described above are, basically, that learning is obligatory. Not only learning about basic unchangeable properties of matter, such as learning the fundamental laws of physics, but also learning about new emerging entities (species, enterprises, products, services, institutions) and new types of relationships emerging among all these.

Disasters are an integral element of the adaptive cycle model. They are critical moments of the evolution of the system, whereby “critical” is to be understood as “screening” or “filtering”, corresponding to the original Ancient Greek sense of the term. In the adaptive cycle model, a disturbance can either have the effect to be absorbed by the system (e.g. if it is below a threshold) or cause a disaster from which the system may take long time to recover and if it does so, the result might give rise to a totally different system.

The adaptive cycle can be used to describe not only cycles where there is a small evolution between the beginning and the end point, but also cycles where there is a large evolution between these two points. A well-known example for this latter case is the story of the sinking of the RMS Titanic which sank on 14 April 1912[169]. Interpreted in terms of the adaptive cycle, the exploitation phase starts with the design of the RMS Titanic. The design was overseen by Thomas Andrews, manager of the Harland and Wolff company. He originally wanted a double hull, sealed watertight bulkheads up to the B deck and 46 lifeboats, but he was overruled by other members of his company on these three points. The exploitation phase is characterized by the driving the system towards accumulating some quantity. In the case of an economic project this quantity is usually money. The exploitation phase allows accruing benefits to be invested. This objective may override security arguments, as the example of the Titanic shows.

On 14 April 1912, the Titanic was evolving on an equilibrium path on surface and absorbed all the usual disturbances coming from the ocean (conservation phase). Captain Smith did acknowledge the numerous iceberg warnings and changed the cap further south and ordered special watch for icebergs, but – motivated by the necessity to not to lose time and keep schedule – continued to order almost full speed ahead in the moonless night. Ten minutes before collision, Senior Wireless Operator Jack Phillips has answered the very clear warning from the neighbouring RMS Californian by rebuffing it.

When First Officer Murdoch spotted the iceberg, the collision was merely 40 to 60 seconds ahead. The coal-powered ships at that time lacked manoeuvrability to respond adequately in this lapse of time. Murdoch sharply steered the ship to the right, but the rudder was too small to allow rapid change of the course. He also ordered to reverse the gear, but the throttle was not directly accessible from the bridge, he had to transmit the order by telegraph to the engine room where it was deciphered and executed. Alas, its effect came too late. The crash with the iceberg was too strong to be absorbed by the ship. The ship sank (release phase, omega phase) and found a new equilibrium state at the bottom of the ocean. The accident was thoroughly investigated thereafter, and numerous lessons were learnt for the future.

After the discovery of the wreck almost a century later, the reorganisation phase began, leading to the exploitation of the ship’s artefacts (alpha phase). In this case, there is a large difference between the starting point and the end point of the cycle. The ship only revives partially, through its artefacts as well as indirectly, through its numerous images that circulate in cultural products.

In terms of the adaptive cycle, the management team of the Titanic run a normal management cycle instead of running an adaptive cycle. The latter would have required the whole system (comprising the design as well as the first cruise) to make use of all the available information and thereby to adapt to the hostile environment. The belief in false security has contributed to this tragic issue. This will be further analysed in the next section.

2.2.6. Panarchy of Psychological Needs

The SDGs have been adopted as a package and hence it can presumably be deducted that they all are of equal importance. The question must be asked as to whether the human needs they all address are also of equal importance, or whether they are, on the contrary, structured in hierarchy. This section shows that none of both is the case. Human needs are neither all equal nor are they hierarchical. They are so to say, “conditionally hierarchical”, meaning that the hierarchy changes as a function of individual and social needs satisfaction. However, the term “conditional hierarchy” is a self-contradiction as such a hierarchy is not really a hierarchy. A hierarchy that is conditional on at least two different scales (individual and social) satisfies the idea of the panarchy as it has been proposed by Gunderson and Holling in 2003 and used in the resilience alliance[170]. For this reason, it is appropriate to refer to psychological needs as a panarchy of needs.

One of the most famous hierarchies of needs has been elaborated by Maslow in 1943[171] and amended in 1954[172]. This Maslow hypothesis has been widely discussed and commented and became immensely popular. The author himself has further developed it in some later publications[173]. The basic idea of the Maslow hypothesis was to state that needs appeared in hierarchy, whereby most basic needs would be satisfied first, and higher needs would be satisfied thereafter and with lesser priorities. Originally Maslow proposed five needs levels (see figure below).

For empirical testing, the Maslow hypothesis has been adapted to modern psychological research which distinguishes six rather than five levels of hierarchy (see figure). This improved hierarchy has been tested empirically in 2011, more than half a century after its formulation, by Tay and Diener[174] in a global survey of more than 60’000 individuals representing 95% of world population from 155 economies of all eight major world regions. Due to the global sample and the universality of conclusions that can be drawn, it is worthwhile to discuss the conclusions of this study. The authors basically tested how satisfaction or deficit of these needs contributed to three types of subjective well-being, namely life evaluations, positive feelings and negative feelings. They also added income as explanatory variable and measured how it influenced subjective well-being (SWB), which is the psychological equivalent of “happiness”.

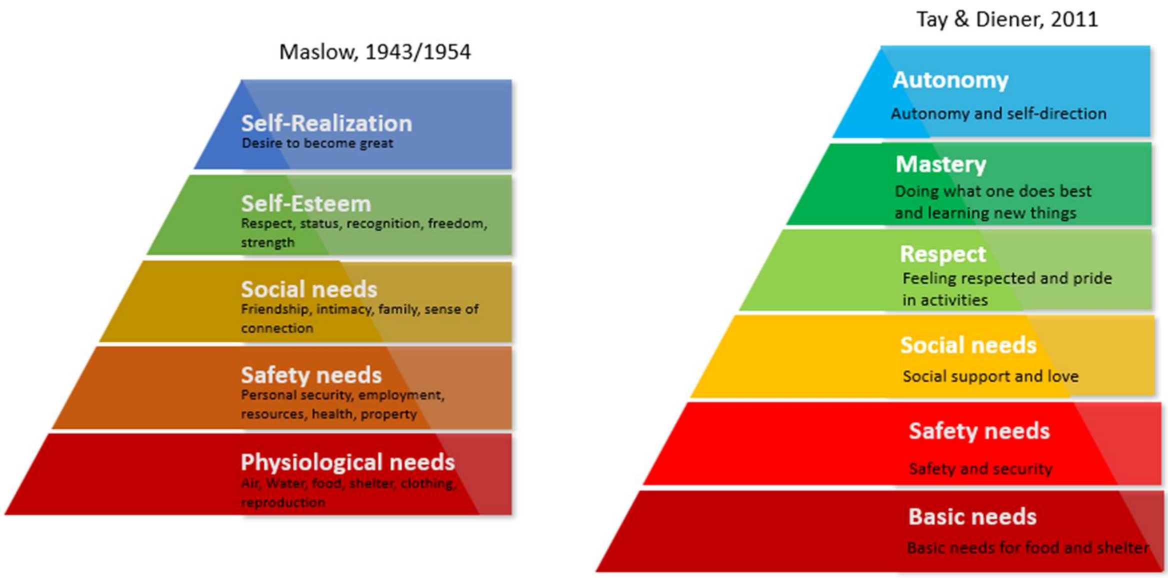


Figure 74: Hierarchy of needs by Maslow (1943/54) and Tay & Diener (2011)

Source: APSEC

The empirical study revealed that there is indeed a tendency, but not a strong one, to fulfil the needs in a specific order. If Maslow's hypothesis were confirmed, the symbols in the figure below would never cross each other. This means, the "1" would always be higher than the "2" which would always be higher than the "3" and so on. Yet, as the figure shows, the empirical result is quite different as it shows a variable hierarchy, i.e. a panarchy. At global average, those having the smallest needs fulfilment (-4 on the x-axis of the figure below) fulfil first safety and basic needs. Those having average needs fulfilment (zero on the x-axis) still fulfil basic needs, followed by all other needs. Those having high needs fulfilment (+4 on the x-axis) slightly prioritize fulfilment of respect and mastery, but still have a high fulfilment rate of basic needs, while lowest priority for them is fulfilment of safety needs which they take for granted.

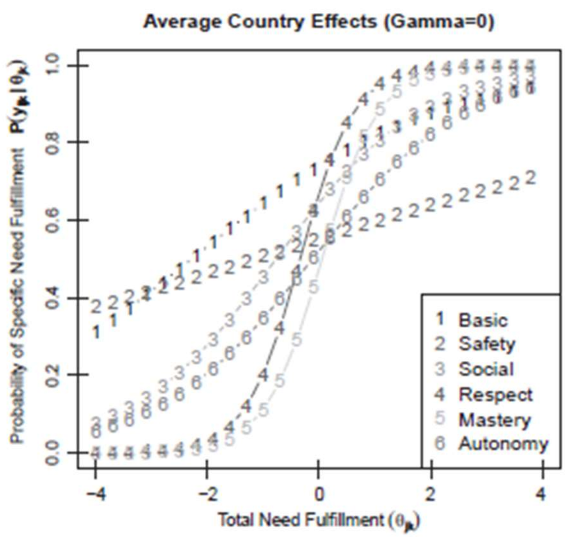


Figure 75: Need fulfilment curves for global average

Source: Tay and Diener

Empirical analysis also shows that these curves are different for societies with high need fulfilment (developed economies) and societies with low need fulfilment (developing economies).

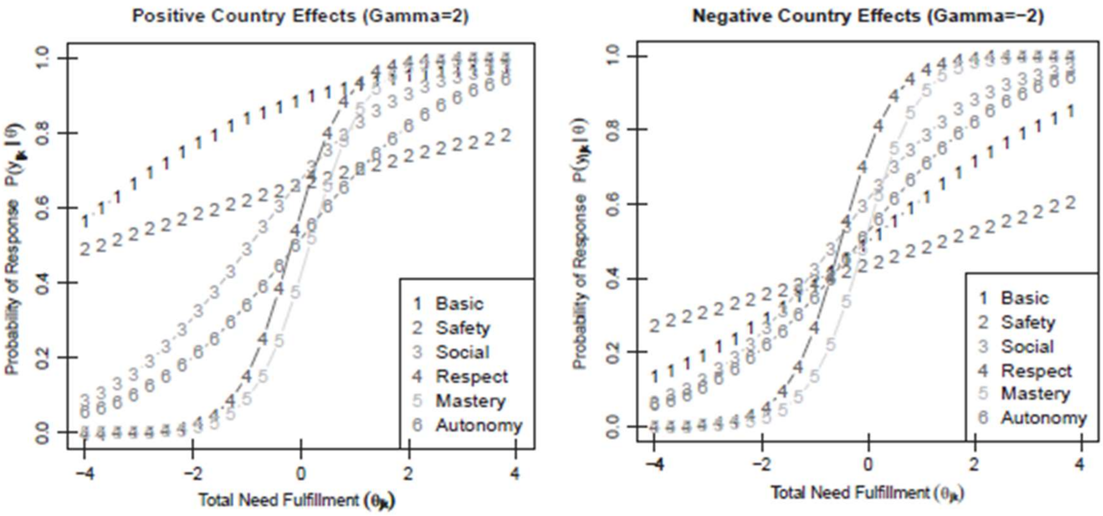


Figure 76: Need fulfilment curves for societies with high (left) and low (right) need fulfilment

Source: Tay and Diener

In developed economies, where the need fulfilment is high, the need fulfilment curves are in a certain sense like in global average. Basic and safety needs are satisfied first, the others follow later. For those having high needs fulfilment, the satisfaction level of basic needs is still very high, whereas they give lowest priority to safety which they take for granted.

In developing economies, where the need fulfilment is lower, those having low needs fulfilment give highest priority to safety, even before satisfying basic needs. The interesting fact is revealed by those living in developing economies and having high needs fulfilment. They prioritize all four psychological needs (respect, mastery, social and autonomy) before satisfying basic needs. They attain less high satisfaction of basic needs compared to those living in developed economies, but they, too, give the lowest priority to safety, similar those with high needs fulfilment living in developed economies.

Some further take-aways from this study are the following:

- The fact that high needs fulfilment (+4 on the x-axis) in all the cases implies lower fulfilment of safety needs than fulfilment of all the other needs deserves attention. This can be called “Titanic effect”: When all needs are satisfied, the red alarm bells are usually ignored. It means that high needs fulfilment always lowers the need to fulfil safety concerns. To the extent that people who have high needs fulfilment contribute or even decisively shape safety and security policies worldwide, these policies, therefore, tend to under evaluate risks and to create fragility or lack of resilience. The above analysis mandates giving key influence for formulating security policies to those who have the lowest needs fulfilment (-4 on the x-axis), for developed and developing economies alike.

- The satisfaction of basic and safety needs is most strongly dependent on the economy and might, therefore, be culturally determined and be beyond the control of individuals.

Societies also have a substantial influence on whether basic and safety needs are fulfilled.

- The very high satisfaction level of basic needs by those having high needs fulfilment (+4 on the x-axis) in developed economies is a significant factor of strain for sustainable development. It reflects the fact that even developed economies are very eager to satisfy basic needs with high priority. This might even be a psychological driver of obesity. Implementing sustainable development policies, therefore, means developing cultural models, especially in developed economies, which are intrinsically built on sustainable consumption-production patterns.

- The study also explains (not shown in the above diagrams) that individuals feel better if their society's basic needs are satisfied, independently of the satisfaction of their own needs. Improving one's own life is not enough to feel well. Society-wide improvement is also required for improving the subjective well-being or "happiness" of individuals. Improving individual well-being therefore includes improving societies. This is the psychological basis for the principle of inclusiveness or leaving no one behind, which is a basic principle of the SDGs. This principle should not be confused with the principle of equality or non-discrimination which is sometimes regarded as instrument for achieving inclusiveness, see e.g. New Urban Agenda[175].

- The three types of subjective well-being or "happiness", namely life evaluations, positive feelings and negative feelings are determined by the following factors: life evaluation is mostly determined by satisfaction of basic needs; positive feelings are mostly determined by satisfaction of social and respect needs, negative feelings are mostly determined by (dis-)satisfaction of basic, respect and autonomy needs.

- Income is important only to the extent that it fulfils basic needs. In this sense it contributes to positive life evaluation. Income does not contribute to positive nor negative feelings.

- This analysis reflects the psychology of individuals who were the respondents of the survey. It should not be misinterpreted to reflect the priorities of organizations.

2.2.7. Theory of Constraints (ToC)

Before terminating the discussion of the theoretical background of planning, it is necessary to briefly explain the theory of constraints. After having shown the complexity of processes and phenomena of urban development, it is now appropriate to show an efficient way to reduce complexity.

The theory of constraints was first proposed by E. M. Goldratt in 1984 in form of a novel which was subsequently revised and re-edited several times[176]. Since its first publication, the theory, originally conceived as management theory for industrial production processes, has become widely known worldwide and applied to improve practically any sphere of management. Applying it to management towards attaining collective global goals such as sustainable development and disaster resilience could contribute towards facilitating the process of implementing these goals by increasing the speed towards attaining the goals.

The basic idea of ToC is simple: just as the strength of any chain depends on its weakest link, the speed of any process, say attaining sustainable development goals, depends on the limiting constraint (i.e. the bottleneck) of that process. To progress as fast as possible, the bottleneck or limiting constraint must be identified and lifted in priority. Thereafter, the process will be limited by another bottleneck which becomes the new limiting constraint to be addressed as a next priority. This process continues until all internal bottlenecks have been eliminated. Thereafter, the process can start addressing the external bottlenecks one by one, following the same logic. The corollary is that spending resources on factors other than the limiting factor is a waste of time and resources.

The first two elements of ToC are the identification of the objective and the limiting constraint. In the understanding of the ToC, these steps are very much a collective task of an organization. Applying ToC in business enterprises is somewhat easier than applying it in other types of organizations because business enterprises normally have the clear single objective to maximize profits. A single objective makes identifying the limiting factor relatively easier. Enterprises producing multiple products might have multiple objectives and one limiting constraint associated to each objective. ToC can then be applied separately by each enterprise unit to its objective and its limited constraint. At later rounds of the ToC cycle the integration of all the parts can take place. The steps of ToC can be resumed as follows[177][178]:

Step	**Objective**
Identify	Identify the objective. The people involved in fulfilling one objective must agree on a single measurable objective.
Identify	Identify the current constraint (the single part of the process that limits the rate at which the goal is achieved). The people involved must agree on the bottleneck. .
Exploit	Make quick improvements to the throughput of the constraint using existing resources (i.e. make the most of what you have, harvest the easy-hanging fruit). People involved must agree on the solution, i.e. on the correct action to resolve the bottleneck.
Subordinate	Review all other activities in the process to ensure that they are aligned with and truly support the needs of the constraint. This means eliminating negative factors affecting the process.
Elevate	If the constraint still exists (i.e. it has not moved), consider what further actions can be taken to eliminate it from being the constraint. Normally, actions are continued at this step until the constraint has been “broken” (until it has moved somewhere else). In some cases, capital investment may be required.
Repeat	The Five Focusing Steps are a continuous improvement cycle. Therefore, once a constraint is resolved the next constraint should immediately be addressed. This step is a reminder to never become complacent – aggressively improve the current constraint…and then immediately move on to the next constraint.

ToC uses a sophisticated problem-solving methodology called the Thinking Process. This is designed to identify cause-and-effect relationships so that the root causes of undesirable effects (UdE) can be identified. The UdEs should then be removed without creating new ones. Some tools that have been formalized as part of the Thinking Process are:

Tool	Role	Description
Current Reality Tree	Documents the current state.	Diagram that shows the current state, which is unsatisfactory and needs improvement. When creating the diagram, UDEs (symptoms of the problem) are identified and traced back to their root cause (the underlying problem).
Evaporating Cloud Tree	Evaluates potential improvements.	Diagram that helps to identify specific changes (called injections) that eliminate UDEs. It is particularly useful for resolving conflicts between different approaches to solving a problem. It is used as part of the process for progressing from the Current Reality Tree to the Future Reality Tree.
Future Reality Tree	Documents the future state.	Diagram that shows the future state, which reflects the results of injecting changes into the system that are designed to eliminate UDEs.
Strategy and Tactics Tree	Provides an action plan for improvement.	Diagram that shows an implementation plan for achieving the future state. Creates a logical structure that organizes knowledge and derives tactics from strategy. Note: this tool is intended to replace the formerly used Prerequisite Tree in the Thinking Processes.

ToC introduces a specific accounting method to measure the performance of the organization. In case of an industrial business enterprise having a profit maximization goal, this is called throughput accounting (see below). For other types of enterprises with other goals, the method must be adapted mutatis mutandis to correspond exactly to measuring the goal(s) to be attained.

Core Measures	Definition
Throughput	The rate at which customer sales are generated less truly variable costs (typically raw materials, sales commissions, and freight). Labour is not considered a truly variable cost unless pay is 100% tied to pieces produced.
Investment	Money that is tied up in physical things: product inventory, machinery and equipment, real estate, etc. Formerly referred to in TOC as Inventory.
Operating Expense	Money spent to create throughput, other than truly variable costs (e.g. payroll, utilities, taxes, etc.). The cost of maintaining a given level of capacity.

ToC distinguishes different types of constraints. The analysis of these constraints can be used in any type of organization and is not limited to business organizations. Experience shows that some types of constraints like e.g. paradigm constraints are better perceived by people from outside an organization.

ConstraintDescription	
Physical	Typically, equipment, but can also be other tangible items, such as material shortages, lack of people, or lack of space.
Policy	Required or recommended ways of working. May be informal (e.g. described to new employees as “how things are done here”). Examples include company procedures (e.g. how lot sizes are calculated, bonus plans, overtime policy), union contracts (e.g. a contract that prohibits cross-training), or government regulations (e.g. mandated breaks).
Paradigm	Deeply engrained beliefs or habits. For example, the belief that “we must always keep our equipment running to lower the manufacturing cost per piece”. A close relative of the policy constraint.
Market	Occurs when production capacity exceeds sales (the external marketplace is constraining throughput). If there is an effective ongoing application of the Theory of Constraints, eventually the constraint is likely to move to the marketplace.

The constraint plays a central role in ToC. When addressing the limiting constraint, either of two outcomes might happen. Either the constraint is broken, in which case it exists no longer, and the process will restart at step one with identifying the next limiting constraint, or the constraint has not been broken yet, in which case further measures, usually investments, must be made for breaking it, or checking, whether the constraint has been correctly identified, which also means to start the process again at step one.

Item	Description
Constraint Broken	If the constraint has been broken (the normal case), recognize that there is a new constraint. Finding and eliminating the new constraint is the new priority (restart at Step One).
Constraint Not Broken	If the constraint has not been broken, recognize that more work is required, and a fresh look needs to be taken, including verifying that the constraint has been correctly identified (restart at Step One).

An interesting aspect of ToC is to concentrate on positive goals, i.e. those whose form in linear programming would have the primal form “maximize target variable X” rather than the associated dual form of “minimizing target variable Y”. In linear programming, both forms are known to be mathematically equivalent. In management practice, this equivalence might not exist as management is not a static process such as linear programming, but a dynamic process with learning effects. In such a dynamic process, the spectrum of possible primal solutions opened by “maximizing a target variable X” might effectively be much larger than the spectrum of possible dual solutions opened by “minimizing a target variable Y”.

The purpose of outlining the ToC here is to show that it can in principle offer a guideline to elaborating a roadmap for sustainable development and implementing SDG targets.

2.3. Integrating Sustainability into Urban Planning

2.3.1. Basic Ideas for Integrating Sustainability

The sustainability discussion came onto the political agenda during the 1980s. In 1983 the UN General Assembly created the Brundtland Commission with the aim to investigate how the destruction of natural resources could be stopped. This commission released its report called Brundtland Report in 1987. It introduced the concept of sustainable development, defined at that time as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The report also called for action on sustainable development to carry out its recommendations. This led to the Rio Summit held in Rio de Janeiro in 1992[179].

The Rio summit rose awareness in many parts of the world that cities should become more sustainable. *APSEC (2018)* shows how the landscape of global organizations and networks of cities has changed during and after the Rio summit.

The Rio summit has also had some effect on theories and practices of urban planning. The New Urbanism movement was founded in 1993[180]. It focuses on key principles such as walkability, green transportation, connectivity, mixed use and diversity, increased density, and maintaining traditional neighbourhood structure. For making cities walkable, the key concept of Euclidean zoning, namely the minimum distance separating two different zones, is being substituted by the concept of minimum (walking) distance between two points. While the different functions of the territory (e.g. housing, office, commercial, industrial, educational, recreational, parking, etc.) are being maintained, the walkability concept requires the sprawl to be disentangled in order to abandon the urban monoculture for a more diversified pattern of urban landscaping.

Abandoning the urban monoculture and creating more diversified urban landscaping can be achieved by vertical diversification. This consists of allocating different functions to different floors of a building. In smaller and medium-sized cities where buildings may be between five to ten floors high, diversified urban landscaping is done by attributing a commercial function to the ground floors while residential function may be left for the upper part of the buildings. In large metropolises that are common in the APEC region, this pattern is further adapted. The *APSEC (2018)*[181] found that APEC was the region of the world where more than 90% of the supertall buildings (>300m height) that are being constructed, planned or envisioned worldwide are located. APEC cities, therefore, are places of high density. In this environment, diversification is increased by more sophisticated forms of vertical stratification, whereby different floors perform different functions.

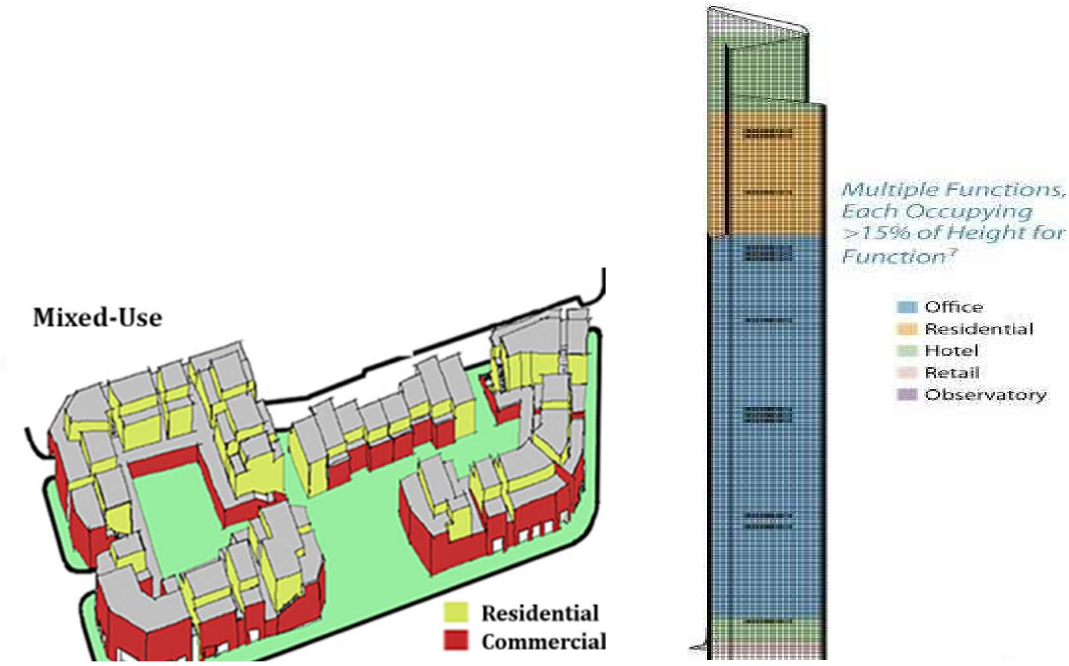


Figure 77: Vertical diversification in small and large cities

Sources: CNU California[182] and CTBUH[183]

Progressing towards a more sustainable urban design not only impacts the buildings and their use, but also the design of neighbourhoods and their relationship to the surrounding avenues and streets. Designing walkable neighbourhoods means giving greater weight to the human scale and respecting specific walking capabilities of humans. The factors determining walkability are the size of building blocks and the width of streets, as has been introduced in section 2.2.1. and will be further developed in section 2.3.5.

A further trend of urban sustainability planning is the increased use of targets and indicators. Indicators and targets have been widely used also in other APEC economies. In China, in the 1980s, it was a requirement for each home to have one full hour of sunshine every day[184]. This requirement, if implemented for the day of lowest solar angle on 21 December and a given geographic location (e.g. Beijing, 27°45), determined the distance-height relationship of buildings of a settlement (e.g. 14m/26.95m). These values can then be neatly integrated into the corresponding land use (e.g. number of floors, building footprint, total floor area, gross apartment area per household, people per apartment, residential density, and floor area ratio).

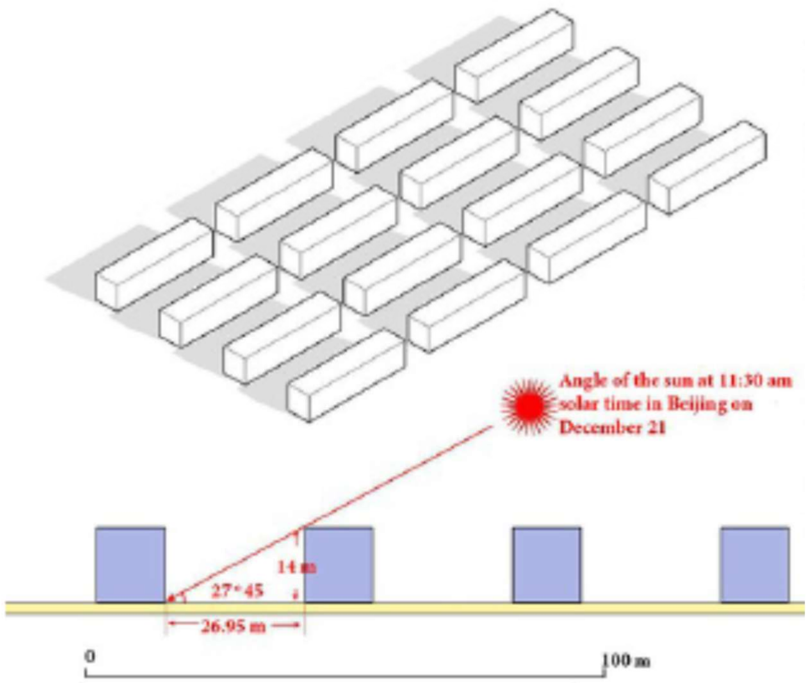


Figure 78: One-hour per day sunshine requirement in China

Source: Alain Bertaud: Order Without Design, 2018

Targets can easily be used in urban planning. In general, planning targets are set by a political authority (e.g. urban targets) or by private enterprises (e.g. management goals). In the former case targets are collective goals and apply to cities, regions, economies or to the global level (e.g. the SDGs), whereas managerial goals apply only to an enterprise. In both cases, targets are decisions. This is sometimes used to discredit targets as "non-scientific". Decisions or targets can, however, be sound if they are the logical consequence of empirical studies. The exact meaning of this will be analysed hereafter using four examples, namely: setting the speed limit in a city street to 50km/h, maintaining the mean annual concentration of PM2.5 in the air at any one point of a city below 10µg/m³, having one hour of sunshine per day in any apartment, or fixing the building block size in a city between 1 and 2ha.

- Average speed enforcement has become popular to limit street accidents[185]. Average speed enforcement is usually being implemented through maximum speed limits and their effective enforcement. This has resulted in reducing maximum speed in cities or urban agglomerations. Maximum speed limits in cities have been the outcome of considerable empirical measurement analysing the reactivity of the driver and the pedestrian as well as vulnerability of pedestrian. Both factors reflect physiological characteristics of humans.

- The progressive lowering of the target of annual mean concentration of air pollutants is based on a vast number of empirical studies, such as the WHO survey released in 2016 estimating that 92% of the world population lives in areas where PM2.5 concentration exceeds WHO annual mean levels of 10µg/m³ [186]. This study represents the most detailed outdoor (or ambient) air pollution related health data, by economy, ever reported by the WHO. The model is based on data derived from satellite measurements, air transport models and ground station monitors at more than 3000 locations, both urban and rural.

- The case of 1-hour sunshine per day for each apartment might be a little more difficult to justify. The WHO suggests[187] that a 5 to 15 minutes exposure to direct sunshine several times a week will suffice to produce the daily requirement of vitamin D[188]. Glass retains UV light and hence sunshine behind closed windows does not have this effect. Without sunshine exposure, the daily vitamin D requirement can be supplied by exposure to artificial UVB light or by taking specific food such as oily fish, eggs, some types of mushrooms, or to a lesser extent milk, butter, cheese, cereals. Still, most vitamin D deficit is due to a lack of sun exposure which causes far more disease than sun overexposure[189]. Overexposure causes sickness mostly in Caucasian skin types and much less in other skin types. Exposure to sunshine also increases serotonin production which helps strengthening mood and diminishing seasonal depression[190]. Considering these relationships, the 1-hour daily sunshine requirement of apartments seems to be motivated by psychological factors or by a desired contribution of the sun to indoor heating, or by reasons of equity or inclusiveness rather than by physiological reasons.

- Fixing the block size of cities between 1 and 2ha is an instrument for improving walkability, i.e. the possibility to attain urban facilities within few minutes walking. Common sense tells that walkability requires smaller building blocks. For grid-based cities this relationship can be easily shown[191]. Where blocks become too small, however, the number of streets to be crossed becomes an impediment to walkability[192]. This impediment can be corrected by creating a pedestrian zone in areas with small block size, like in historic town centres which are highly walkable. The problem is that walkable cities must also be somehow accessible for cars. This requires a mix of small and large blocks and streets. Melbourne in Australia is an example of such a mix[193]. This mix shows that the 1ha to 2ha block size is a requirement for a neighbourhood rather than a city. Moreover, walkability is an instrument for inclusiveness (leaving no one behind). Besides walkability, inclusiveness may also include other criteria such as being wheelchair friendly, i.e. addressing specifically vulnerable groups.

Another use of targets is given in the example of South California integrated transport planning. Planning of transport infrastructure has been done and implemented at the level of a region composed of several towns.

In 2008, California enacted the landmark Sustainable Communities and Climate Protection Law (Senate Bill 375). Under this legislation, the three regions of Southern California, San Diego and Sacramento have become America's first three regions to adopt transportation plans specifically designed to reduce their greenhouse gas emissions[194]. Each one of the three regions created a long-range transportation and land use plan to reduce greenhouse gas emissions[195]. Besides improving transit and de-congesting roads, the measures delivered important co-benefits, such as saving residents and local governments money, and encouraging the creation of communities that can improve public health. The plan also monitored the job-to-household ratio of each region in view of each region approaching by 2035 the 1.2 jobs-to-households ratio defined as ideal.

TABLE 1. JOB HOUSING BALANCE IN FOUR-MILE RADIUS OF MAJOR EMPLOYMENT CENTERS

COUNTY	EMPLOYMENT CENTER	JOB-HOUSING BALANCE	
		2008	2035
El Dorado	Latrobe Business Park	0.98	1.14
Placer	Roseville-Douglas Corridor	0.98	1.12
Placer	Sunset Industrial Area	0.98	1.17
Sacramento	Downton Sacramento	2.25	2.00
Sacramento	East Sac/UC Davis Medical Center	1.92	1.72
Sacramento	Power Inn/Florin-Perkins	1.34	1.18
Sacramento	Rancho Cordova	1.52	1.44
Sacramento	Folsom	1.38	1.41
Sacramento	Elk Grove/Laguna Springs	0.61	0.75
Sacramento	Expo-Arden-Point West Area	1.80	1.68
Sacramento	Northgate/North Market Area	1.14	1.22
Sutter	Yuba City/Hwy 20	1.08	1.10
Yolo	UC Davis	1.31	1.30
Yolo	West Sacramento/Harbor/Industrial Area	2.16	1.87
Yolo	NE Woodland Industrial Area	1.47	1.44
Yuba	Downtown Marysville	1.09	1.11

All of the SACOG region's major employment centers are projected to move towards the ideal 1.2 jobs-to-household ratio between 2008 and 2035. Jobs to household ratio is a common metric employed by planners to determine whether the region is providing an appropriate balance of employment and housing opportunities. Past plans have only examined job-housing balance at a regional scale. For the first time with this plan, SACOG examined this indicator within the 4-mile radius of its 15 major employment centers, aiming to reduce commuting distances and improve convenience.

Figure 79: Planned job-to-household ratio in south Californian regions

Source: NDRC Report R:12-09 A[196]

Cities designed from the outset to be smart and sustainable may have a still higher zoning diversification which includes several other design elements such as renewable energy, sustainable food production, and integrated water management. The masterplan of a modern sustainable and smart city may have some striking similarities with the design of the agricultural city proposed by von Thünen in the 19th century (see section 2.2.2.), but with much higher complexity and technology.

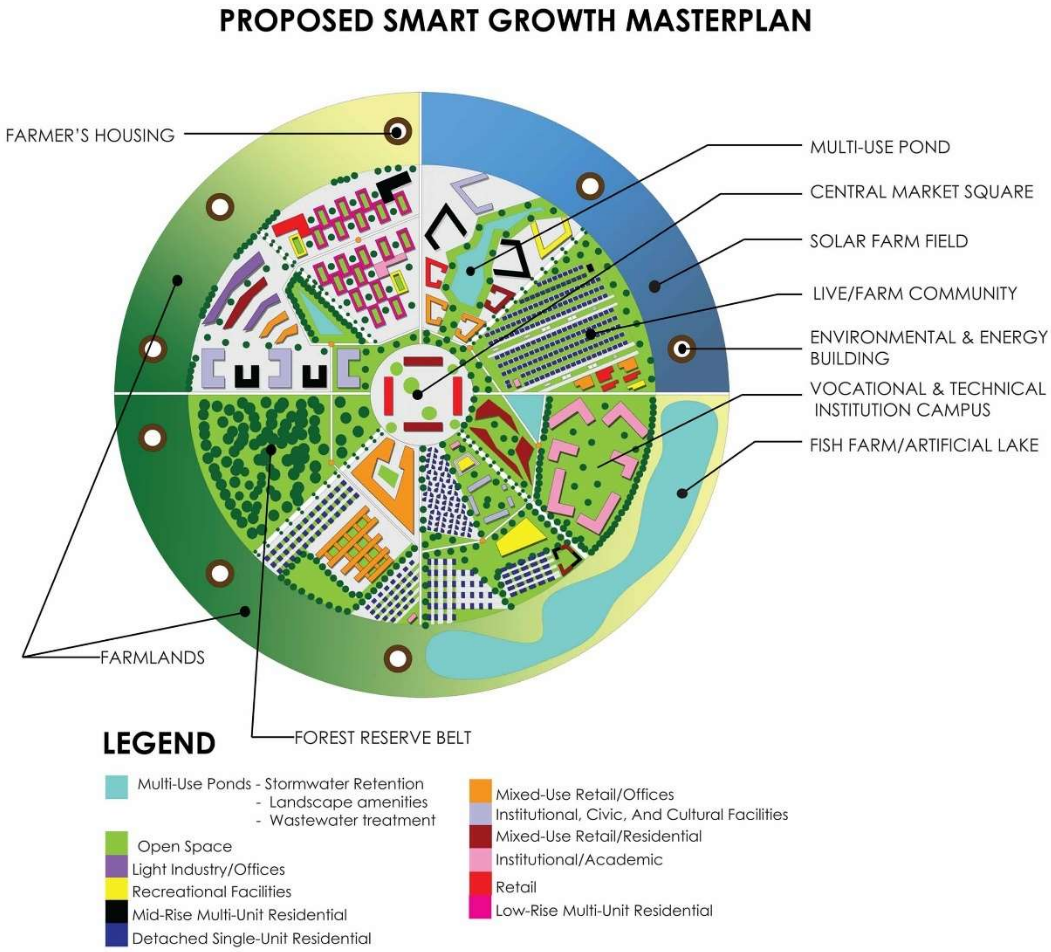


Figure 80: Masterplan of a smart city

Source: Rachel Watsky[197]

2.3.2. Integrating the Sustainable Development Goals (SDGs)

The major shift in moving from sectoral urban planning towards sustainability and disaster resilience oriented integrated planning comes from integrating the different planning aspects as described above (land panning, infrastructure planning, emergency planning, fiscal planning) into a coherent framework called Integrated Urban Planning. It is only by integrating these – and other aspects as described further down – into urban planning that urban planning can make the cities sustainable and disaster resilient. The global political framework for sustainability is made of the Sustainable Development Goals (SDG) that are part of the *2030 Agenda for Sustainable Development*[198], and two other important political documents, namely the *UN Sendai Framework for Disaster Risk Reduction*[199] and the *Paris Climate Agreement*[200]. For cities, the *New Urban Agenda*[201] adopted at Habitat III Conference in Quito in 2016 is also part of these basic international political frameworks.

Sustainable Development Goals (SDG) were adopted by the UN General Assembly in September 2015 as part of the *2030 Agenda for Sustainable Development*. *APSEC (2018)* describes the process and the importance of the SDGs and the other related global frameworks.

The 17 Sustainable Development Goals and their 169 targets have been adopted September 2015 by the UN General Assembly. In July 2017, the UN General Assembly completed the task by adopting the framework of Sustainable Development Goal Indicators[202]. The total number of SDG indicators is 244, of which 12 appear more than once, so that the net number of indicators is 232[203]. Subsequent annual updates have adapted some of the indicators. The 2020 update provides for 247 indicators altogether of which 231 are unique[204].

Compared to the preceding Millennium Development Goals adopted in 2000 and the three pillars put forward at the Rio Earth Summit in 1992, the Sustainable Development Goals represent a remarkable progress:

- They have a universally broad thematic coverage addressing all development levels, including developing economies, emerging economies as well as developed economies alike. The coverage includes issues such as poverty, health, education, gender, water, energy, economy, cities, climate.

- They are goal-driven rather than rule-driven. This has allowed SDGs to enter a global context without entering conflict with the already existing large stock of global rules such as those of the WTO agreements[205], the hundreds of Regional Trade Agreements[206] based thereupon, and the more than 2000 Bilateral Investment Treaties and Treaties with Investment Provisions[207]. Continuing the rule-driven character would have been extremely burdensome if not impossible. This goal-driven character of the SDGs is nothing less than a paradigm change of global cooperation. It is for the highest interest for target-based urban planning.

- The SDGs are voluntary goals and targets, not mandatory ones. Hence the use of public information and tracking or monitoring of goals and targets is the instrument of choice guiding their implementation.

- Their formulation strongly involved civil society, a process that was modelled upon the broad stakeholder involvement used in the Rio Earth Summit and its follow-up summits. Nonetheless, the SDG process is a new process that started in 2012, just before the Rio+20 summit.

- They are semi-long term, using 15 years (i.e. half a human generation) planning horizon until 2030, allowing for enough time to make some significant changes, but not too far to become irrelevant for present-day policy makers. 2030 is also an important milestone of documents closely related to the SDGs such as the *Sendai Framework for Disaster Risk Reduction 2015 - 2030*[208] and the *Paris Climate Agreement* adopted in December 2015[209].

Application of SDGs at the local level has been discussed in 2016 in Quito, Ecuador, during the global Habitat III conference. This Conference, the third in a 20-year cycle following Habitat I (Vancouver, 1976) and Habitat II (Istanbul, 1996), produced the New Urban Agenda NUA which was endorsed by the UN General Assembly in December 2016[210]. It may be worthwhile to recall the three interlinked key principles in Article 14 of the NUA:

- Leave no one behind by ending poverty in all its forms and dimensions, including the eradication of extreme poverty […]

- Ensure sustainable and inclusive urban economies by leveraging agglomeration benefits of well-planned urbanization, including high productivity, competitiveness and innovation […]
- Ensure environmental sustainability by promoting clean energy and sustainable use of land and resources in urban development […]

For urban planning, the SDGs are of high interest as one of the Sustainable Development Goals specifically addresses cities: SDG 11 (sustainable cities and communities) focuses on sustainable cities and communities. Each SDG contains substantive targets (identified only by numbers, e.g. 11.1.) and instrumental targets (identified by a number and a letter, e.g. 11.a.). SDG 11 targets and indicators are given below. This distinction appears for targets (left column below) as well as indicators (right column), but it has not been made explicit in the UN documents. Below, see the quote from SDG 11:

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable

11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums	11.1.1 Proportion of urban population living in slums, informal settlements or inadequate housing
11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons	11.2.1 Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities
11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries	11.3.1 Ratio of land consumption rate to population growth rate 11.3.2 Proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and democratically
11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage	11.4.1 Total per capita expenditure on the preservation, protection and conservation of all cultural and natural heritage, by source of funding (public, private), type of heritage (cultural, natural) and level of government (national, regional, and local/municipal)
11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations	11.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population 11.5.2 Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters
11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	11.6.1 Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated, by cities 11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)
11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities	11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities 11.7.2 Proportion of persons victim of physical or sexual harassment, by sex, age, disability status and place of occurrence, in the previous 12 months

11.a Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning	11.a.1 Number of countries that have national urban policies or regional development plans that (a) respond to population dynamics; (b) ensure balanced territorial development; and (c) increase local fiscal space
11.b By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the *Sendai Framework for Disaster Risk Reduction 2015–2030*, holistic disaster risk management at all levels	11.b.1 Number of countries that adopt and implement national disaster risk reduction strategies in line with the *Sendai Framework for Disaster Risk Reduction 2015–2030* 11.b.2 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies
11.c Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials	*No suitable replacement indicator was proposed. The global statistical community is encouraged to work to develop an indicator that could be proposed for the 2025 comprehensive review. See E/CN.3/2020/2, paragraph 23.*

In short, SDG 11 lists the following substantive core tasks of local communities:

- Adequate, safe and affordable housing and upgrading slums
- Sustainable transport systems with access for all vulnerable persons
- Integrated urban planning with stakeholder participation
- Protect cultural and natural heritage
- Diminish human and economic losses caused by disasters
- Treat municipal solid waste and diminish particle emissions into the air
- Build safe, inclusive, accessible and green public spaces that are harassment-free

Instruments for attaining these goals are:

- Integrate population and resource needs into urban planning
- National disaster risk reduction (DRR) strategies in line with the *Sendai Framework*
- Local disaster risk reduction strategy in line with the national DRR strategy
- Financial support for retrofitting buildings to make them sustainable, resilient and resource-efficient using local materials

The novelties of SDG11 as compared to some conventional planning philosophies:

- Stakeholder participation in planning
- Integrate all sectoral plans or dimensions to form integrated urban planning
- Integrate all levels to become multi-level or multi-scale planning

In other words, integrated urban planning requires considering the other SDGs besides SDG 11. The meaning of this will be illustrated in the following sections.

The important merits of the SDGs are to be the first time in history that leaders at global level define sustainable development by a set of measurable indicators covering practically the whole range of development for the 15 years following adoption by the UN General Assembly. This is without any doubt a step change and big leap forward towards holistic analysis of development.

2.3.3. New Thematic Clusters of Urban Planning

Above it has been shown how targets can be integrated into urban planning. As the SDGs contain specific targets and indices, the question is how these can be used in integrated planning comprising all government levels. A big challenge for integrated planners is to coordinate the different levels of government – local, regional, economy-wide – and the numerous goals – poverty, health, education, gender, water, energy, economy, cities, climate, etc – among each other to create a harmonious, holistic development path, without losing focus and coherence. A simple tool for starting to work with SDGs is to use some sort of representation or conceptualization of the SDGs allowing to grasp their scope.

One of the first unfortunate steps towards making the conceptualization of sustainable development is to stop using the very popular Venn diagram showing three pillars of sustainable development in form of three circles representing the economy, the society and the environment, with intersections between each of these circles. This Venn diagram has appeared around the period of the Rio Earth Summit 1992 and has, unfortunately, given rise to important misunderstandings and misinterpretations about sustainable development (see below). From this diagram, the reader could wrongly understand that there are economic activities that are not social, i.e. outside the social sphere, and that there are social activities that are not taking place within the ecological sphere. This kind of misunderstanding is awfully wrong and should be corrected.

Instead, this diagram should be replaced by a diagram of concentric circles, with the innermost circle being the economy, as all economic activity is also social, and the outermost circle being environment or ecology, as any social activity is taking place within the overarching ecological sphere (see below). To this diagram, a fourth sphere, governance, should be added in the centre, indicating that governance is in fact a specialized part of the economy.

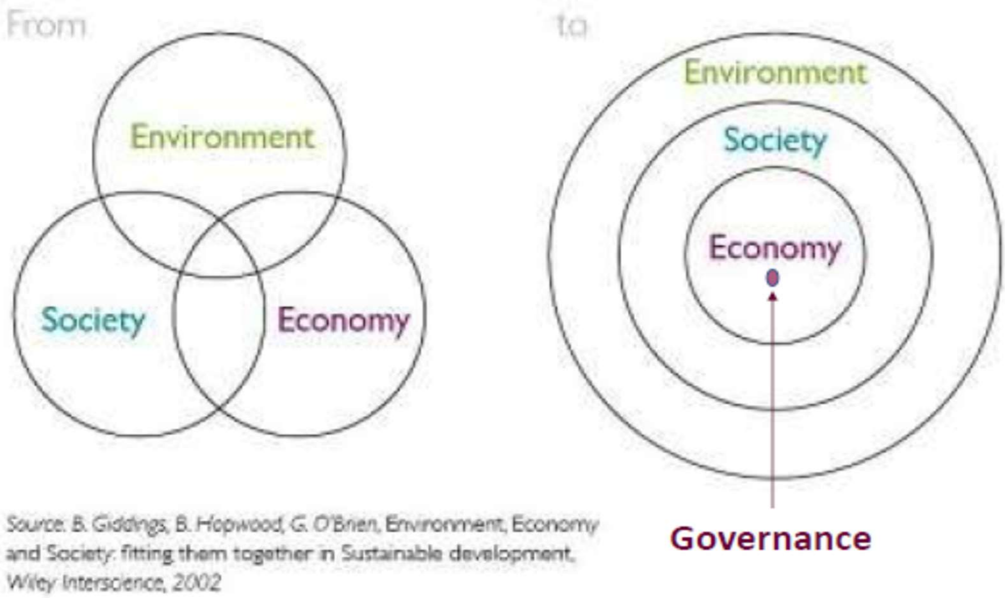


Figure 81: Representation shift of sustainable development

Source: APSEC based upon Giddings, Hopwood, O'Brien (2002)[211]

The new, right-hand diagram is an improvement over the left-hand one as it does not give rise to the false interpretation stated earlier. Yet even the concentric diagram should be interpreted with some caution. In fact, the delimitations between environment and society, as well as between society and economy and between economy and governance, are not precise. Rather, these delimitations are of a fuzzy nature. The point is, that some infrastructures described further above are of socio-ecological nature (e.g. those related to water and to wastewater). Furthermore, a large part of human activity is of socio-economic nature (e.g. the analysis of poverty, income disparity, health or educational policies). Governance uses economic instruments but may also its own specific instruments. It is, therefore, useless to try and find exactness among the definitions of environment, society and economy and governance. Each of these spheres can be characterized as having a specific medium of interaction among its elements. This is shown in the following figure.

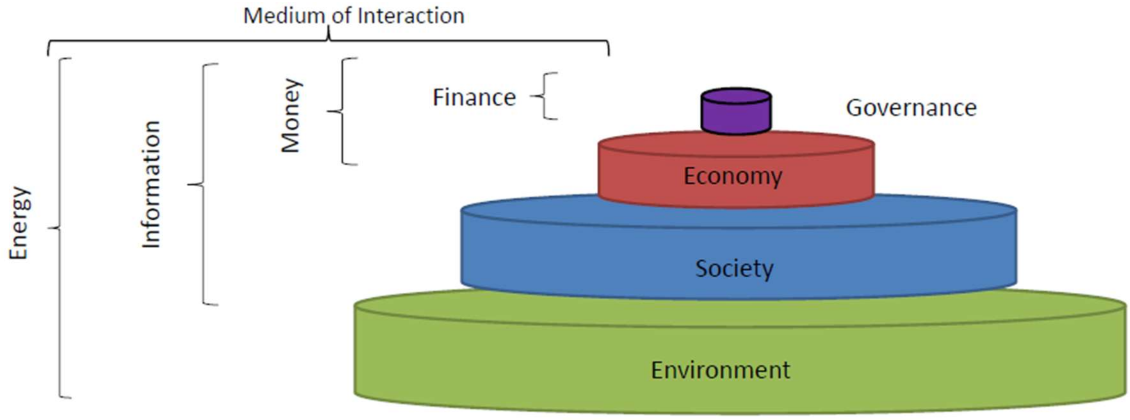


Figure 82: Medium of interaction characterizing each sphere

Source: APSEC

Within the outermost sphere – the physical or natural environment – all interactions are based upon energy. There is no physical interaction without energy. Energetic interaction can take two forms, either material interaction (exchange of particles or bigger pieces of matter) or radiative interaction (exchange of electromagnetic or other massless types of energy). Hence material or radiative exchanges are always present in the physical or natural environment. As all spheres are included in the physical sphere, energetic interaction is ubiquitous.

Interaction within the society, the second circle, is usually characterized by exchange of information. Even though exchange of information (e.g. when we talk, phone, write messages) also uses energy, this energy is very small and usually without interest, as the focus in the second circle lies on the message. Information can be based on human language or on other cultural vectors (signs, symbols). Culture, being the sum of all types of information exchanges among members of a society, is a characteristic of human society. In this understanding, adding culture as the fourth pillar of sustainable development[212] does not add anything to the social sphere as culture is already included in the social sphere. Culture includes all the skills, all the formal and informal knowledge and all collective memory. Strictly speaking, the members of a human society can interact by both, information (or cultural) and by non-cultural (i.e. purely energetic) exchanges. The information-based exchange is called civilization, whereas the exchange without information can be called lack of culture. A society from which culture has been removed is a society reduced to purely energetic interactions, i.e. purely physical, biological or physiological interactions, as they happen during violent conflicts.

Within the economic sphere, the characteristic medium of interaction is money. Money is nothing but a special kind of quantitative information that is conventionally exchanged in economic transactions whereby one agent (e.g. a buyer of a product) deducts a specific amount of money from his account and transfers it to the account of a seller. Accounts are information storages or memories. While money is the characteristic medium of interaction within the economic sphere, interaction of other information plays an important role in markets and hence in the economy. Efficient markets require information symmetry between buyer and seller[213]. In sum, the economic sphere may use all three types of interactions, namely money, information and energy. On energy markets energy is being exchanged in civilized manner among members of the society.

The fourth sphere of sustainable development is governance. The characteristic medium of exchange in this sphere is finance. Finance is nothing but a special type of money that is transferred without sale of goods or services, but against trust. An agent becomes debtor (case of a loan) if he is trustworthy and agrees to be governed by rules (namely pay interests and reimburse the principal). An agent becomes equity holder (case of equity) if he manages to convince the market that he will behave in an economically sound manner. Given that governance is the innermost sphere, this means that governance uses all four media of interaction: Governance uses loans (as just described). Governance uses sale of goods or services (by setting market rules, including rules for raising taxes). Governance uses information (by publishing legislation and informing the citizens), and, finally, governance uses energy or physical power for enforcing the laws and regulations.

The 17 SDGs can now be represented in a format that is compatible with the above concentric circles. Many authors have, indeed arranged the 17 SDGs into the three spheres economy, society and environment. Yet without using concentric circles, it is practically impossible to arrive at a generally acceptable result. Two totally different examples are given below to illustrate the level of possible disagreement.

Paoli & Addeo state that those SDGs with social direct impacts were aggregated into the social pillar, those with economic direct impacts and goals were aggregated into the economic pillar, those with ecological direct impacts and goals were aggregated into the environmental pillar.

Figure 83: SDGs in the three-pillar approach

Source: Paoli & Addeo[214]

Unfortunately, the authors fail to explain why SDG 6 (clean water and sanitation) and SDG 14 (life below water) do not figure in any of these three pillars. Another example is given by Kostoska & Kocarev who simply cluster the SDGs into the different pillars without using concentric cercles.

Figure 84: SDGs clustered into the three pillars

Source: Kostoska & Kocarev[215]

A more convincing pattern, taking account of concentric spheres, has been proposed by Rockström & Sukhdev from the Stockholm Resilience Centre.

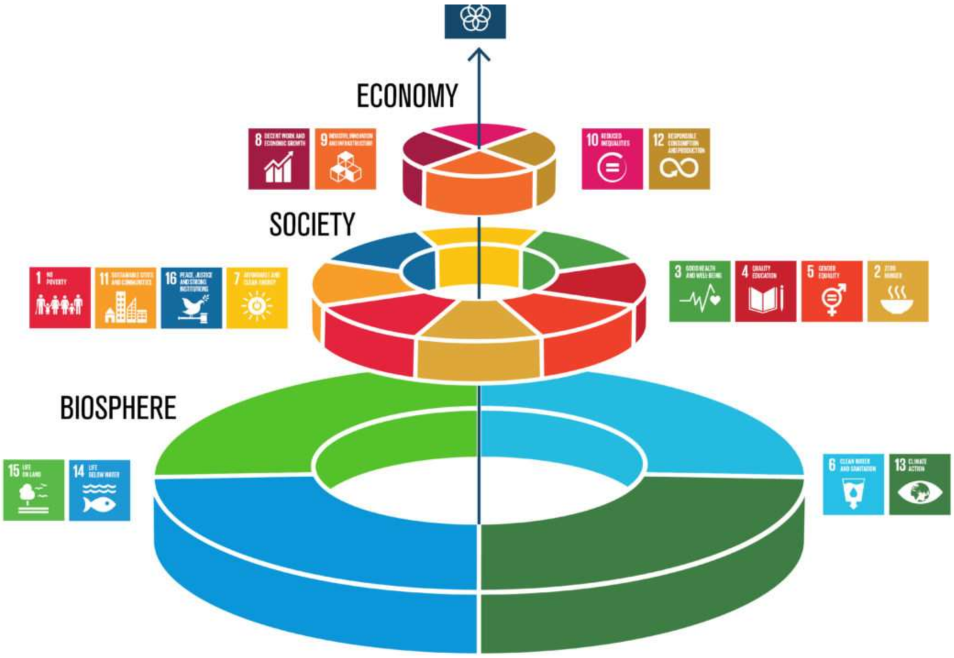


Figure 85: Attribution of SDGs to the three concentric spheres of sustainable development

Source: Rockström & Sukhdev[216]

This figure gives to a large extent a meaningful representation of the SDGs in terms of the four concentric sustainability spheres. This diagram is interpreted as follows:

All SDGs are part of the environmental domain in the large sense. The environmental domain includes, besides the biosphere, also the hydrosphere, atmosphere and the lithosphere. No SDG addresses the lithosphere specifically. The reason for this might be that the lithosphere is not perceived to be threatened in any manner. Atmosphere, hydrosphere and biosphere are being addressed in SDG 13 (climate action), SDG 14 (life below water) and SDG 15 (life on land), respectively. Considering all SDGs as being part of the environment has important analytical implications as it will allow addressing all SDG-relevant developments in a single theoretical framework as show further down.

As already remarked above in relation to the concentric circles, the domains in the above figure should also be understood to be fuzzy. The above figure shows SDG 6 (clean water and sanitation) as part of the biosphere. Indeed, it is hybrid between the biosphere and the social sphere. As 97% of global water is saltwater[217] and 3% is freshwater, and as SDG 6 addresses primarily freshwater and sanitation for which specific infrastructures exist that have been described further above, SDG 6 is a hybrid in the socio-ecological sphere[218].

Besides the just mentioned SDGs, all the remaining SDGs are part of the social domain in the larger sense of this term. This fact plays an important role in modelling the developments that are relevant to sustainability and disaster resilience. The importance of social forces, social and cultural trends, and social groups in shaping sustainability and resilience of societies should never be underestimated. In this analysis, the genuinely social SDGs are SDG 1 (no poverty), SDG 2 (zero hunger), SDG 3 (good health and well-being), SDG 4 (quality education), SDG 5 (gender equality), SDG 7 (affordable and clean energy), SDG 11 (sustainable cities and communities) and SDG 16 (peace, justice and strong institutions).

Within the thus defined social sphere, those SDGs addressing particularly the economic domain are SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 10 (reduced inequalities), SDG 12 (responsible consumption and production), and SDG 17 (partnerships for the goals). As mentioned, the characteristic interaction within the economic sphere takes place by using money. As money circulates through the entire economy and does not disappear in economic exchanges of goods and services, money can be considered as a kind of blood of the society. In specific circumstances, money has also the property to accelerate some processes. In this sense it can be called a catalyst of social processes. In chemistry, catalysts have the function to increase the speed of the chemical reaction in which they participate. Catalysts are inputs that are conserved in a reaction and hence are also outputs. In biological systems, catalysts are called enzymes and are used in practically every cell to regulate the speed of specific biochemical reactions.

Finally, it is important to realize the special role of SDG 17 within the economic sphere. SDG 17, which in full reads *Strengthen the means of implementation and revitalize the global partnership for sustainable development*, is different from the sixteen other SDGs in the sense that it describes the instruments or governing system to attain the other SDGs. It contains indicators about finance (e.g. development aid), technology (e.g. internet connections), capacity-building, trade, and systemic issues (e.g. policy coherence, multi-stakeholder partnerships, data, monitoring and accountability) used by governments to attain SDGs.

The representation of all the SDGs in concentric sets is shown in the figure below. The blue water wave separates the two water-related goals from the others.

Figure 86: SDGs in their relevant ecological, social, economic and governance spheres

Source: APSEC

In the above representation, the four spheres (environment, social, economy, governance) are represented in different grey shadings. Together with the given explanations, it is possible to identify several thematic clusters of SDGs. These will be illustrated hereafter.

A first thematic cluster is the food security and biodiversity cluster. This cluster is mentioned here at the first place as it focuses on the outermost sphere which contains the purely ecological SDGs, namely SDGs 14 (life below water) and SDG 15 (life on land) which determine biodiversity and long-term food security. Long-term food security is also determined by the low-end of the food supply chain in SDG 2 (zero hunger) and the high-end of the food supply chain in SDG 12 (responsible consumption and production). The governance in SDG 17 (partnerships for the goals) is included per definition in each thematic cluster described below. The reason is that SDG17 contains instruments to attain the targets. Without instruments, the targets would not be attained. Therefore, it makes sense to include the “toolbox” in each cluster described below.

The cluster of food security and biodiversity is also mentioned at the first place here to underline that long-term food security is essentially determined outside cities. Integrated urban planning can only contribute to marginal aspects of food security, e.g. to short term food security by measures such as precautionary stockholding and by regulating food distribution at times of food crisis. The only contribution cities can make towards long-term food security is by promoting research on maintenance of biodiversity in the food chain. Note, however, that the implementation of the results of such research relies again on the rural communities.

Figure 87: Food security and biodiversity cluster

Source: APSEC

The relationship between biodiversity and long-term food security can be shown by three examples, all three having their origin in the APEC region.

Bananas originally come from Southeast Asia from where they have been introduced to many other areas around the globe. As they are cloned fruit, they show higher disease susceptibility than usual fruit[219]. The current Cavendish type of banana is therefore said to disappear in the coming decades.

The future of chocolate depends on the availability of cocoa beans. These originate from the Andean South America and developed during the Maya and Aztec civilizations in today’s Mexico. The future of cocoa beans also depends on limiting the threat to their biodiversity[220].

Potatoes originally come from Peru. They are threatened by loss of biodiversity at a time when the resilience of the dominating varieties to climate change diminishes[221].

A second thematic cluster is the green urban economy. It comprises the themes of climate mitigation and climate adaptation (including resilience against climate-related disasters). It contains all activities that can be addressed by means of urban technical infrastructures, including waste treatment, material footprint reduction, renewable energy, and connecting the households to basic services. These can be identified among SDG 1 (no poverty), SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), 11 (sustainable cities and communities), SDG 12 (responsible consumption and production), SDG 13 (climate action) and SDG 17 (partnerships for the goals).

Figure 88: Green urban economy cluster

Source: APSEC

Three of this cluster's SDGs share three identical SDG indicators among themselves:

- 1.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population, which is identical with 11.5.1. and 13.1.1.
- 1.5.3 Number of economies that adopt and implement national disaster risk reduction strategies in line with the *Sendai Framework for Disaster Risk Reduction 2015–2030*, which is identical with 11.b.1. and 13.1.2.
- 1.5.4 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies, which is identical with 11.b.2. and 13.1.3.

Three further SDGs of this cluster share two identical indicators among themselves:

- 8.4.1 Material footprint, material footprint per capita, and material footprint per GDP, which is identical with 12.2.1.
- 8.4.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP, which is identical with 12.2.2.
- 7.b.1. Installed renewable energy-generating capacity in developing economies (in watts per capita), added in the 2020 update, is identical with 12.a.1. also added in 2020.

Note that SDG 12 (responsible consumption and production) is part of both, the food and biodiversity as well as of the green urban economy cluster as it contains indicators on food waste as well as on other types of waste.

The green urban economy as defined above includes two sub-clusters. One of them is on climate adaptation and reduction of disaster risk of climatic origin. It can be identified among SDG 1 (no poverty), SDG 9 (industry, innovation and infrastructure), SDG 11 (sustainable cities and communities, industry, innovation and infrastructure), SDG 13 (climate action), and SDG 17 (partnerships for the goals).

Figure 89. Sub-cluster on climate adaptation and disaster risk reduction

Source: APSEC

A second sub-cluster included in the green urban economy is the one on technical urban infrastructures such as transport, energy, water and waste. It can be identified among SDG 1 (no poverty), SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), SDG 9 (industry, innovation and infrastructure), SDG 11 (sustainable cities and communities), SDG 12 (responsible consumption and production), and SDG 17 (partnerships for the goals).

Figure 90: Sub-cluster on technical urban infrastructure

Source: APSEC

A third cluster is the social inclusion cluster. It comprises SDGs that are related to non-discrimination (poverty, gender, economic and before the law) and to social infrastructure (schools, hospitals, law courts, IT). It can be identified among SDG 1 (no poverty), SDG 3 (good health and well-being), SDG 4 (quality education), SDG 5 (gender equality), SDG 10 (reduced inequalities), SDG 16 (peace, justice and strong institutions) and SDG 17 (partnerships for the goals).

Figure 91: Social inclusion cluster

Source: APSEC

Note that SDG 1 (no poverty) is part of both, the green urban economy as well as the social inclusion cluster as fighting poverty is simultaneously an infrastructure as well as a social inclusion issue.

Two of this cluster's SDGs share two identical indicators among themselves:

- 10.3.1 Proportion of population reporting having personally felt discriminated against or harassed in the previous 12 months on the basis of a ground of discrimination prohibited under international human rights law, which is identical with 16.b.1
- 10.6.1 Proportion of members and voting rights of developing economies in international organizations, which is identical with 16.8.1.

The social inclusion cluster has one sub-cluster on social infrastructures. It can be identified in SDG 3 (good health and well-being), SDG 4 (quality education), SDG 16 (peace, justice and strong institutions) and SDG 17 (partnerships for the goals).

Figure 92: Sub-cluster on social infrastructures

Source: APSEC

The important merit of the SDGs is to be the first time in history that leaders at global level define sustainable development by a set of measurable indicators covering practically the whole range of development for the 15 years following adoption by the UN General Assembly. This is without any doubt a step change and big leap forward towards holistic analysis of development.

This is the place to make an important remark on a system theoretical interpretation of the SDGs. Everyday experience teaches that for any one goal to be attained, one needs at least one separate instrument for each dimension. Take a car as an example. A car driving on a two-dimensional street grid needs at least two instruments to attain a target destination: an accelerator and a steering wheel. With less than two instruments it becomes a question of luck if a car managed to attain a fixed target destination. To allow fine tuning the ride, cars have of course many more instruments than those two. In systems theory, this principle can be derived as indirect consequence from the law of requisite variety stating that a governing system must have at least the variety of the governed system[222]. Translated to the 17 SDGs and their 169 targets measured by 231 unique indicators (after 2020 refinement), the quest for instruments is a matter of necessity. We interpret the 231 indicators as refinement of the original 169 targets (as they have officially been called), and not as instruments to attain the targets. So a priori, at least 231 separate instruments are needed to attain the 231 indicator-targets. Furthermore, some indicators require fulfilment for sub-populations, e.g. 11.2.1 Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities. Each of these adds a corresponding number of supplementary targets that require fulfilment. Therefore, the number of instruments would need to be correspondingly higher.

As mentioned above, SDG 17 can be interpreted as an instrumental goal. It contains 25 independent instruments. Furthermore, each SDG contains provisions that are being identified by letters (e.g. SDG11: 11.a.1, 11.b.1, 11.b.2, 11.c.1). Looking at their content, it is different from remaining content of that SDG. Further above, these indicators have been called instruments. Looking at the entire SDG set, it is possible to identify around 50 such indicator-instruments. The SDGs do not themselves make a rigorous distinction between indicator-targets and indicator-instruments as, e.g. indicator-instrument 11.b.1 is identical to indicator-targets 1.5.3. and 1.3.1, and indicator-instrument 16.b.1 is identical to indicator-target 10.3.1. Even when ignoring all these imprecisions it seems that of the 231 SDG indicators, only 22+50 are instruments. Considering that the remaining (231-75=156) indicators are the targets, the proportion between the 75 instruments and the 156 targets is still less than 50%.

Two alternative conclusions can be drawn: either SDGs remain silent about this issue and, therefore, leave it to the national authorities to choose themselves the instruments they deem adequate to attain the SDGs.

Alternatively, the conclusion can be drawn that the SDGs should be interpreted in conjunction with another UN document that provides the required instruments.

This report argues that for the special case of cities, another UN document exists so that the SDGs, which do not specifically target cities, can still be implemented by cities which, by combining the SDGs with this other instrument, will dispose of the necessary number of globally agreed instruments specifically designed for cities.

This other UN document is the Disaster Resilience Scorecard for Cities published by the United Nations Disaster Risk Reduction (DRR) Office[223]. It is compatible with the *Sendai*

Framework for Disaster Risk Reduction 2015 – 2030 and exists in two versions allowing for a preliminary or a detailed assessment, respectively.

A preliminary assessment level comprises 47 indicator criteria, whereas the detailed assessment level comprises 117 indicator criteria. The detailed assessment level would theoretically be able to supply the necessary number of instruments to attain the SDG indicator-targets. While the theory states that it is necessary to find more instruments to attain all SDG indicator-targets, the above simple count must not, however, be misinterpreted as a guarantee that the newly found instruments are sufficient to attain all the SDG indicator targets. The sufficiency depends on whether the instruments are adequate to attain the targets, i.e. whether there exist sufficiently strong cause-effect relationships between the instruments and the targets. The introduction of disaster resilience to integrated urban planning is further discussed in Chapter 3.

Irrespective of the merits of SDGs this might be the place to mention some deficits of SDGs.

- The SDGs could establish a substantive link to the SEEA, the UN System of Environmental-Economic Accounting adopted by the UN in 2012[224]. *APSEC (2018)* explains the relevance of SEEA for sustainable development. The SEEA is the world's leading long-term measuring system for economic and environmental flows and stocks, whereas the SDGs are an incentive program valid for the period 2015 – 2030. Both, SEEA and SDGs would profit from a substantive link between the two. SEEA would gain in learning which elements are specially monitored during the current 2015 – 2030 period, and whether they are also measured in SEEA or not. SDG would gain in improved systematic analysis which would show which parts of SEEA are excluded from the SDGs.

- An indicator that has not been included in the SDG indicators is life expectancy. Life expectancy is a key achievement of development, but it could start decreasing in some economies in the future years. These might be arguments for including it in future sustainability indicators.

- Not included in SDG indicators are the mean years of schooling and the expected years of schooling of children at school entry age. Both indicators are being used in the Human Development Index HDI[225]. They are a proxy for human capital. Human capital starts to be measured in the SEEA.

- Depletion of mineral resources is not included in the SDG indicators, but it starts already to be measured in SEEA.

- Cyber security is a rising systemic risk that is neither included in the SDG indicators, nor in the SEEA, nor is it the object of any global multilateral agreement. The growing threat of cyber criminality and cyber warfare might motivate the international community to start putting this subject onto the global sustainability and disaster resilience agenda, possibly together with other systemic risks.

- Military weapon stocks are neither included in SDG indicators nor in SEEA. Even though a good case could be made in favour of such inclusion into a genuinely holistic development approach, the chances of this happening are rather small.

2.3.4. Transit-Oriented Development (TOD)

Transit-oriented development designates a type of development that aims at developing cities and communities along stations, hubs or corridors of public transport, usually railway or subway, by opposition to the private car. TOD was originally proposed by Peter Calthorpe[226]. A Center for Transit Oriented Development (CTOD) was created in 2004[227]. Transit is the way public transport is being called in Northern America where the term public transport would not be very appealing. But basically, the two designate one and the same thing.

TOD is sometimes misunderstood as being simple development of transit infrastructures. While development of transit infrastructure is indeed the backbone of TOD, the transit infrastructure development embraces by far not the entirety of TOD substance. TOD is a more complex concept that designates a type of urban development that redesigns and restructures cities or neighbourhoods and thereby brings about an in-depth transformation. The main elements of TOD are the following[228]:

- Walkable design with pedestrian as highest priority
- The train or subway station becomes the centre of the city life
- In front of the train station there is a public square as meeting point
- The train station is the node around which amenities cluster (offices, shops, residential areas, take away food, grocery shops), which all should be reachable within 10 minutes walking time
- Besides the train or subway, other modes of transport are available at the train station (streetcars, tramways or light trains, bus services, taxis)
- Transit stations offer possibilities to park self-owned and shared bicycles and scooters for commuting. However, they may sometimes reduce car parking in their proximity (i.e. within 10 minutes walking distance) in case car parks generate too little value or are otherwise not desired.

Due to the combination of these factors, TOD is a form of regional development, city revitalization, suburban renewal and walkability at the same time. The TOD has the following effects[229]:

- Reduce congestion and to increase mobility options. Residents near transit stations are offered a variety of alternative mobility choices besides the private car. This allows them to drive substantially less than residents of car-friendly neighbourhoods.
- TOD neighbourhoods offer greater liveability. This changes the budget structure of TOD residents. In the US, the combined share for housing and transport expenses drops from 57% in a car-dependent neighbourhood to 41% in a TOD. This benefits low and middle-income households.

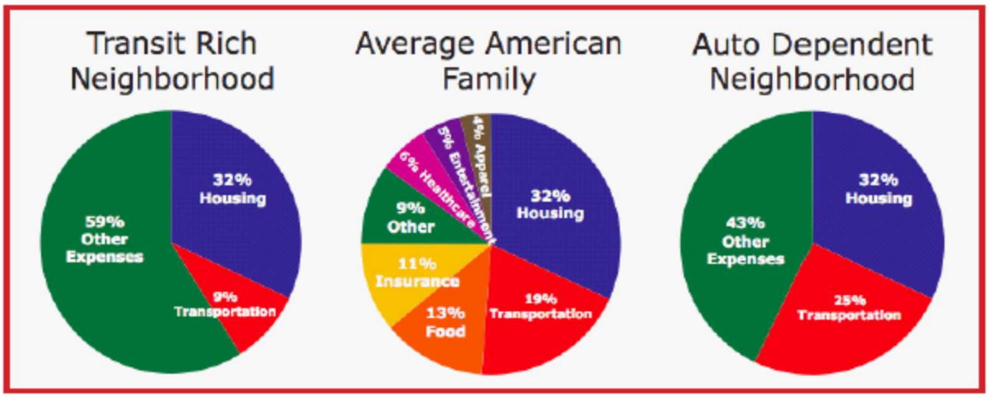


Figure 93: Expenditure comparison neighbourhoods

Source: Center for Transit-Oriented Development[230]

- TOD neighbourhoods offer increased economic activity by the possibility to link job centres with transportation. This induces not only the creation of new jobs for railway or bus maintenance, but also the creation of jobs indirectly linked to these new activities as well as service jobs located preferentially in lively city centres. Local governments can reap a green dividend from lower car maintenance cost of residents.
- TOD neighbourhoods offer improved environmental quality and health by a drop of congestion-related air pollution and by the possibility to go from two-car households to one car households with corresponding less distance travelled per year.

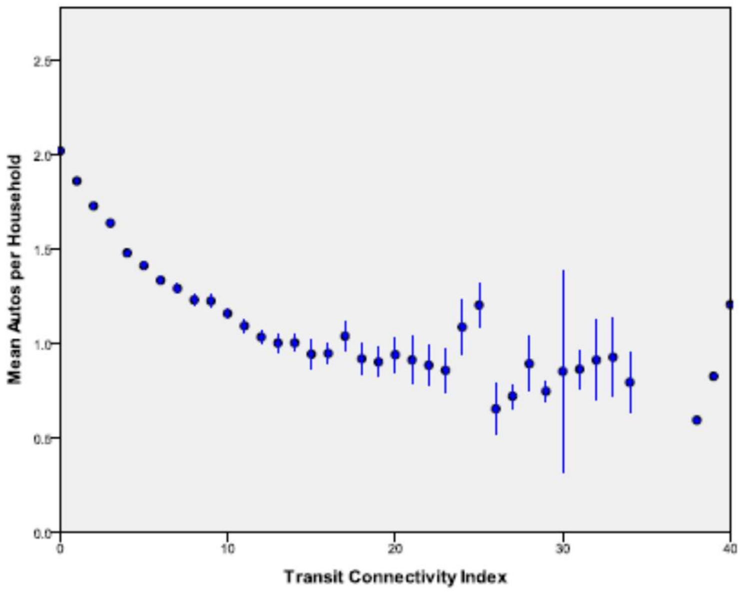


Figure 94: Car ownership vs transit connectivity

Source: Center for Transit-Oriented Development[231]

- TOD neighbourhoods offer much better land use efficiency than car-friendly cities due to higher concentration of activities. This is already the case for bus rapid transit (BRT) as compared to passenger cars, but a much higher degree so for railways.

Figure 95: Road area used by cars, cyclists and bus passengers

Source: World Bank[232]

- TOD maximize the efficiency of transportation and real estate investments by creating synergies between public and private sectors. These synergies can be used and captured to finance the extension of the TOD. Estate developers show increasing interest in investing in TOD neighbourhoods.
- TOD ensures higher utilization rates of the public transport system than non-TOD models. This in turn generates higher cost coverage rates (farebox recovery ratio) of public transport by users. In Hong Kong[233], Tokyo[234] and Singapore, where TOD has been implemented at the highest level, the transit enterprises can become financially self-sufficient.
- TOD creates more diverse neighbourhoods for age, income, household type and ethnicity. TOD can be an effective response to demographic change of ageing population and smaller households and a trend to live in downtowns.

While TOD pursues the general aim to develop cities or local communities around transit stations, the precise meaning of this general idea is quite different depending on the way these cities have been developed until now. Common sense tells that transit develops best in a densely populated environment. Population density of major cities is, however, very different in different cities of the globe. In East and Southeast Asia, the cities are denser than in Europe, and in Europe they are denser than in Australia and Canada, whereas density is even lower in US cities.

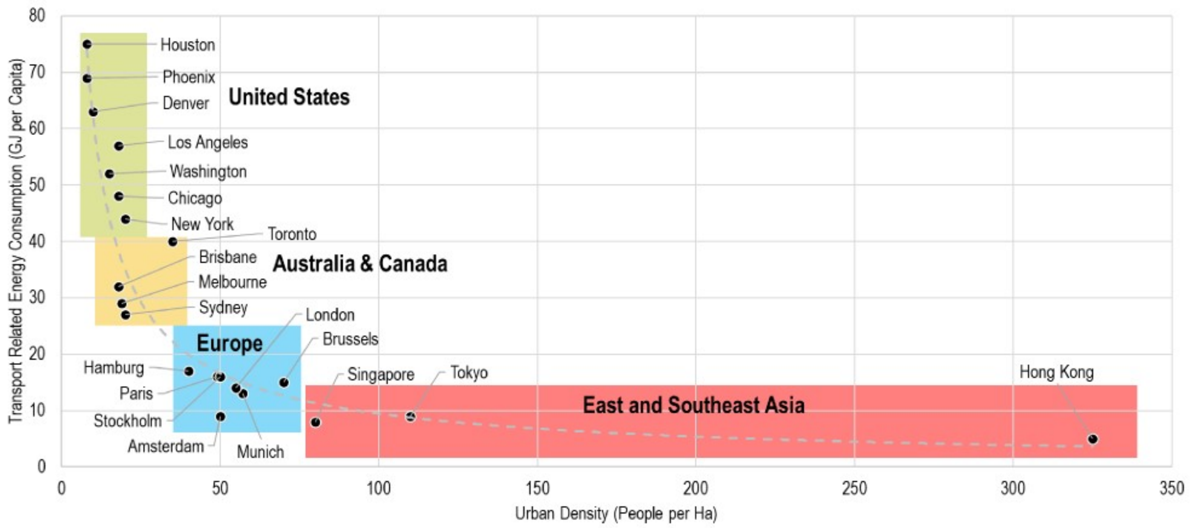


Figure 96: Transport related energy consumption vs urban density

Source: Geography of Transport Systems[235]

TOD can be called one form of sustainable development as its benefits have been identified in three categories, environmental, economic (or fiscal) and social:

Environmental Benefits

- Reduced traffic congestion
- Reduced fuel consumption
- Better air quality
- Reduced sprawl
- Conservation of open space

Fiscal Benefits

- Reduced road and parking facility costs
- Economic development benefits through agglomeration efficiencies and increased productivity
- Increased property values
- Increased property tax revenues

Social Benefits

- Improved social cohesion through positive interactions among people in a community
- Improved fitness and health as a result of increased walking and biking
- Reduced traffic accidents
- Improved transportation options, particularly for non-drivers
- Reduced consumer transportation costs
- Expanded labor market shed for employers
- Improved access to job opportunities for workers (and increased labor market shed for employers)
- Neighborhood revitalization

Figure 97: Benefits of TOD

Source: Capturing the Value of Transit[236]

The big problem of TOD is that it might create the expectation that the above-mentioned benefits are an automatic or guaranteed result of an urban development strategy that clusters around urban transit station. Unfortunately, this is not the case. Given the wide diversity of cities' key parameters such as population density, it would be a surprise if success were guaranteed in every case. Success in this sense means that all the above-mentioned benefits materialize simultaneously and for all categories of the population. In most of the cases, TOD strategies will, however, give substantive improvements to many of the above indicators and for many population categories. Nonetheless, the rule that nobody should be left behind should be taken seriously. A development model that systematically excludes some category of population is less sustainable than if inclusion is implemented. Also, in case economic and fiscal benefits do not materialize as expected, careful evaluations should be made and appropriate corrections to the model should implemented.

Before discussing the elements of successful TOD, it might be useful to briefly outline what TOD is not.

TOD does not mean to build railway or other public transport systems in low or middle density settlements and to hope that economic development will automatically cluster around the newly built transit stations. The good news is that in many cases, a positive effect of new transit infrastructure on economic development, measured in this case by increased land values around the transit station, has been measured[237]. However, two kinds of failures are nonetheless common, and they may be linked with one another, causing a self-defeating vicious circle.

1. Transit systems rarely recover all their operational costs. Usually, the so-called farebox recovery ratio is lower than 1, meaning the systems run in deficit which is usually covered by the local city budget.

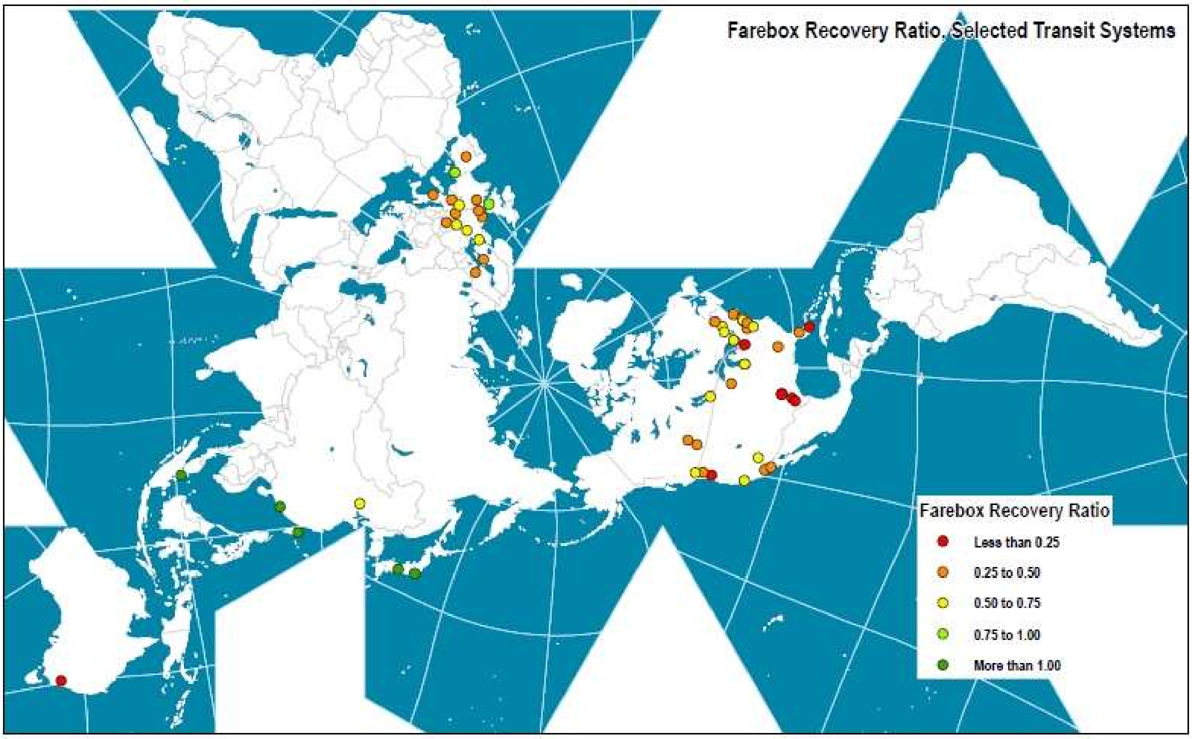


Figure 98: Farebox recovery ratio of transit systems

Source: Geography of Transport Systems[238]

2. TOD is likely to produce gentrification as improved transit infrastructures increases land prices in the neighbourhood of transit stations, which causes the low- and middle-income people to be squeezed away from transit stations[239]. Gentrification is likely to decrease the user rate of transit systems as gentry is likely to own cars and use them more often than the low-income people. Declined user rate further

decreases the farebox recovery rate of transit systems and hence increase need for deficit cover by municipalities. The municipalities then incite these transit systems to offer less frequent service, which makes them in turn less attractive to users. The user rate further declines.

This vicious circle has been widely observed in US cities[240]. It put severe stress on urban transit systems. For this reason, some people refuse TOD right away[241].

This shows that financial viability is a critical success factor for successful TOD. The sole fact of building and if necessary, subsidizing a transit infrastructure is not sufficient to make successful TOD. To make TOD successful, the construction of transit infrastructures must be combined with other factors that create sustainable economic value and growth. For this reason, financially and economically successful TOD is a combination of three factors:

- Construction of transit infrastructure
- Construction of affordable housing in walkable distance to stations
- Creation of jobs in walkable distance to jobs

If anyone of these three factors is missing, TOD can become a pure waste of money. Moreover, even these three factors together do not always bring financially viable development. The key factor creating financial viability is land value capture (LVC). This is explained in the next section. Both, TOD and LVC have been promoted by the World Bank which has also edited several important publications on that matter:

- H. Suzuki and others: *Transforming Cities with Transit – Transit and Land Use Integration for Sustainable Development*, World Bank (2013)

- H. Suzuki and others: *Financing Transit-Oriented Development with Land Values – Adopting Land Value Capture in Developing Countries*, World Bank (2015)

- Serge Salat and Gerald Ollivier: *Transforming the Urban Space through Transit Oriented Development – the 3V Approach*, World Bank (2017)

2.3.5. Land Value Capture (LVC)

Land Value Capture (LVC) is a method for financing Transit Oriented Development (TOD) by means of harvesting the increased value of land generated by TOD. For LVC to generate sufficient resources, the TOD must itself be conceived as combination of constructing transit systems with access to affordable housing and jobs so that value is created in the TOD. Before attempting to capture value, TOD must create value. Before looking at the LVC proper, it is useful to see how TOD creates value.

Any development, including TOD, creates value in many ways. The most evident one is growth of value added or GDP. *APSEC (2018)* derives a simplified definition of the GDP in two approaches, namely in the expenditure approach and the income and value-added approaches, both based on the UN System of National Accounts SNA 2008[242]. The third (value-added) approach can only be approximated in this simple framework.

Take a simplified economy consisting of an aggregate branch **A** (e.g. energy and food producers), a branch **B** (all other industry except financial industry), **R** (financial industry), Government (all levels of government, being also the owner of natural resources, column **G** stands for government spending and row **T** for taxes), households (the labour-supplying branch, column **C** is household consumption and line **W** are wages), the rest of the world (column **X** for exports and line **Z** for imports) and an accumulation account (column **I** for investments and line **S** for savings and profits). Line **S** is also the balancing line making that all line-sums always equal the column-sums. AB shows supply from branch A to branch B, while the payment goes in reverse direction, etc. AV is the intermediary total of AA+AB+AR and gives the intermediary production of **A**. The Leontief matrix of intermediary production is the light grey matrix. AU is the intermediary total of AG and AC. Total output of branch **A** is A in column **SUM**. Likewise, for the vertical sums: AG+BG+RG=G, TG+WG=UG, etc.

	A	**B**	**R**	**V**	**G**	**C**	**U**	**X**	**I**	**SUM**
A	AA	AB	AR	AV	AG	AC	AU	AX	AI	A
B	BA	BB	BR	BV	BG	BC	BU	BX	BI	B
R	RA	RB	RR	RV	RG	RC	RU	RX	RI	R
V	VA	VB	VR	VV	G	C	VU	X	I	V
T	TA	TB	TR	T	TG	TC	TU	TX	TI	T
W	WA	WB	WR	W	WG	WC	WU	WX	WI	W
U	UA	UB	UR	UV	UG	UC	UU	UX	UI	U
Z	ZA	ZB	ZR	Z	UG	ZC	ZU	ZX	ZI	Z
S	SA	SB	SR	S	SG	SC	SU	SX	0	S = I
SUM	A	B	R	V	T	W	U	Z	I = S	TOT

Matrix representation of the economy
Source: own work

Figure 99: Matrix representation of the economy

Source: APSEC (2018)

It shows that the GDP, noted Y, can be calculated in three approaches:

Expenditure approach $Y = G + C + X - Z + I$

Income approach $Y = T + W + S$

Value-added approach $Y = (V - Z) - VV$

The value-added approach (= total output – intermediary consumption) can only be approximated in this simplified formalism.

The GDP is the sum of current government spending (G), consumption (C), the trade balance, i.e. exports minus imports (X – Z) and gross investment flow (I), which are the aggregates of the expenditure approach. These are equal to the sum of taxes (T), wages (W) and savings (S), which, in this simplification, are the aggregates of both, the income and the value-added approaches. From the above table, it can be seen that:

$$V = VV + G + C + X + I = VV + T + W + Z + S, \text{ therefore}$$

$$Y = G + C + (X - Z) + I = T + W + S = GDP$$

As this is an accounting relationship, it means that any increase of the GDP or aggregate value-added of a local, regional or national community can only take place if it materializes by an increase of one (or more) left hand (expenditure) and one (or more) right hand (income) terms. The default (pure accounting) compensation of an increase of a left-hand term of the above equation (e.g. G, C, X, or I) is an increase of the term S on the right-hand side. These terms all describe flows. On a sustainable development path, not only these flows are increasing harmoniously, but also the different types of capital stocks (not shown in the definition of GDP) are not depleted. Such stocks are the lithosphere (e.g. mineral resources), hydrosphere, atmosphere, biosphere and socio-sphere (especially the human capital). These start to be measured in the UN System of Environmental Economic Accounting SEEA 2012[243], see also *APSEC2019* for a more detailed presentation of the SEEA. If these stocks are depleted, the process is environmentally unsustainable even though it might be economically and socially sustainable.

For analysing the creation of value-added by TOD, the following effects must be distinguished, whereby the broader categories of GDP growth during construction, GDP growth after construction (other than by land value) and wealth by land value increase should be distinguished.

GDP growth during construction:

- Indispensable prerequisite of the construction of large infrastructures such as TOD is the availability of corresponding amounts of initial capital, mostly secured by the international financial system. These operations are not reflected in GDP. During construction of a new transit infrastructure, this loan is then being spent on construction companies, materializing in an increase of spending by the local government (G), thereby increasing GDP. If G is increasing, the default compensation on the value-added side is increase of S. Construction companies having received income then pay for their cost and distribute their income either in form of corporate taxes (T), wages (W), interest payments (R) or for acquiring inputs from other companies. This is the usual business stimulation effect of construction. This stimulation effect, however, profits the local community only if both, the jobs (i.e. enterprises) and the workers are in the community (which is not necessarily the case). Usually, local communities manage to keep only a fraction of this GDP on their territory, as the construction materials and equipment are rarely produced in the same community where the construction takes place. Another effect of large infrastructures is to be added to the formation of fix capital (i.e. adding to the investment flow I) of the community, nominally increasing GDP. This is a one-time effect of large magnitude. In communities which invest continuously in local infrastructures, this creates a notable effect on local GDP. Capital accumulated in this way is being steadily depreciated over the duration of its lifespan.

After construction phase, several effects can be identified:

- Successful TOD combines operating new transit infrastructures with creating new jobs after the construction phase. This is planned from the outset by securing an attractive environment for enterprises. The creation or implantation of new enterprises creates locally produced income which is the source of different forms of spending. This is the jobs capture effect of TOD. The attraction of enterprises is not in itself increasing local GDP, but it gives rise to other activities that increase local GDP.

- If these newly arrived or created enterprises reside in the same community, they will also pay corporate taxes there. In this manner, the local community will receive more corporate taxes T. The local GDP is increasing by the amount of these taxes T, which allow more local government spending G. This is the tax capture effect of TOD.

- If the newly arrived or created enterprises are high-tech enterprises producing mainly export-oriented products, this will increase exports X (instead of increasing local consumption C). An increase of exports increases the trade balance (X – Z) and thus increases GDP. This increase of GDP is providing corresponding additional profits S to their enterprises. This is the foreign trade effect of TOD.

- If the workers living near the transit system substitute their fuel-driven cars and use instead the transit system for commuting, this will increase the farebox recovery ratio of the transit system and hence the receipts of the transit system. This is an income effect of TOD for the municipal government owning the transit system, even if it does not increase GDP as it substitutes one type of consumption C by another one.

- If the above substitution of cars by increased use of transit for commuting materializes itself in a substitution of imported car fuel by locally produced electricity, the trade balance (X – Z) of the community increases as imports Z diminish. This improvement of the trade balance increases the GDP on the expenditure side with corresponding increase of foreign exchange (included in the term S) on the income side. This is the import substitution effect of TOD. This improvement is conditional that the consumers do not pay more for their new transit system than for the car transport which it has replaced.

Wealth effects of land value increase:

- Where the TOD increases the value of the adjacent land, this is creating a wealth effet but as land is not a produced good, it is generally not considered as formation of fix capital. Such land price increase may either materialize only when the plot is sold at higher price or it may be recognized earlier in corresponding accounting practices. In either case it is accompanied by an increase of profits S. This is the land value effect of TOD and is at the heart of land value capture (LVC). LVC means financing transit infrastructures by growth and by capturing the increased land value from that growth. Two ways of LVC have been described[244]: Development based LVC and tax based LVC. Development based LVC attempts to use the proceeds from the sale of land to finance the TOD infrastructure. The sale of property may also include the more general sale of long-term leasehold against a one-time upfront payment. Tax based LVC attempts to transform the increased land value into a tax on income generated from property or a tax indexed to the price of land. The terminology is a little unfortunate as in the general sense, the tax can also be a fee, or a rent generated from property. Section 2.1.3. above has enumerated different land use categories which may be relevant to LVC. The above simplified accounting framework does not allow distinguishing between income of the public sector due to sale of land (included in T) and tax income-proper (T) of the public sector. Therefore, both types of land value capture result in an increase of the agents' payment T at the expense of their profits S.

A selected list of the two types of LVC instruments can be found hereafter.

	Instrument	Description
Tax- or fee-based	Property and land tax	Tax levied on estimated value of land or land and buildings combined, with revenues usually going into budgets for general purposes.
	Betterment charges and special assessments	Surtaxes imposed by governments on estimated benefits created by public investments, requiring property owners who benefit directly from public investments to pay for their costs.
	Tax increment financing	A surtax on properties within an area that will be redeveloped by public investment financed by municipal bonds against the expected increase in property taxes. Mainly used in the United States.
Development-based	Land sale or lease	Governments sell developers land or its development rights, whose values have increased thanks to a public investment or regulatory change, in return for an up-front payment, leasehold charge, or annual land rent payments through the term of the lease.
	Joint development	A well-coordinated development of transit station facilities and adjacent private properties between transit agencies and developers, where the latter usually contribute physically or financially to the construction of the station facilities, as their property value will increase thanks to the transit investment. Used in Japan, the United States, and other countries.
	Air rights sale	Governments sell development rights extended beyond the limits specified in land use regulations (such as floor area ratios [FARs]) or created by regulatory changes to raise funds to finance public infrastructure and services.
	Land readjustment	Landowners pool their land and contribute a portion of their land for sale to raise funds and partially defray public infrastructure development costs.
	Urban redevelopment schemes	Landowners and a developer establish a cooperative entity to consolidate piecemeal land parcels into a single site that they then develop (such as a high-rise mixed-use building) with new access roads and public open spaces. The local government modifies zoning codes and increases maximum FARs in the targeted redevelopment areas (typically around rail transit stations) and finances the infrastructure. Mainly used in Japan.

Figure 100: Selected LVC instruments

Source: Suzuki and others (2015)[245]

The points above show how TOD creates value-added in form of GDP growth. This includes the specific case of wealth effect created by land value increase. Land value, more specifically, is driven in two distinctive ways. In principle, land prices can increase either by the effect of investments that the owner of a parcel makes on his own plot of land, or by the effect of investments that his neighbours (or the nearby transit system) make on their respective land plot. In the first case the increase of land value is being paid for by the owner of the parcel himself, whereas in the second one it is being paid for by the neighbours, giving the owner of the parcel a so-called external benefit or windfall profit, i.e. a positive effect to which he did not contribute. In this case this owner is a free rider. Land Value Capture has much to do with capturing free riders, or with implementing the who-benefits-pays-principle.

Before explaining how TOD and LVC are being applied, it is necessary to look at the way how transport systems create value for their own land and for the land of their neighbours. This has been described in the 3V approach[246] which distinguishes between node value, place value and market potential value.

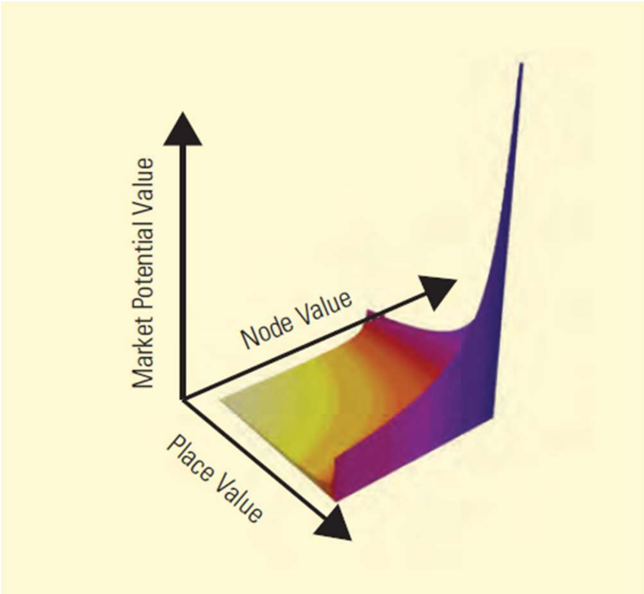


Figure 101: Elements of the 3V approach

Source: Salat and Ollivier[247]

Node value is a concept borrowed from network sciences. In terms of network sciences, any station is a node and any connection between two stations is an edge. The more connections a station has, the more it is important. Connections are not only measured in terms of a single transport mode (e.g. train), but in terms of the overall multi-modal connectivity. The most important stations are at the centre of networks, whereas the least important stations are the terminuses at the end of radial lines which have a single connection. Often city networks have a core of highly interconnected stations in the centre and radial branches towards the exterior which represent about half of the number of stations of the entire system.

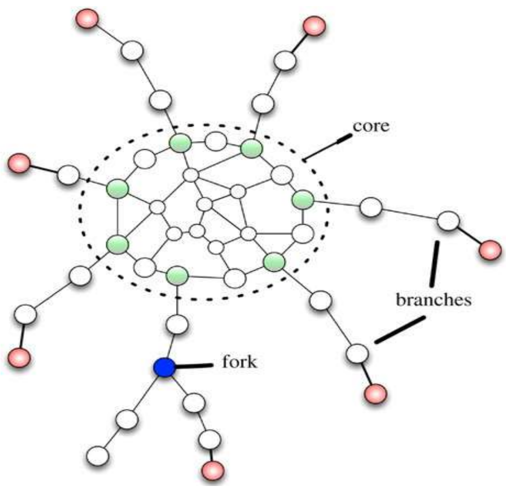


Figure 102: Typical structure of a subway network

Source: Roth and others[248]

Each station has a specific centrality score, defined as a function of three centralities:

- Degree centrality of a node is the number of links of each node. Terminuses have degree 1, usual transit stations degree 2, forks degree 3, and important hubs can have degree 4 or higher.
- Closeness centrality of a node is the average distance, measured in number of links, of a node to every other node. Closeness is expressed as the reciprocal of the sum of the length of the shortest paths between the node and any other nodes. Terminuses of subway systems of major cities have closeness below 0.05, whereas hubs have closeness over 0.1.
- Betweenness centrality of a node is the number of shortest paths from all other nodes that pass through that node. Usually, this number is then divided or normalized by the total number of shortest paths between any two nodes of the network. Betweenness indicates the "bridge" role of any node in the network.

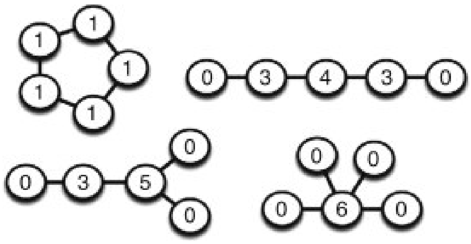


Figure 103: Betweenness of nodes (not normalized)

Source: Perez and Germon[249]

- With transit systems, not only the centrality measures calculated from the network design matter, but also the frequency of service in any given node. It can be indicated e.g. by a ridership index comprising the daily number of departures from that given node (including departures without stopping).
- The indicators above, if calculated for a node of a subway system, do not measure intermodal connectivity of each node (i.e. between subway and other transit systems). This should be added by calculating the intermodal diversity as the supplementary intermodal links of each node.

The node value of any given node is then calculated as a weighted measure of the three centrality measures together with the ridership index and the intermodal diversity index.

Place value is the second type of value of a node. Place value has four sub-components:

- The street intersection density index shows the number of street intersections per km2 within an 800 m radius around each transit node. High values can be found in Venice (688), Toledo (420), Florence (255), and Turin (191). Medium valued are in Paris Etoile (133), Manhattan (120), Barcelona Cerdà design (103). Low values are in Shanghai (17 – 27), Beijing South (13 – 16)[250].

  In the Five Principles of its new strategy of urban sustainable neighbourhood planning, UN Habitat[251] recommends that the street area of a neighbourhood should be at least 30% of the land area, or at least 18km street length per km^2 (Principle 1). As an example, in an area of 1km^2, there should be nine horizontal and nine vertical streets, totalling to 18km length, with distance of 111m between adjacent streets and 81 street intersections per km^2. Both, streets and blocks should be hierarchized in larger and smaller ones. This grid resembles the Barcelona grid described earlier (section 2.2.1.).

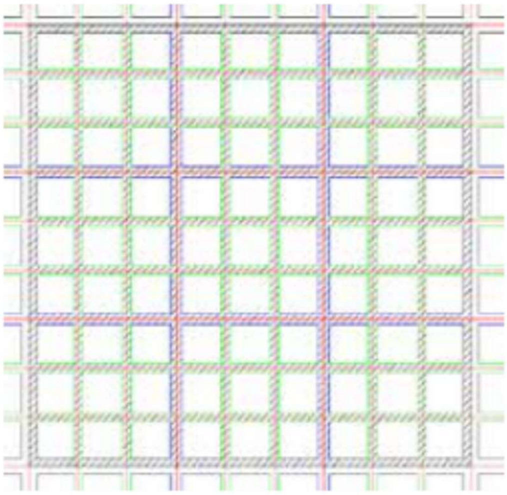


Figure 104: Street grid proposed by UN Habitat

Source: UN Habitat[252]

- Proportion of pedestrian accessibility area within 800m radius and 10 minutes' walk around each transit node. Depending on street layout and cityscape permeability, this index is between 0.8 for high accessibility and less than 0.2 for low accessibility.

- Diversity index of land use around each transit node: This indicates the diversity of use among the different types of land use (residential, commercial, industrial, community). It can be calculated by the Shannon entropy of the different uses. This is highest (1) if all the uses are equally abundant around a transit node and lower (e.g. 0.2) for a transit node presenting high degree of monoculture.

  The Five Principles of sustainable neighbourhood planning by UN Habitat recommend at least 40% floor space for commercial use and not more than 50% floor space for residential use in any neighbourhood (Principle 3). Furthermore, not more than 10% of blocks in any neighbourhood should have single use (Principle 5).

- Density of social infrastructure within 800m around a transit node: this is somewhat more difficult to measure, e.g. by the number of social infrastructure institutions (schools, hospitals, etc.) within the given perimeter of a transit node.

The sub-components of the place value can be aggregated to a weighted place value index.

Market potential value is the third type of value of a transit node. It can be subdivided into demand side and supply side measures.

- The demand side is indicated by elements such as the population density and the jobs density per square km within 800m around a transit node or the number of jobs accessible within 30 minutes by combined walking and transit use, a forecast of these densities over the next 20 years, and the jobs/residents ratio. Information on social stratification can be the average or median income or the ratio of managers in the labour force around the transit node.

The Five Principles of UN Habitat recommend density of at least 15000 people per km2, or 150 people per ha (Principle 2). They also recommend that 20% - 50% of residential floor area should be allocated to affordable housing and that no neighbourhood should contain more than 50% of housing of a singly type (Principle 4).

- The demand side is indicated by the developable land and floor space around a transit hub, within the 500m radius and the 1km radius perimeters. This takes account, among others, of unused FAR in these perimeters.

The process of how TOD and LVC are being applied is shown hereafter. An important role in this process is the way how a city manages its land supply.

2.3.6. Applying TOD and LVC

The above sections show the theoretical underpinnings of TOD and LVC. The present section aims at showing how both, TOD and LVC, are being combined and applied in concrete cases.

APSEC (2018) explains how growth of cities in general is the result of two forces that oppose each other: the centripetal (or attracting) force that favours higher concentration and growth, essentially driven by different types of economies of scale, and the centrifugal (or repelling) force, mainly driven by rising costs, that favour less dense cities, slowing down growth and driving residents and enterprises out of cities. Most of the cities in the world are growing, therefore the usual case is that centripetal forces are stronger than centrifugal forces. That does not mean that the latter do not exist.

Cities are engines of economic growth for their economies. This is especially the case for APEC cities; *APSEC (2018)* shows that APEC is the region of the world where cities contribute more to growth than any other region. The inverse is also true: where cities fail to grow, the economies slow down. One of the most important tasks of cities in terms of securing their economic performance is to keep costs down and to struggle against any source of rising costs. Costs can rise due to two different factors:

- Rising infrastructure fees from local infrastructures (transport, energy, water, waste, social): The local municipalities who often own and operate local infrastructures have the power to decide the user cost of these infrastructures. Many of these infrastructures are network-based (e.g. streets, electricity or gas grids, water and sewage grids, ITC infrastructures). This means that the users normally only have one single connection point, which confers to the “last mile” section of these infrastructures the character of natural monopolies for the user. Where cities own or operate infrastructures that have the character of natural monopolies for their users, it is easy for the cities to limit the price for their use. This contributes to diminish unnecessary costs.

- Rising external cost from using infrastructures: The most important external cost impacting on urban economic activity is congestion of urban streets. Congestion on urban streets has the effect that city loses internal permeability and hence internal communication, which is its biggest advantage. Other important external costs of cities are increased health issues due to air pollution. TOD is designed as development model addressing both these issues at the root, namely by minimizing the need for transport.

- Rising land value. Where urban land prices are increasing, this can impact any urban activity to the extent that parts of the value chain are located within the city become unprofitable. Rising land value is an important factor of local inflation. As local land value depends on the supply-demand balance of land, this source of inflation is difficult to control. Cities must implement measures to use land in the centres of agglomerations as efficiently as possible. If they fail to control it, the local authorities should try to capture it as a source of financing TOD by LVC.

The particularity of transit infrastructures is that they are capital-intensive. In large cities, a transit infrastructure can easily cost one billion USD per km length. On the other hand, the land value increases, depending on the kind of TOD that is being realized. Where TOD is of high quality with high pedestrian accessibility, the land value increase is greater than where TOD does not provide for sufficient pedestrian accessibility. This shows that LVC takes place essentially in the 800m perimeter around transit nodes that is accessible to pedestrians.

As mentioned, TOD is the combination between construction of a transit system with access to jobs and affordable housing. Such project necessarily involves different stakeholder categories. A central – but not unique – role is played by the transit agency play. But as the focus is not limited to transit, two other stakeholder categories, namely developers and landowners/tenants are usually included in this process that takes place under the umbrella of the local community. The different steps of a TOD can be described as follows:

A) Planning and design phase

The first phase consists of planning the TOD extensions and to identify and design developable land. Planning of TOD is usually being done along transit corridors. This process involves elaboration of master plans and the vision over a horizon of several decades ahead (e.g. 2050). Most importantly, they show the development capacity of the transit system and of the real estate business in a certain perimeter, e.g. 800m, around the transit nodes. Such nodes can be planned in built-up areas or planned as greenfield developments. Master plans show the existing land use (zoning and FAR) and identify underutilized land. Master plans might propose options for financing.

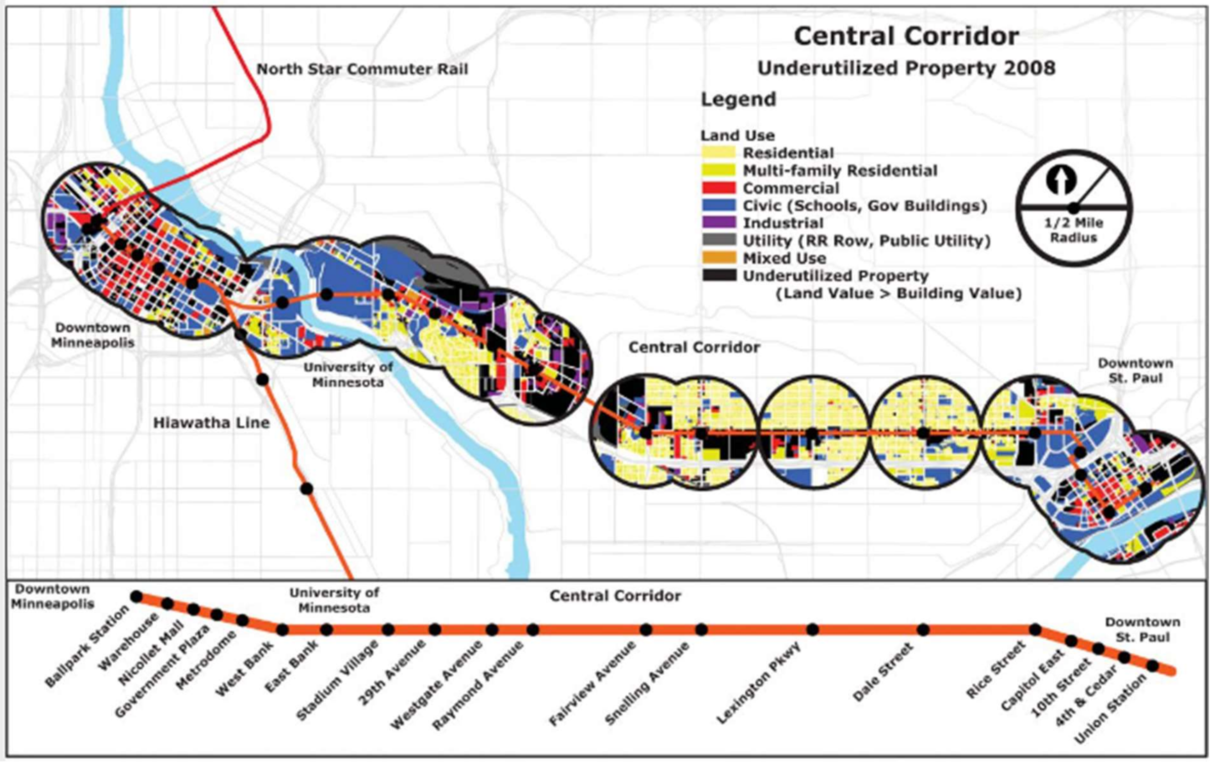


Figure 105: Example of corridor planning of Minnesota

Source: 2030 Palette[253]

B) Land consolidation phase

The second phase consists in creating the right of way for the transit system and simultaneously increases the land value of the adjacent landowners. These results are achieved through land assemblage. Successful land assemblage consists of a joint value creation and profit-sharing scheme which transforms a fragmented ownership into a joint and consolidated one. This is shown in the figure below. The fragmented landowners A, B, C, D, E, F and G become joint owners of the new central building which has higher access and better infrastructure provision. The owners of buildings a, b, c, d, and f become new owners of the main section of the new building. The transit company benefits from the higher population and jobs density which will give it higher farebox recovery rates. The developer may receive a land section X and the floor area rights (FAR) that are being created in the process by upgrading maximum FAR from 2 to 6. In exchange the developer may be required to build the streets and do the city scaping. The FAR upgrading is the financing source for the transit system, together with some subsidies from the central government to finance the process of land consolidation. The local government will profit from the transformation of single use zones to mixed use zones with higher FAR. This provides for higher property tax revenue and economic development. Not later than during this phase, the local government will fix the public requirements such as the proportion of affordable housing, the jobs-to-household ratio, the proportion of public open space, but also any other public policy requirements such as improved protection against earthquakes or other disasters or requirements on the energy mix.

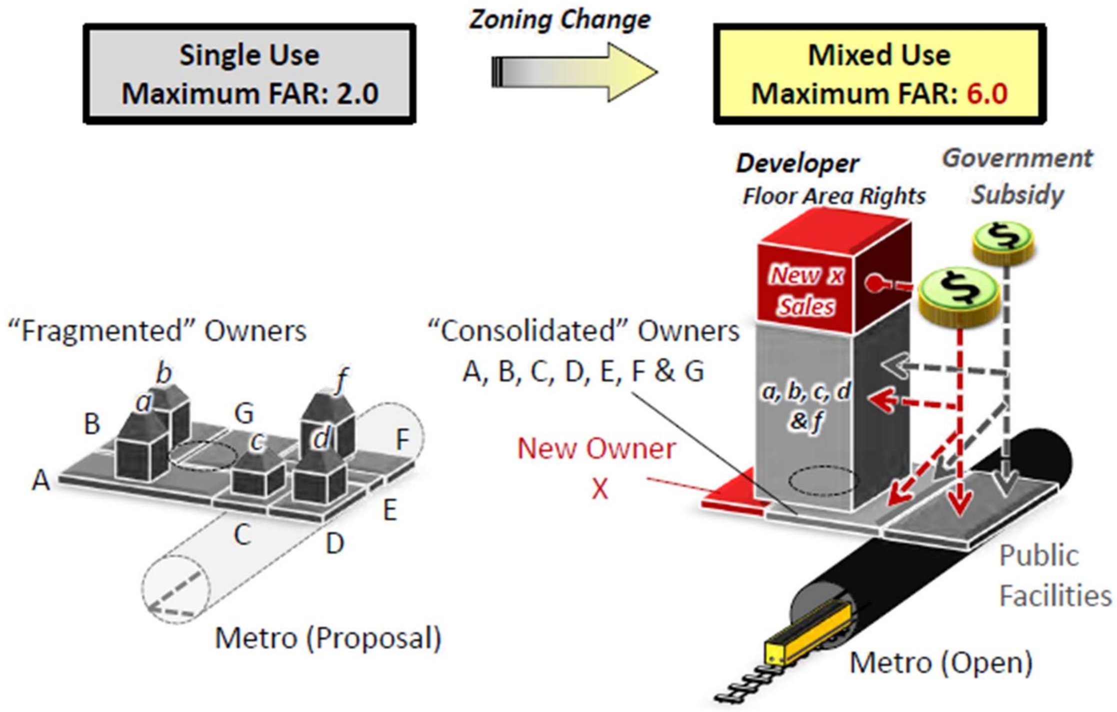


Figure 106: Land consolidation phase in urban redevelopment case

Source: Suzuki[254]

C) Joint development phase

The joint development phase starts with the land auctions, where these are necessary, the property lease contracts and the creation of the public-private partnerships PPP that will build and manage the different components of the development. The phase ends with the construction of the transit infrastructure and the associated affordable housing and commercial buildings that make up the TOD project.

D) Operation and maintenance phase

After construction, the operation and maintenance phase consists of running the built transit infrastructures and the businesses (property management, retail, tourism, leisure) that are in the buildings. This is the asset management phase of the TOD.

E) Evaluation phase

In this phase the project is being evaluated and assessed having regard to the set objectives and indicators. Together with the evaluation, corrective action (i.e. regeneration) can be formulated and proposed. This can consist of further re-zoning, amending indicators, creating further visions that incorporate new technologies, carrying out technical audits including energy audits for improving management efficiency, and eventually reinvesting for future development.

2.3.7. Best Practice Cases

Developing a city or local community along a TOD and LVC model is a complex and endeavouring project. It requires not only good preparation and strong leadership from city authorities, but also sustained implementation by stakeholder entities and enterprises. While many cities have done TOD combined with LVC, only few have managed to achieve holistic improvement across the board. Where most cities fail, unfortunately, is on the question of making transit systems run financially break-even or even profitably. In the overwhelming number of cities, transit systems run financial losses, and the key question is how to deal with such losses.

If some few examples merit to be mentioned in this section, it is because they have been built on a TOD model that, so to say, manages in an elegant way to deal with the tricky question of financial losses of the transit system. These examples have in common to consider TOD as a form of development. Development, especially land development, is the primary objective. In these examples, transit is merely an instrument for the development of land. The priority given to development over transit is reflected in the business structure of the respective agency that runs the transit system. In these examples, land development is more important than construction of transit infrastructure, which is reflected in the structure of income of this model. In these examples, a major part of income stems from property management, and only a minor part of income stems from transit. In other words, it is estate developers that produce the transit network as an accessory, and not the inverse.

The first example to be mentioned is Hong Kong. The example of Hong Kong is described in detail in Suzuki (2015). In this section only three points merit mention. Firstly, Hong Kong's MTR transit company is a publicly owned company which has been opened in the year 2000 to 23% private ownership. The presence of private investors has increased pressure on the management to be market-oriented, price-responsive and open to public concerns. This has positively impacted the management efficiency in many areas. One of them is energy efficiency of the transport services. As an example, the energy used for each person-km in the heavy rail section has diminished by 17% in the period 2008 - 2018[255]. The second point to be mentioned in this section is the diversity of income. In the twelve years following partial privatization, the biggest source of income (38%) has been originating from property developments. A second source of income has been originating from railway and related operations (34%). The income mix has been completed by two other types of income, namely income from station commercial business (15%) and from rental and management business (13%). These two latter income sources show LVC by capturing value generated from business and retail activities that are being provided by third parties in transit nodes. The third point to be mentioned is that MTR company has become a company that is building and operating transit infrastructures in many other cities all around the world[256].

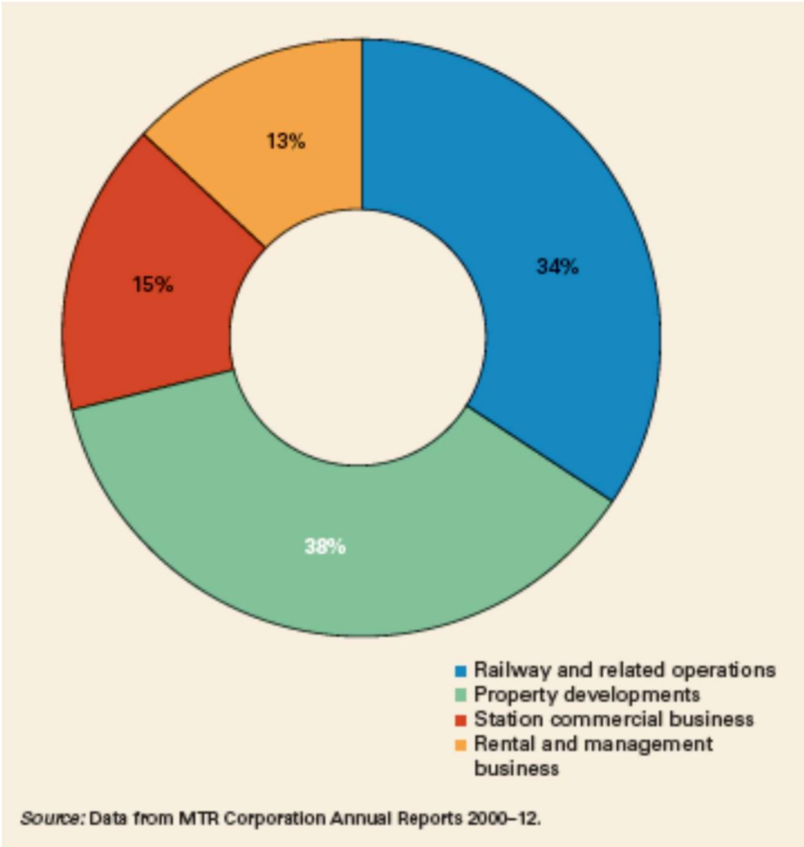


Figure 107: Income share of Hong Kong's MTR Corporation

Source: Suzuki (2015)[257]

Future development of Hong Kong might be influenced by the Pearl River development initiative that aims at increasing links and complementarities around the concept of satellite cities between Hong Kong, Macau and nine cities in the Guangdong province. The success of this regional initiative will heavily depend on receiving guidance from the central government in view of promoting TOD at regional level.

The second example to be mentioned in this section is Tokyo in Japan. Like Hong Kong, it is also described in detail in Suzuki (2015). The population of Tokyo together with its conurbation area of 14'000km^2 is around 37 million inhabitants which makes it the world's most populous urban centre that also hosts the world's most extensive railway network. The agglomeration area is fragmented among many local and regional jurisdictions, comprising not only the Tokyo metropolitan government, but also several prefectures, cities, towns and villages. Each of these entities is drawing up its own master plan. Fragmentation also characterizes the railway ownership which consists of 48 public, semi-private and private enterprises and real estate developers. The Railway Business Law of 1987 allows owners of rail lines to share a line among different operators. The coherent TOD of this region could impossibly have been achieved without strong guidance from the central government which has promoted a rail-oriented culture over the last half of a century and prepared transport infrastructure development strategies as well as a regional development vision such as the series of National Capital Region Master Plans (NCRMP) which started in 1958. These aim at creating highly self-contained as well as mutually supportive satellite cities. Since 1999, nine satellite cities have been identified.

In this section, only a few points need to be mentioned. The revenue mix of the Tokyu company, the biggest railway company in Tokyo, originates from transportation (41%), real estate (34%), residential services (15%), business services (5%) and hotel and leisure services (5%). This composition is like the one of Hong Kong's MTR corporation.

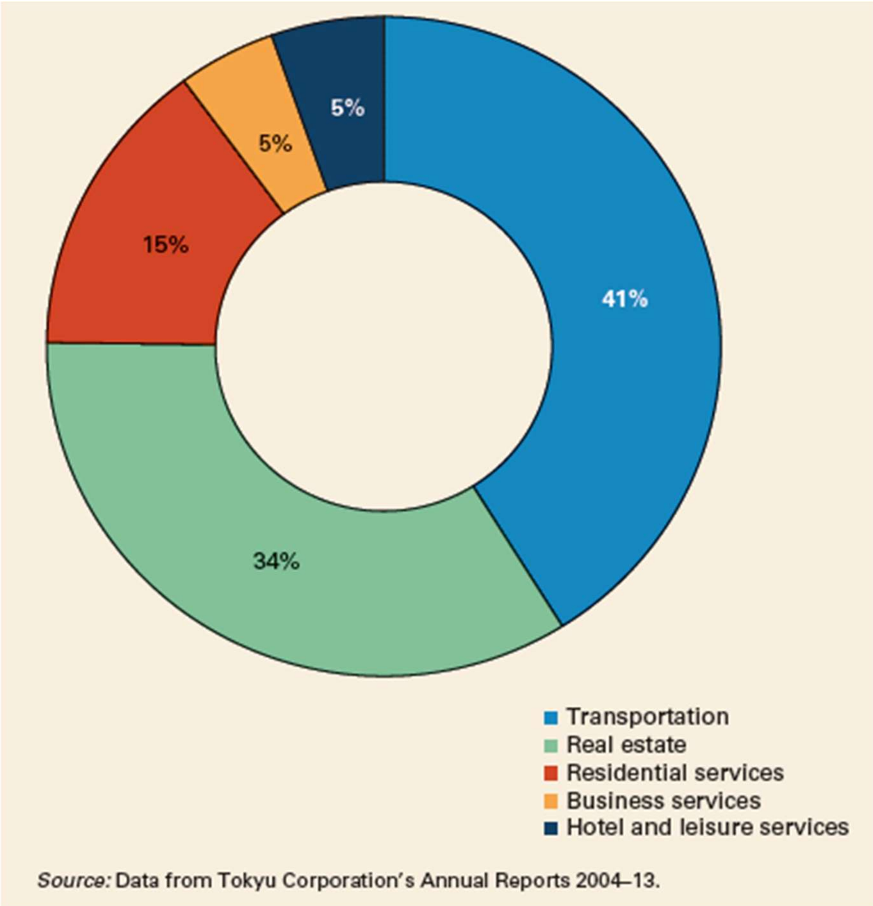


Figure 108: Revenue components of Tokyu Corporation

Source: Suzuki (2015)[258]

The triple fragmented nature of jurisdictions, railway and land ownership in the Tokyo area has at times been a challenge to keeping the transit enterprises in the profitable range. But all in all, the Tokyo TOD

2.3.8. Selected Key Technologies

The successful implementation of the above-described TOD and LVC processes requires some key technologies. The most important is a technology allowing for mass transport of persons and/or freight. As a matter of fact, a rail-based mass transport system is a likely choice. Most emerging cities have opted for underground rail transport systems, but this is not mandatory at all. The municipality of Bangkok shows that a sky-based rail system is similarly efficient as a subway, while it may cost less.

APSEC (2018) describes other technologies that may play a key role in making cities more sustainable. Clusters of neighbouring cities may also plan for transporting goods between their member-cities under the ground. Technical and economic feasibility of such systems has been shown long time ago. The Swiss Cargo Sous-Terrain (CST) project may worldwide be the most advanced one of this type, but other regions, especially some cities in China, are not lagging far behind. These systems may be totally automatic, running in 24h service and entirely powered by renewable electricity. Again, the underground nature is not mandatory. For long distance goods transport, an alternative might be a combined intermodal system placing heavy goods vehicles on trains as it exists in Europe operated by Hupac[259].

Figure 109: Fully automated underground goods transport

Source: Cargo Sous-Terrain[260]

For urban planning, the trend towards plus-energy districts might be interesting for APEC economies. Plus-energy districts are a further development of plus-energy housing which transforms residential housing form purely consuming to producing-consuming (or “prosuming”) spaces. Plus-energy districts apply high insulation combined with third and fourth generation PV, including building-integrated PV, battery energy storage, efficient vertical transport and new urban wind turbines. These technologies will be integrated into microgrids with community trading and other behaviour incentives and will draw on supplementary sources such as wastewater-to-energy and waste-to-energy. For a description of plus-energy districts see *APSEC (2018).*

Individual mobility will have increasing shares of electric vehicles and fuel cell vehicles with self-driving cars penetrating in specific traffic segments. Smart infrastructures will be used for congestion management. Experience will show whether PV roads and mobile wireless charging will further develop.

Highly developed IT systems comprising big data, intelligent apps, artificial intelligence, robotics, internet of things and 5G, virtual and augmented reality, high performance and quantum computing as well as blockchain and distributed ledger technologies will play an increasing part for integrated management of all processes and infrastructures as well as for improved early warning systems against the increasing number and complexity of disasters. See also *APSEC (2018).*

3. Integrating Disaster Resilience into Urban Planning

Resilience is presented as an emerging property of complex adaptive systems (CAS) to which all socio-economic systems belong. Any resilient system breaks down if a shock is too strong. Resilience is very similar to sustainability, to which it adds mainly the notions of tipping points and of essential functions but lacks the long-term dimension. The report analyses resilience for each of the four sustainability domains ecology, society, economy and governance, and discusses the numerous resilience frameworks, most importantly the Disaster Resilience Scorecard for cities elaborated by the UN. Ecological resilience of cities involves an equilibrium between efforts to increase biodiversity in cities on one side, and integrated pest management to stop massive development of unwanted pests on the other. Social resilience of cities means strengthening the social fabric of communities. The most important aspect of social resilience involves setting socially accepted tolerance levels for specific risks. Economic resilience is the capacity of an economy to withstand shocks and rapidly build-up economic activity after a shock. Economic fitness is identified as key concept determining economic resilience. This concept has not yet been applied to cities. The analysis of integrated governance for sustainability and disaster resilience is made with the help of the framework of the International Risk Governance Center IRGC. The report then addresses the conflict between disaster resilience and sustainability which can be resolved by mimicking the governance of the human body, namely the so-called autonomic balance.

As resilience analysis should be described in relation to specific disasters, the report describes resilience against climate-related or hydrometeorological disasters comprising inland water flooding, coastal flooding, and extreme temperatures including wildfires. Resilience against inland water flooding can be addressed by integrated water resources management as provided for in SDG 6.5. The report recalls the challenges and presents a host of measures, among them the sponge city. Resilience against coastal flooding includes measures against sea-level rise as well as cyclone-resilient architecture. The Saffir-Simpson hurricane scale underestimates the effects of local coastal shape on storm surge. Resilience against extreme temperatures bases upon local climate change as reflected in the Köppen-Geiger climate classification. Forecasts point to a more general requirement of urban cooling and heating. Wildfire resistant architecture and landscaping needs to be further developed in affected APEC regions.

Geological disaster resilience includes earthquake-proof architecture, protection against tsunamis and against damage from volcanic activity. APEC region hosts the world's 20 strongest ever measured earthquakes. Earthquake magnitude scales underestimate the destructive capacity of strong (>7) earthquakes as they fail to measure earthquake duration. Thousand-year-old earthquake resistant architecture in China, Japan and Korea offers solutions to earthquake-resistant skyscrapers. Earthquake-upgrading of existing buildings can be done in combination with thermal upgrading, making both cheaper. Tsunami resilience requires a combination of all available measures. The March 2011 tsunami brought about a paradigm change in Japan. For smaller 150-year events, protective walls suffice, whereas for bigger events, supplementary measures such as retreat of habitat, protective forests, and vertical evacuation are taken. Most volcanic eruptions are local events that are being addressed by local planning measures. Historically observed large eruptions (1815 AD, 1257 AD, and 1613 BC) as well as pre-historic extreme eruptions are global events that have temporarily impacted the global climate.

Epidemic resilience based upon experience from SARS in 2003 has shown its insufficiency for COVID-19. The biggest challenge of COVID-19 is the rapid aerosol-based spread of the virus. This report proposes to make all interior spaces in infrastructures pathogen-resilient by adding UV-C light sources with sterilizing effect within heating, ventilating and air condition (HVAC) equipment or at other appropriate locations. This is a low-cost and high efficiency measure. To bridge the absence of vaccine, this report echoes the proposal made by a microbiologist of John Hopkins University to treat infected cases by using human convalescent serum (or passive antibody administration). This is low-cost measure is best adaptable to cities hosting enough recovered cases. To avoid the conflict between epidemic resilience and sustainability, economic stimulus packages should consistently be used as instruments to implement SDGs and targets.

Cyber-resilience is not yet a commonly used term. IT systems are still not designed to be intrinsically cyber-resilient. To guarantee continuity of computer services, cities are advised to use all available means to protect their IT infrastructure such as grass-root bottom-up protection, modularity, firewalling and virus-protecting all components. An important threat to cybersecurity stems from human nature and inattentiveness in handling sensitive data, a situation that can be improved by training.

3.1. Integrating Resilience into Urban Planning

3.1.1. Resilience as Emerging Property of Complex Adaptive Systems (CAS)

A consequence of perduring systems is that they have the capacity to survive some types of disturbances or shocks. This general idea of surviving disturbances is often called resilience. The terms of resilience and resiliency are synonyms, but resilience is used about five times more frequently and in more general contexts than resiliency[261]. Resiliency is used mainly in particular research areas such as psychology and social sciences. Expressed in the most general terms, resilience of a system is the capacity to survive disturbances. Whether or not a system will survive a disturbance depends not only on the system but also on the strength of the disturbance. Some systems have higher capacity to survive disturbances and can even withstand extreme shocks, whereas others are more fragile and only support very weak disturbances. Those systems that survive a disturbance are more resilient or elastic than others which are more fragile, inelastic or vulnerable.

The exact meaning of “survive” in this context will depend on the type and nature of the system. A simple system can be exemplified by a rubber ball. If it is perfectly elastic, it will survive shocks until a certain strength. Survive will mean return to its original shape with kinetic energy KE being maintained (see figure below), while the trajectory after the shock may be totally different.

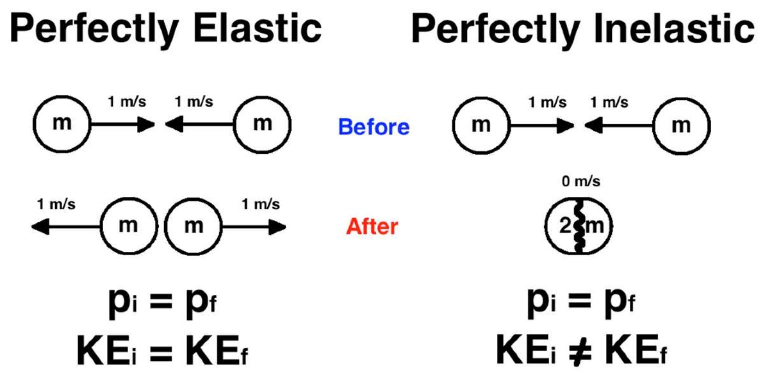


Figure 110: Elastic and inelastic collisions

Source: Stony Brook University[262]

Note that the above figure shows the strength of a shock and not the intrinsic property of a simple system. If the shock is too strong because the collision speed is too high, even an elastic rubber ball will break into parts. There is no physical system that can withstand shocks of any intensity. Even the smallest physical sub-atomic particles break at high-energy shocks. For this reason, it is misleading to refer to "resilient" systems. Any "resilient" system will break down if the shock is too strong. In the context of socio-economic systems in general or urban systems in particular, it is much safer to refer to "disaster resilient systems", which implies that a city would to a certain extent be ready to face disasters of the type and intensity that have occurred there in the past.

Resilience of a system can be measured and expressed in terms of intensity of a shock that the system can still survive or absorb. This point is called the breaking point or tipping point of the system. The knowledge about tipping points of systems and sub-systems is essential for both, ensuring sustainability and avoiding disasters. Tipping points can be seen in simple systems like the rubber balls above, or in complex adaptive systems (CAS) as introduced hereafter. The special interest of analysing CAS is that resilience appears to be an emerging property of CAS.

Complex adaptive systems (CAS) can be defined as systems that have different interacting system-parts whose behaviour, taken separately, does not explain the behaviour and the change of behaviour of the system as a whole[263]. Often, the simpler term of "complex systems" is used. This short form is not very precise as it is sometimes also used to describe "the study of complex systems" which is a subset of systems theory. Under the term of "complex system" one might also include writing systems such as alphabets, Chinese characters, sign systems or mathematics. However, these are usually not included in the notion of complex systems. In practice, complex systems are systems that have many different components that may interact with each other AND have some form of energetic metabolism (i.e. transform energy or matter) while doing so.

Not all the complex systems defined in this way are complex adaptive systems (CAS). A large dam below which other essential infrastructures are located is a complex system. It cumulates risk from dam failure with risk of failure of each individual infrastructure located below the dam. Such risk cumulation does indeed originate from a complex system, and the resilience of each subsystem contributes to improving the resilience of the integrated system. But the integrated system does not change with its overall behaviour when the behaviour of its sub-systems changes. It is not per se a complex adaptive system. A complex system becomes a complex adaptive system (CAS) if e.g. its tipping points depend on the state of the system or sub-systems. Another way to make a dam system combined with other infrastructures become like a CAS is e.g. when the managers of the overall system realize that they should move essential infrastructures away from the area below dam. By doing so, they integrate knowledge that has come up and take the necessary consequences.

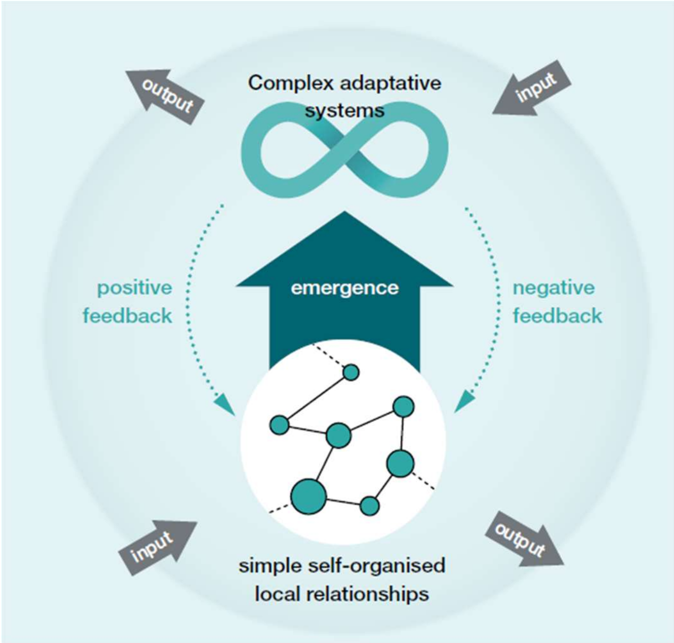


Figure 111: Complex adaptive systems (CAS)

Source: International Risk Governance Center IRGC (2018)[264]

The main categories of complex systems are:

- Physical: e.g. the hydrometeorological systems such as climate and weather systems, or geophysical systems such as the movement of tectonic plates, the solar system, the universe.
- Biological: e.g. all biological organisms or parts thereof, e.g. the brain, cells
- Ecological: e.g. eco-systems such as forests, coral reefs, rivers, lakes, oceans.
- Engineered: e.g. all types of mechanical engines (electric engines, petrol engines, steam engines) as well as the system which they serve (vehicles, planes, ships, buildings)
- Infrastructures: e.g. transport, energy, water, wastewater, social infrastructures
- Information technology systems: e.g. all types of computers, IT networks, the internet and their software
- Socio-economic systems: e.g. cities, enterprises, organizations, social networks, markets, components of economywide systems such as the banking system, the health system, the transport system.

Some of these systems are complex adaptive systems (e.g. the climate), others show too little adaptation to be called adaptive, which may cause their failure (as in the case of the sinking of the RMS Titanic). Before describing resilience of complex adaptive systems (CAS), some other aspects of CAS should be outlined.

- CAS can only be studied if the system boundary separating the system from its environment as well as the boundaries between its sub-systems are precisely defined.

- The distinction between concrete systems (being composed of physical "hardware" elements) and discrete systems (composed of "soft" elements such as information sharing systems) tends to diminish. In socio-economic systems both parts are found anyway. Thus, e.g. the term "enterprise" designates the "hardware" (buildings, machinery, staff, raw material and product stocks, and the "software", i.e. the legal infrastructure, the policies, paradigms, skills, and markets).

- CAS produce emerging properties that are not visible at the scale of the elements of the system, but only at the scale of the CAS. As mentioned, resilience is one of these emerging properties. Emerging properties were first described in purely physical systems. The best-known emerging property is temperature which is not identifiable at the micro-scale of molecules but clearly and objectively measurable at macro-scale. Temperature is linked to energy (a temperature times an entropy equals an energy), but this link is not proportional.

- CAS generate new types of emerging phenomena, such as self-organization, spontaneous order, memory, learning, adaptation, non-linearity. Due to this last characteristic, they wipe out the distinction between being deterministic one-cause-one-effect and being chaotic (impossibility to exactly predict an effect from a cause).

- CAS (e.g. forests) can be nested, meaning that the components of the CAS are also CAS (e.g. trees), which may yet be made of other CAS (e.g. cells) whose components are molecules, which are made up of up to 10^7 atoms each.

- CAS are often represented as networks or discrete systems, where the nodes represent the components of the system and the edges represent their interactions. As the number of relationships (edges) grows quadratically with the number of nodes, the complexity of large systems can rapidly increase. For this reason, complex systems may much more be determined by relationships between the system components than by the system components themselves.

The analysis of resilience of CAS is more complicated than for simple systems. Simple systems as well as complex systems might have in common to have fix tipping points. But as already mentioned, for CAS, the tipping point may itself depend on the state of one or more subsystems. The discussion on resilience will first show some mathematical characteristics of resilience and loss of resilience (frailness), followed by examples of from different scientific fields.

Resilience can be defined by a set of mathematical characteristics which opposes resilient systems to frail or vulnerable systems. As mentioned already, complex systems are made up of sub-systems that interact in such a way that either an overall resilient pattern emerges, or on the contrary, a frail pattern of development emerges that can bring the system beyond its tipping point and will bring it to collapse or to stabilize in a completely new state of equilibrium. A complex system can best be understood as a network of subsystems. Network science shows some interesting mathematical communalities of resilient systems of different disciplines, which distinguishes them from frail systems. These characteristics are listed below:

- Loss of gradient: If a resilient system is being compared with a frail (i.e. less resilient) system, the latter shows overall weaker reactions to a disturbance. This is illustrated by a weaker gradient or slope leading towards equilibrium. In the figure below the resilient system has a strong gradient towards the equilibrium (image A) whereas the frail system has a weaker gradient towards equilibrium (image B).

- Slowing down of reaction time: A resilient system has a short reaction time or short recovery time (image C) whereas the frail system has a longer reaction time indicating slower recovery (D) than the resilient system. The slowing down of recovery time is recognized as one of the most important characteristics of lower resilience.
- Increase of variance: In a resilient system, key target variables vary within a limited bandwidth and hence show little variance (image E). Also, the deviations show usually little temporal autocorrelation among themselves. On the contrary, the frail system shows higher variance of its key target variables, which is also accompanied by higher temporal autocorrelation of the deviations. This means a deviation has a certain probability to predict the size and direction of the next following deviation. The tipping point can then be defined as the distance below which system will still swing back to the equilibrium value. Beyond the tipping point, the system will find another equilibrium. The new equilibrium means that the system will have evolved.
- Increase of cross-correlation between sub-systems: In a resilient system, the sub-systems which compose it are not strongly correlated among each other. If a sub-system experiences a disturbance, this disturbance will have little effect on the other sub-systems, and hence little effect on the overall system. This means, in a resilient system, a disturbance remains local or isolated. In the frail system, on the contrary, a disturbance in one sub-system is likely to create a disturbance in another sub-system, which in turn may create more disturbances in third sub-systems. The overall system becomes frail.

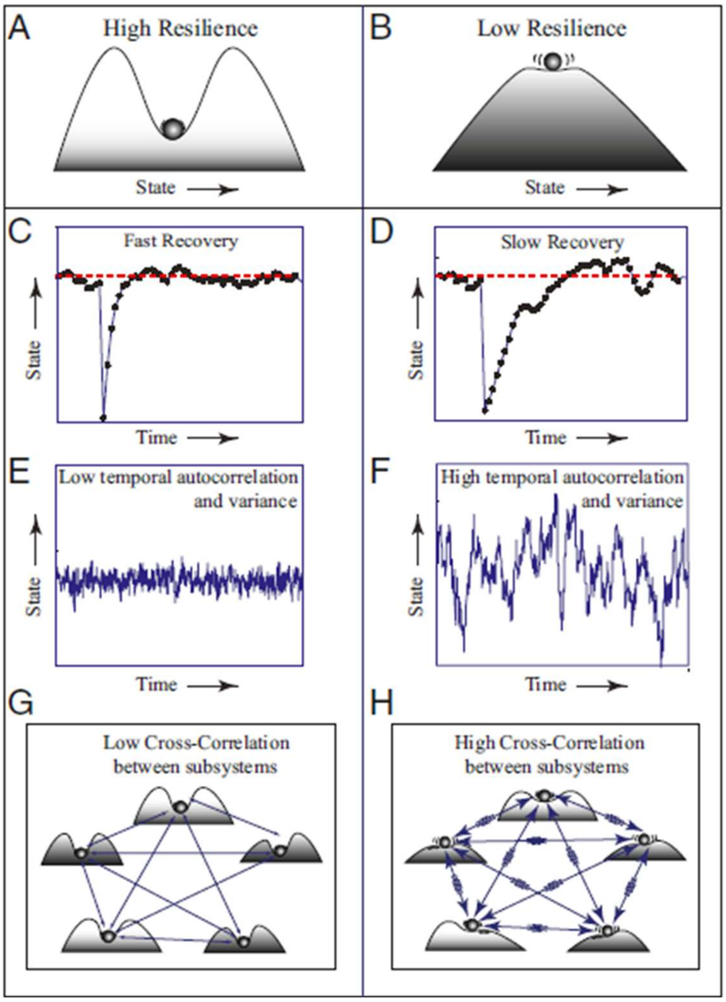


Figure 112: Dynamic indicators of resilience (DIORs)

Source: Marten Scheffer and others[265]

The statistical analysis aims at identifying which variables are so-called dynamic indicators of resilience (DIORs) that show to express resilience or fragility by means of quantitative measures. To the temporal DIORs, spatial DIORS can be added, namely spatial clustering. An illustrative example of evolving spatial clustering of a frail system can be seen from images of the drying up of the Aral Sea which started shrinking in the 1960s and whose surface today is a fraction of the one of 1960[266267] (see also section 3.2.1. below). Besides the Aral Sea, also the Caspian Sea level has been decreasing at a rate of 6.72cm/year since the mid-1990s. If the main reason of declining sea level, namely higher evaporation due to higher temperatures[268] is ascertained and this trend continues, then spatial form of the Caspian Sea may evolve, showing clustering behaviour.

These mathematical characteristics of resilience should be completed by some examples. It will become apparent that some CAS are “frail”, whereas others are “regenerative”.

“Frail” systems are those whose tipping point creates a very sharp discontinuity beyond which the overall system will be irreversibly damaged (e.g. death of biological organisms, or total crash of engineered systems like the Titanic). For “frail” systems, resilience is all about how to avoid reaching the tipping point.

“Regenerative” or partially resilient systems are those which may have important tipping points, but these tipping points are not lethal. They still represent a strong hiatus of metabolic activity, from beyond which (e.g. F1 in the computer simulation below) it is nearly impossible to come back to earlier activity levels (only F2 can be reached). As examples, many types of plants easily support trim or cut within certain limits but overgrazing or overharvesting will cause damage. The same can be said for overharvesting of many other biological resources. Not only overharvesting, but also other environmental impact may cause going beyond tipping points. Coral reefs are e.g. said to be unable to survive the acidification caused by climate change[269].

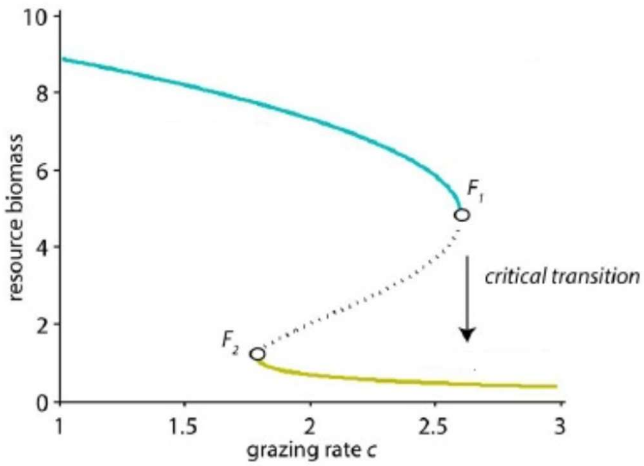


Figure 113: Tipping point F1 of regenerative biological resources

Source: Dakos and others (2012)[270]

For both, plants and animals, resilience is only partial as neither of both will survive all types of shocks. Because of the possibility to trim plants, the (partial) resilience of plants is sometimes believed to be greater than the (partial) resilience of animals. In animals, on the contrary, the capacity to regenerate parts of their body is very rare. An example of an animal having the capacity to regenerate severed limbs is the Axolotl, a type of salamander[271]. The capacity to regenerate itself after being cut is also known in the planarian flat worm which, when cut into two halves splits into two organisms[272]. Due to this capability, such animal species are very demanded for scientific research. Both, plants and animals are, however, locally regenerative, meaning that a local damage of a part of the organism (e.g. an injury of a tissue) will usually be repaired and functions will be restored. This local resilience is facilitated by cell-based morphology of biological organisms that have the capacity to repair broken cells and tissues by new cells and fresh tissue.

The above-made illustrative distinction between “frail” systems and “regenerating” systems should not be misinterpreted to mean that “frail” systems are always “frail”, and “regenerating” systems are always “regenerating”. It should be emphasized that cities belong to both, “frail” and “regenerating”.

- Cities, just as most socio-economic systems, are often regenerating as cities, while their components are frail. Only exceptionally, cities become frail and extinct. Machu Picchu in Peru or Chichen Itza and other Mayan cities in Mexico have become extinct. The extinction of Maya cities is now believed to have been the result of local climate change due to deforestation[273]. Looking at similar systems in nature that are regenerating but have frail components can be helpful for city planners in trying to better understand and master the frailness of cities.

- In forests, two very different kinds of reactions in stress situations can be found. The resilient forests (shown in red in the figure below) satisfy the description of resilience given in the preceding paragraph. When impacted by usual types of disturbance such as hurricanes or fires they may undergo heavy losses over ground but maintain the essential functions underground which allows them to quickly recover. The resistant forests (shown blue in the figure) may resist to heavier types of disturbances than the resilient types of forests, but once a disturbance is so heavy that the tipping point is exceeded, they suffer heavy losses from which they recover only very slowly if at all[274]. The distinction between resilient and resistant forests depends on the type and place of the disturbance. Disturbances of forests are e.g. windstorms, tornadoes, ice storms, droughts, wildfires, floods, landslides, avalanches, insect infestations, herbivory, and volcanoes.

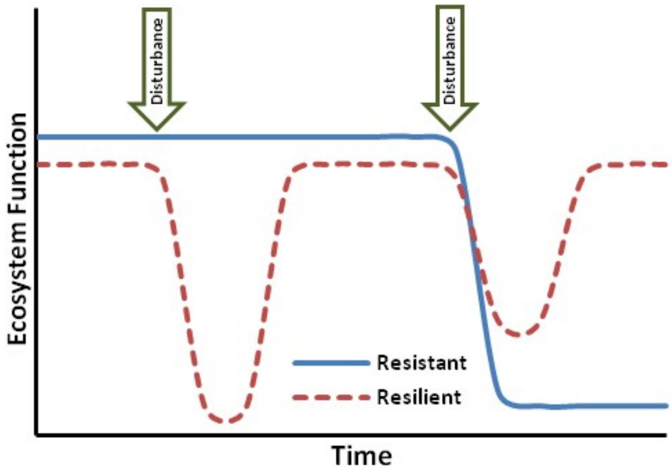


Figure 114: Resistant versus resilient forest types

Source: Silviculture and Applied Forest Ecology[275]

- The climate is about to change and thereby to affect important (frail) sub-systems. The climate itself will, however, be more resilient and survive but with modified characteristics.
- IT systems are disturbed by cyber-attacks that affect their (frail) software, but normally leave their (more resilient) hardware untouched.
- Electricity grids can experience blackouts affecting their (frail) operation, but their (more resilient) hardware may remain unaffected.

A very special type of CAS is the human body. Together with some other similar animals it shares the characteristic of a double governance composed of a fast (nervous) system and a slow (autocrine, paracrine, endocrine) system. The human body is overall frail, but partially resilient. Resilience depends on many interacting systems shown in the outer circle of the figure hereafter. They manage not only blood temperature, but a large series of other variables. A few of them are shown in the inner circle of the figure. All these are homeostatic but are also affected by external influences. As an example, blood temperature is falling under exposure to a cold environment and rising in a hot environment. In both cases a resilient body acts either to produce heat e.g. by shivering, or by evacuating heat through transpiration. Similar mechanisms exist for all the other homeostatic target variables.

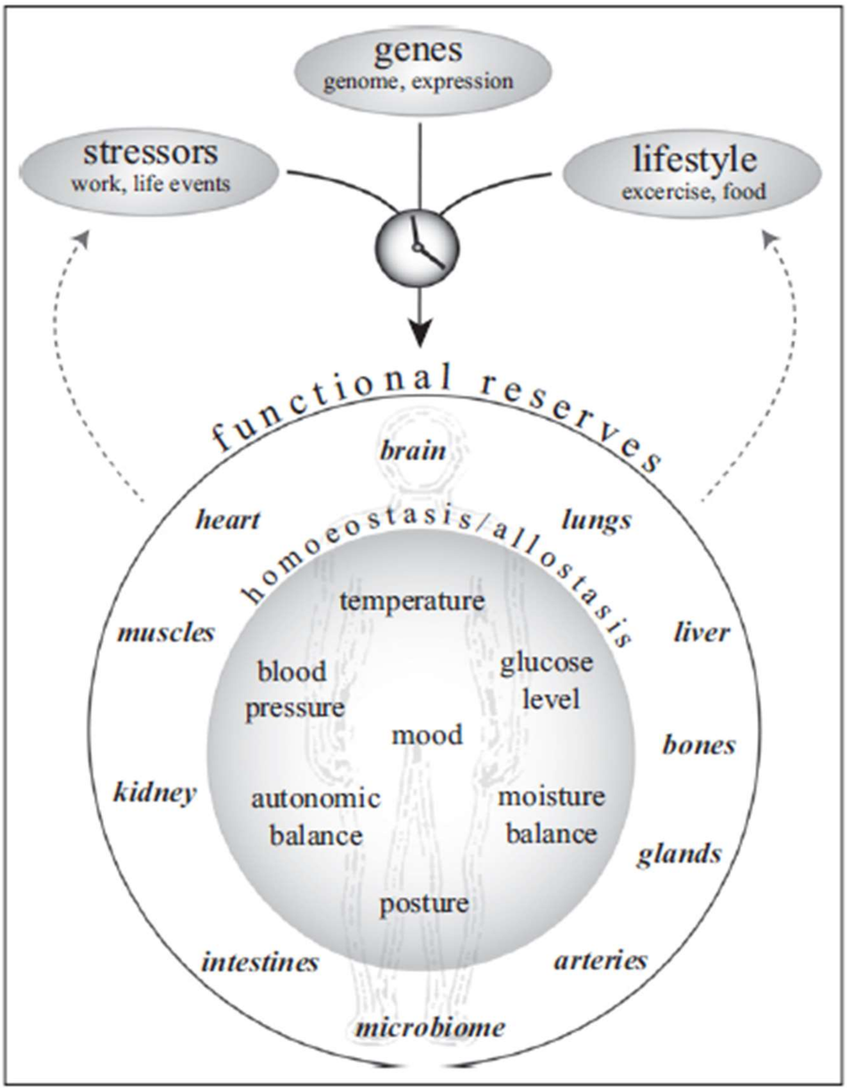


Figure 115: Sub-systems (outer circle) and control variables (inner circle) of human health

Source: Scheffer and others[276]

The special characteristic of the human body as complex adaptive system (CAS) is to have several types of homeostatic regulatory mechanisms[277]. Body temperature may be the best-known of them. These homeostats are involuntary in the sense that their target value (e.g. body temperature) cannot be influenced by voluntary choice. They are governed to a certain extent by the so-called autonomic balance, a tight equilibrium interaction between the sympathetic nervous system (SNS) which brings the individual into the "fight or flight" mode, and the parasympathetic nervous system (PNS) which brings it into the "rest and digest" mode. Both are part of the non-voluntary peripheral nervous system. In case of a sudden disaster like an earthquake, the SNS immediately activates the "fight or flight mode" (increased heart rate, blood pressure, converting glycogen to glucose, stop intestinal contractions) facilitating the individual's search for shelter or protection. On the contrary, in the absence of any frightening stimulus, especially after meals, the PNS activates the "rest and digest" mode lowering heart rate and blood pressure, and resuming intestinal contractions and production of glycogen, facilitating build-up of body resilience[278]. But contrary to an automobile that either accelerates (SNS) or breaks (PNS), the healthy human body living in a normal environment does both together, either at medium or at high level. The healthy conditions are shown in the green quadrants of the autonomic balance diagram. Quadrant 5 shows a balanced healthy individual in a neutral environment, quadrants 8 (relaxation response) and 9 (autonomic hypertonia) an athletic or well-trained individual. Quadrant 3 (severe stress response) shows an individual under constant stress but having still the capacity to react, whereas quadrant 1 (autonomic dystonia) shows an individual having lost resilience in both modes, “fight or flight” as well as “rest and digest”. Quadrant 7 indicates deep relaxation, which is not quite identical to sleep. Sleep is a cyclic succession of different activity phases during which autonomic balance changes[279][280][281].

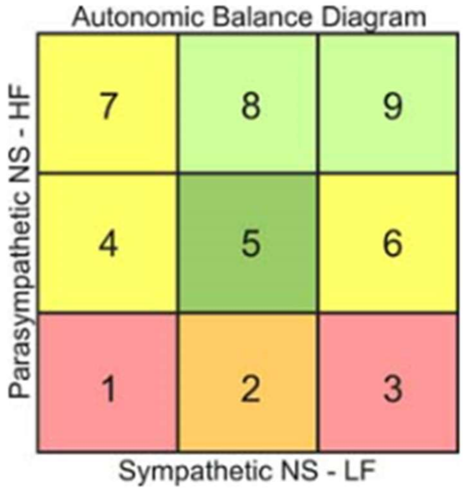


Figure 116: Autonomic balance diagram

Source: Biocomtech[282]

When referring to resilience for the human body, people usually mean healthy lifestyle comprising e.g. balanced exercises, food. Most specialists advise keeping a so-called healthy lifestyle which contains any or all the following:

- Abstain from smoking and reduce drinking alcohol
- Eat a diet high in fruits and vegetables, cook meat thoroughly.
- Exercise regularly
- Maintain a healthy weight
- Get adequate sleep
- Keep hygiene high (wash hands, wear face mask during epidemics)
- Minimize stress

The scientific problem is that most of these common-sense rules of healthy lifestyle have not yet been experimentally validated in scientific methods using a sample and a control-sample[283]. Up to now little direct links between lifestyle and enhanced immune system have been proven. The same uncertainty also exists for defining what resilience means for socio-economic systems like cities. While general ideas of resilience for socio-economic systems emerge, further research should determine exact causalities. Some major such ideas are exposed in the following sections.

3.1.2. Integrating Ecological Resilience into Urban Planning

The following sections analyse city-level resilience with respect to impacted urban sub-systems, from the most general to the most specific sustainability domain – ecology, society, economy, governance. As mentioned earlier, "resilience" without referring to specific types of disasters or shocks is a misleading concept. Just as a "healthy" person can die as consequence of an accident, a "resilient" city can collapse if an unexpected type of disaster occurs. A way to interpret "resilience" is as capacity to address residual risk, i.e. the risk that exists even if all precautionary measures against specific known disasters have been put in place. But understood in this manner, without relation to specific disasters, the meaning of "resilience" is very close to the meaning of "sustainability".

To recall the basic idea of sustainability, as defined in the Brundtland Report (1987)[284], is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Because of its focus on the future, sustainability is a long-term issue. The context of the Brundtland report as well as the 1992 Rio Conference focused on managing resources. In terms of resource management, the objective of sustainability is to protect today's resources by avoiding overconsumption today and to keep resources available for tomorrow. In terms of resource management, sustainability means that the harvesting rate of resources should not exceed their regeneration rate. *APSEC (2018)* shows that when not only harvesting and regenerating rates are considered, but also the stocks of pre-existing resources, sustainability can be interpreted as the conquest of time and measured as product of stocks and time ("H-indicator"). The UN System of Environment and Economic Accounts (SEEA) offers the basis for calculating specific indicators based on that idea.

As for resilience, the preceding section identifies it as emerging property of Complex Adaptive Systems (CAS) and points to the fact that the tipping points of CAS are not fix but depend on the state of its sub-systems. The resilience analysis, therefore, adds the discussion on tipping points, a concept which sustainability analysis does not have. It should be recalled tipping points are determined by the specific type of disaster and the specific type of CAS and its sub-systems on which it impacts.

Another addition of the resilience analysis is to try to identify essential functions of a CAS. The essential functions of a CAS are those which allow an impacted CAS to regenerate after a disaster. Regeneration of a CAS may include regeneration of each of it sub-systems which might have their own specific essential functions.

If applied to the climate, which is the top-level CAS considered in relation to cities and socio-economic entities, it appears that the climate will have a long-term effect on all the different meso-level systems (cities, socio-economic systems, eco-systems, biological organisms). Furthermore, the COVID-19 pandemic adds the awareness that also the micro-level systems (bacteria, viruses and other pathogens) can produce decisive shocks to all the meso-level systems.

The UN has collected material to synergize resilience with sustainability within its NAP-SDG iFrame project. An overview can be found in the figure below.

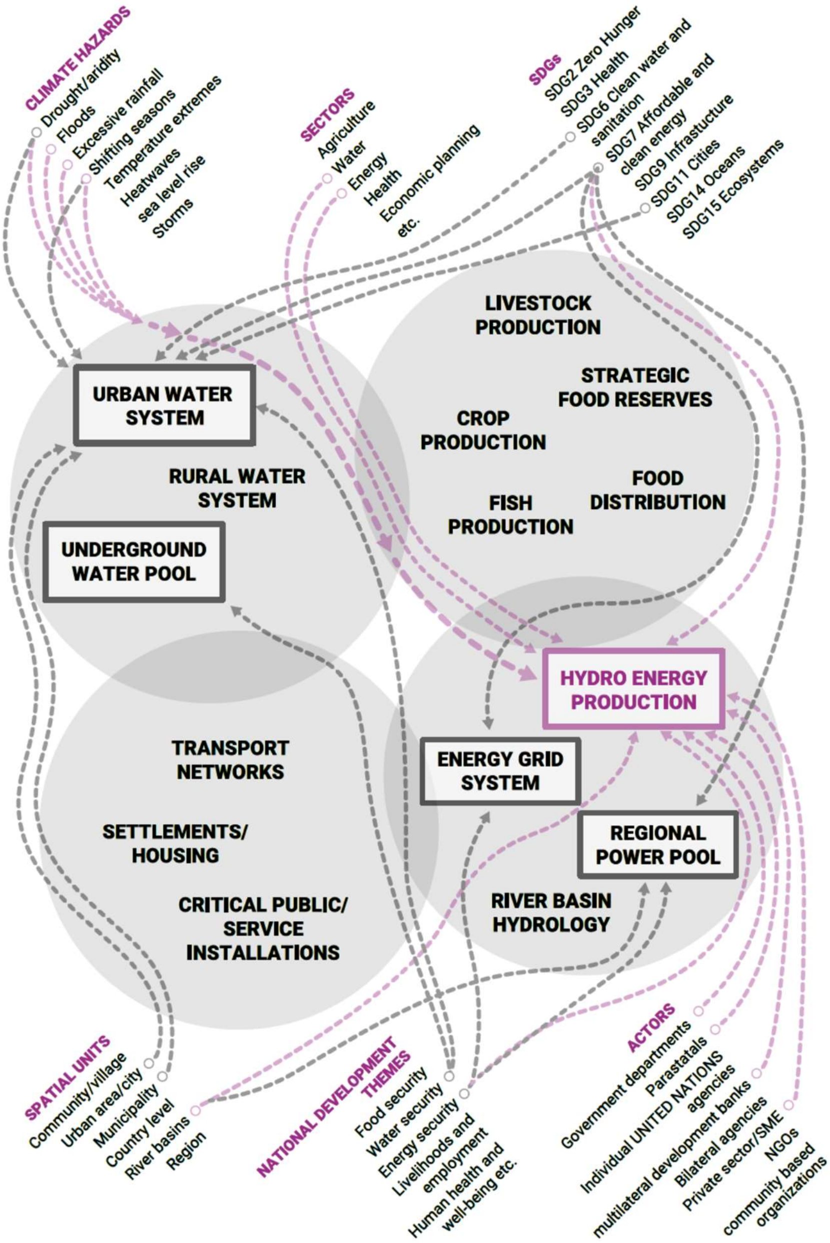


Figure 117: Multilevel systemic view of SDG, DRR and CCA

Source: UN Global Assessment Report on DRR 2019[285]

Cities are just a part of that picture. City-level sustainability is simpler compared to regional or economywide sustainability as problems such as food security, life on land and life below water are usually not a matter to be dealt with by cities. Earlier in section 2.3.3. it has been described that cities are affected by, but do not themselves contribute a lot to shaping the food security and biodiversity cluster.

Cities do have an urban ecology. Urban biodiversity can be monitored in open spaces, parks, alleys, waterways, ponds, on rooftops and vertical gardens. They contribute largely to liveability of the city and could be an economic factor that favours tourism. These measures of urban ecology management can be called expansive as they contribute to expand and enrich biodiversity in cities. Since the 1992 Rio Summit suggestions have been made to integrate biodiversity into urban planning[286].

Figure 118: Wildlife in the streets of Mui Wo, Hong Kong

Source: APSEC

Coastal cities have the possibility to develop underwater biodiversity of their seashore. The example of Tohoku Bay, Japan, is worth mentioning, where underwater physical structures are being created from debris from the earthquake of 11 March 2011 to provide shelter for marine communities. This is known to accelerate submarine revival[287].

On the opposite side, managing biodiversity also means controlling species that develop too strongly. Such species are called pests, and they are being controlled in so-called Integrated Pest Management (IPM) which aims at using simple, efficient, and cost-effective methods to manage rapidly proliferating species[288]. The motivations for such type of control are manifold.

- Protection of human health against diseases and epidemics such as bubonic pest from rats.
- Avoidance of domestic nuisances such as cockroaches or moths or similar, which is accompanied by some lifestyle changes of inhabitants.
- Protection of cultural heritage of cities from pigeon excrements in cities where pigeons or similar nuisances proliferate. A measure of choice has been to forbid uncontrolled feeding of some species of wild animals, or to feed them with special food that diminishes their reproductive capacity
- Avoidance of proliferation of certain species of fish and birds in urban ponds; some cities forbid to feed these animals. In some APEC economies, also other animal populations such as squirrels or apes develop too rapidly as they are being fed by tourists
- Protection of endangered indigenous species from Invasive Alien Species (IAS).

The problem of Invasive Alien Species is specifically addressed in SDG 15, Target 15.8. Not all alien species are invasive. They become invasive from the moment they proliferate excessively so that they threaten or eliminate indigenous fauna or flora, or become vectors of epidemics, or compete with biological resources required in the agriculture or pisciculture food chain and threaten human food supplies. The International Union for the Conservation of Nature (IUCN) issued various types of guidelines for addressing the IAS[289].

The takeaway from this short discussion is that both, expansive and protective measures of urban ecology should be integrated into urban planning and keep a kind of dynamic equilibrium in which extremes on both sides should be avoided. The generalized, massive, and preventive use of pesticides is just as harmful as the opposite idea that cities should avoid taking any measures against nature in view of allowing nature to re-conquer cities. The overall resilience and sustainability of cities can be improved through ecological resilience by integrating both, biodiversity management and integrated pest management which helps also maintaining the relevant skills among the local population.

3.1.3. Integrating Social Resilience into Urban Planning

In the concentric model of SDGs shown in section 2.3.3. the social sphere also contains the economic sphere and the governance sphere as concentric sub-spheres. The present section focuses on resilience and sustainability of the social sphere. Separation between the social sphere and the other two spheres is not necessary for those matters that are common to all three spheres and for which an integrative approach is sought. Approaches to urban resilience that primarily focus on infrastructure are treated further down under economic resilience.

Within the subject area of urban resilience, social resilience plays an important role. Disasters and long-term stress may damage not only the physical infrastructure, but also the social fabric. The maintenance and reconstruction of social fabric regenerates the skills which are the germ for reconstruction of physical infrastructure. More importantly, a well-functioning social fabric produces and disseminates the necessary social change and social adaptation that allows the society to address future disasters and future stress with greater ease. This social adaptation is the social equivalent of “build back better” in physical infrastructures. “Build back better” increases the tipping point level of infrastructures facing a disaster.

The prerequisite of “build back better” in physical infrastructures is social adaptation that determines (usually lowers) the social tolerance level of disaster impacts after each disaster. Between 1900 and 2020, social tolerance levels of disaster mortality in APEC economies have dramatically decreased across all types of disasters. Consequently, better infrastructure was built that led to an unprecedented decrease of mortality from disasters of natural origin in APEC, especially floods and droughts (see section 1.2.1.). Furthermore, vulnerable populations may today have better means to emigrate from areas hit by natural disasters than before. The lowering of social tolerance levels is a genuinely social process which either may take place spontaneously and unnoticed or may be driven by deliberate discussion. COVID-19, e.g., revealed that the social tolerance level of deaths by epidemic had substantially decreased since the Spanish flu in 1919/20, meaning that in 2020, most people did not want to accept a mortality rate similar to the 1919 Spanish flu.

For urban planning, lowering of social disaster tolerance together with “build back better” after disasters translates to specific measures such as e.g. adapting the zoning plan to the new situation caused by a disaster, or building protective infrastructures. These are costly and are easier to implement with broad support by the affected population. The affected population should have a possibility to discuss non-technical key questions such as: What is the expected future life span of a re-built infrastructure? Experts should use all available information to show what difference it makes in terms of cost to re-build an infrastructure or settlement designed to last for e.g. 10, 20, 50, 100 or 200 years or more, given the known local hazards, their probability of occurrence and their uncertainty.

For addressing community resilience, various resilience approaches have been proposed and some are described below. The role of social resilience in the narrow sense of this term is to manage social tolerance and create broad understanding of disasters and ways to avoid them. The frameworks described below are all fulfilling this role to a large extent.

The resilience discussion received impetus following the 2004 tsunami. The Canadian-based International Development Research Centre edited a comprehensive study on Strengthening Resilience in Post-disaster Situations[290] which compiles stories, experience and lessons learnt from South Asia after the 2004 tsunami. Its focus lies on coastal rural populations having suffered from the tsunami. The main message is to prepare them to the possibility of future floods due to climate change. Its illustrations are designed to be communicative to rural populations with low English proficiency and literacy.

Specifically destined to cities, the UN Disaster Resilience Scorecard for Cities has first been established by the UN within the Hyogo Framework (2005) and then updated by the UN Office for Disaster Risk Reduction to the succeeding Sendai Disaster Risk Reduction Framework (2015)[291]. The Scorecard comprises a two-level assessment.

Level 1 of the Scorecard is a preliminary assessment of 47 indicators, each evaluated on the score 0 to 3, which the city can undertake in 1 to 2 days. The Scorecard is organized around "Ten Essentials for Making Cities Resilient" which are divided into three categories: governance and financial capacity, integrated planning, and disaster response and recovery, as shown in table hereafter.

No.	Essential	Category
1.	Organise for disaster resilience	Governance, finance
2.	Identify, understand, and use current and future risk scenarios	Governance, finance
3.	Strengthen financial capability for resilience	Integrated planning
4.	Pursue resilient urban development and design	Integrated planning
5.	Safeguard natural buffers to enhance the protective functions offered by natural capital	Integrated planning
6.	Strengthen institutional capacity for resilience	Integrated planning
7.	Understand and strengthen societal capacity for resilience	Integrated planning
8.	Increase infrastructure resilience	Integrated planning
9.	Ensure effective disaster response	Response, recovery
10.	Expedite recovery and build back better	Response, recovery

Table 16: The ten essentials of the UNDRR Disaster Resilience Scorecard for cities

Source: UNDRR[292]

The ten essentials of the Scorecard can be shown in a diagram (see below) and put into relation to the sustainability analysis made earlier in section 2.3.3. They can be ordered in the emergency continuum comprising on one side the most urgent action and on the other side the most normal action. In this diagram, the most urgent action is disaster response. This requires an immediate and focused action by all members of an affected community to fight against a disaster. The focus of disaster response lies in the social sphere. A little less urgent and taking more time are the actions in the governance areas, comprising organization for disaster resilience, identifying risk scenarios, and strengthening financial capability. Still more time is required by disaster recovery and build back better. As for the last five essentials on integrated urban planning they focus on all spheres and may require long time to be realized due to investment and construction activities. They comprise urban planning and design, strengthening of natural buffers to add protection to potentially affected communities, strengthening the institutional capacity, societal capacity, and infrastructures.

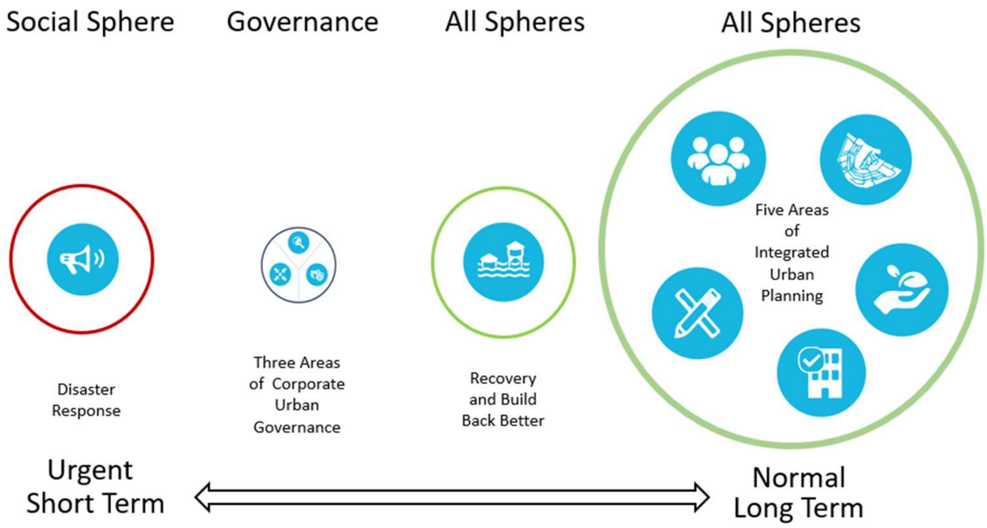


Figure 119: The ten essentials of the UNDRR Scorecard for Cities

Source: APSEC

Level 2 of the Scorecard is a detailed assessment of 117 assessment criteria evaluated on the score 0 to 5, which the city would normally manage in a few months. Annex 4 gives the full set of indicator criteria for the detailed level 2 assessment of cities according to the Disaster Resilience Scorecard. The comprehensive nature of this framework covers key aspects of all the four sustainable development pillars that have been identified in section 2.3.3. above. The indicators are defined with a certain generality so that they can be largely shaped and adapted to the specific needs of each city or community. The only remark concerning the Scorecard is the absence of public-private partnerships (PPP) as means to make the public and private sectors cooperate. Instead, the Scorecard mentions MOUs as preferred means for such cooperation.

The Disaster Risk Scorecard is becoming popular among cities as already more than 4300 cities worldwide have started implementing the assessment provided for by this framework.

Figure 120: 4324 cities or local communities participating in the making cities resilient campaign

Source: UNISDR[293]

Section 2.3.3. above has already suggested considering disaster resilience as instrument for attaining sustainability. Further analysis will be done under the resilience governance section further down. This section will describe some other alternative urban resilience frameworks.

UN Habitat has created the City Resilience Profiling Tool CRPT for helping cities to become resilient. It is compatible with the UN 2030 Development Agenda. In one of its definitions, UN Habitat defines resilience as the measurable ability of any urban system, with its inhabitants, to maintain continuity through all shocks and stresses, while positively adapting and transforming toward sustainability[294]. Resilient cities are persistent, adaptable and inclusive, and these three characteristics are being attained through being integrated, reflexive, and transformative. The CRPT process provides for several steps: initiation/training, data collection and diagnosis, analysis, actions for resilience, a possible feedback return to analysis, and then taking it further. Four sets of data are being collected: 1) City ID, 2) Local governments and stakeholders, 3) Shocks, stresses and challenges, and 4) Urban elements. Among the collected data are hazards and challenges as well as shocks, external as well as internal and complex stresses, risk reduction as well as vulnerability reduction measures. The CRPT also makes a detailed stakeholder mapping. With all this, CRPT certainly contains the necessary data to address local resilience, but the data requirement is very heavy and less focused than the Disaster Risk Scoreboard. This entails the risk to lose focus in secondary questions.

The City Resilience Framework is an integrative approach to resilience allowing cities to assess their strength and weaknesses and make consecutive improvements[295]. The framework has been developed into an index, the City Resilience Index CRI[296]. It divides the city into four categories of goals (health and well-being, economy and society, infrastructure and ecosystems, and leadership and strategy), 12 goals, 52 indicators and 156 qualitative scenarios and quantitative metrics. It is intentionally hazard-neutral and designed to be a complement to traditional disaster reduction methods mitigating specific disasters[297]. The index is questionnaire-based, whereby around half the required data are new and have traditionally not been collected.

Figure 121: City Resilience Framework

Source: City Resilience Framework[298]

The CRI is comparatively data-heavy, requiring collection of hundreds of new data. The result is shown for each of the 12 goals on a scale 1 to 5 or a colour code where green is best, and red is worst. Placing infrastructure and ecosystems into the same group may be an unfortunate design error as the control over infrastructures is much higher than the control over ecosystems. The CRI program which aimed at making 100 resilient cities has been reduced in 2019 due to lack of funding.

Figure 122: City Resilience Index for Mexico City (l), Carlisle, PA, USA, (c), Semarang, Indonesia (r)

Source: City Resilience Index CRI[299]

The World Bank's City Strength Resilient Cities Program is a rapid diagnosis tool which has been launched in 2013. The known APEC city having been diagnosed with this tool is Can Tho City of Viet Nam, located in the Mekong delta and for which a diagnosis has been made in 2014[300]. 98% of the city is lower than 2m above sea level and is often struck by floods. Furthermore, the city is under pressure from newly arriving migrants clustering around transport axes at the city edge. The diagnosis consists of analysing seven important urban domains (urban planning and development, municipal finance, disaster risk management and climate change adaptation, community and social protection, energy, transportation, and water and sanitation). Each one of these is scrutinised for various resilience characteristics (robustness, reflectiveness, redundancy, coordination, diversity, and inclusiveness). The diagnosis is issued in form of a descriptive text and a table with immediate measures to start relieving the most urgent pressures. The World Bank has extended this program to become the City Resilience Program (CRP) in 2017.

The importance of international standards for improving sustainability has been described in *APSEC (2018).* The standards ISO 37120, 37122 and 37123 all refer to sustainable cities and communities and describe sets of indices. More specifically, ISO 37120 is about city services and quality of life, 37122 about smart cities, and 37123 about resilient cities. The World Council on City Data WCCD has cooperated at the elaboration of ISO 37120 and keeps an open data register for those cities that are certified ISO 37120[301]. In its respective focus area, each standard establishes a set of indicators that provide a uniform approach to what is measured and how that measurement is to be undertaken. These standards do not provide numerical thresholds or tolerance levels but agreed expert-level definitions of the respective indicators. They can very well be used as tools by communities to discuss, among others, what tolerance levels for disasters the communities should establish to the extent tolerance levels have not been set or are not sufficiently precise the SDGs. For disaster mitigation, SDGs mainly require improvement in the sense of diminution of the number of deaths per 100'000 persons. Local communities can decide themselves how much improvement they want to achieve and for what type of disaster.

A Community Resilience Planning Guide has also been published by the US National Institute for Standards and Technology NIST in 2015. It is a 6-step guide allowing communities to prioritize and set performance goals for key urban infrastructures (health, education, public safety, transport, energy, communication, water and wastewater). It provides for a comprehensive method to align the priorities and its resources with resilience goals. Step 3 has the ingredients for achieving social resilience as outlined above.

Figure 123: Step 3 of the Community Resilience Planning Guide

Source: NIST[302]

City resilience indices have also been proposed by private companies. Especially insurance companies can collect a lot of information about accidents and disasters and are, therefore, well placed to propose indices. An example might be the City Resilience Score presented within the methodology of the Cambridge Global Risk Framework of the Global Risk Outlook 2018[303]. This index is a composite metric of socio-economic and fiscal resilience. It takes the resilience-related elements from the INFORM GRI risk index, namely vulnerability and lack of coping capacity (see section 1.1.3.) which it completes with fiscal resilience. The City Resilience Score is given by the geometric mean of vulnerability, lack of coping capacity and fiscal resilience. This approach sounds interesting, for economies as well as for cities, but no publicly available values of this index have been found.

A label for resilient infrastructure has been proposed during the Paris Climate Conference in 2015[304]. This SuRe label covers 14 themes and 61 criteria across the pillars of environment, society, and governance. Unfortunately, the economic pillar is missing in this standard. Infrastructures are expensive, and hence, economic viability of infrastructures is key to their development and extension, as has been evidenced in the earlier sections on TOD and LVC.

Environment	Society	Governance
Themes	Themes	Themes
Climate	Human Rights	Management and Oversight
Biodiversity and Ecosystems	Labour Rights and Working Conditions	Sustainability and Resilience Management
Resource Management	Community Protection	Stakeholder Engagement
Pollution	Customer Focus and Community Involvement	Anti-corruption and Transparency
Land Use and Landscape	Socioeconomic Development	
18 Criteria	24 Criteria	19 Criteria

Figure 124: Pillars and themes of the SuRe infrastructure label

Source: SuRe[305]

3.1.4. Integrating Economic Resilience into Urban Planning

Some of the above frameworks already include economic resilience as part of more general social resilience. Economic resilience has nonetheless specificities that are addressed in some other specific frameworks described below.

The most important specific aspect of economic resilience is the reconquest of markets. The Kobe earthquake shows that some business-to-consumer (B2C) markets may never be recovered again after a disaster (see section 3.2.2. below for further details). This can be interpreted as adaptation by consumers who permanently change their consumption pattern after a disaster. Not only the consumer markets are affected by such change. COVID-19 has shown that business-to-business (B2B) markets, i.e. supply chains, might get interrupted as well. The question arises whether economic resilience in the sense of reconquering markets after an interruption can be favoured by specific measures.

This discussion has traditionally been held within the analysis of product substitution. This analysis expects that a non-substitutable product returns rapidly after a supply disruption. Products that are difficult to substitute are products with low demand elasticity. Traditionally, oil has been identified as product with low demand elasticity. Since 1973, the then created IEA has been building up and monitoring 90 days oil stockholding as general obligation for member states. Stockholding is of course a way to overcome short-term security of supply issues for any critical product.

Overcoming security of demand issues after a city or region has been struck by a disaster is a different issue. Traditional analysis suggests that all producers are in perfect competition and that entry as well as exit of market happens at no cost, therefore the problem of resilience does not exist. Even if this hypothesis is rarely verified, market authorities might still bear in mind that eliminating unfair competition practices is particularly important after disasters, if they wish to enable the greatest number of producers to re-enter markets as rapidly as possible. Besides that, the question should be asked, what other factors can guarantee that the products produced in a city or region will rapidly reconquer their original markets. The answer lies in competitiveness of the city or region. The higher the competitiveness of a city, the stronger its market-resilience after a disaster.

Competitiveness has been described in many ways. For cities specifically, competitiveness has been analysed by the World Economic Forum for 2014[306]. The accent is placed on a competitiveness agenda that includes:

- Institutions (how to reform): Leadership and vision, institutional strength, decentralization, windows of opportunity,
- Policies and regulation of the business environment (what to reform): Getting the basics right, developing own foreign economic policies
- Hard connectivity (core physical infrastructure): a mix of planning and organic growth is needed, close hard connectivity gaps, prefer urban density to urban sprawl, intelligent choices in infrastructure
- Soft connectivity: social (knowledge) capital, education, digital infrastructure, making cities more liveable, learn from soft connectivity failures

The World Bank is also visualizing competitiveness of 750 cities, with a focus on growth[307].

An argument to link resilience to globalisation can also be made. The better a city can attain markets in as many as possible parts of the world, the more resilient is that city's economy. This type of resilience is reflected in a globalization index. Globalization indices exist[308], but are only available for economies, not for cities.

An entirely new approach to competitiveness has been developed since 2009 by Hidalgo and Hausmann (H&H). Their approach, called economic complexity, is to measure competitiveness on the sole basis of exports. Their Economic Complexity Index ECI is available online[309]. It exists only for economies, but the idea merits also discussion for cities. Economic complexity according to H&H is based upon the idea that revealed comparative advantage (RCA) of an economy for a given product is greater than average when the export share of that product is larger than the global share of that product. The proposed method provides to collect RCI values in a binary economy-product matrix, whereby RCI values above average are set to 1, and values below average are set to 0. Diversity of an economy is then defined as sum over products of that economy in the economy-product matrix, and ubiquity of a product is defined as sum over economies of that product in that same matrix. Finally, economic complexity is evaluated in a specific iterative procedure in which diversity corrects ubiquity and vice versa until convergence is achieved. For more details see the quoted source. The problem with ECI is that the iteration is not always converging at meaningful results, and that the interpretation does not clearly relate to a theory.

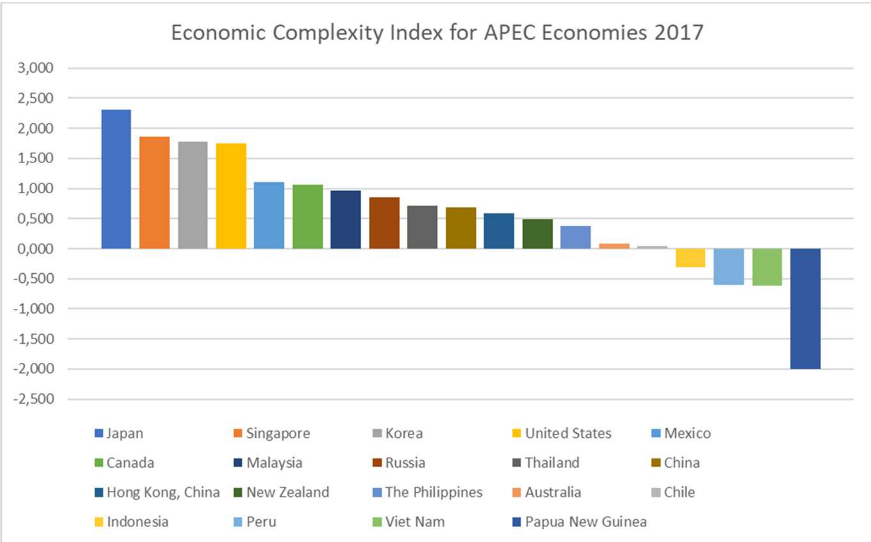


Figure 125: Economic complexity index of APEC economies, 2017

Data source: ECI[310]

Economic fitness (EF) has been proposed in 2012[311] as alternative and improvement over the ECI. An easy understandable explanation of EF can be found in Pietronero and others[312]. EF uses the same export data as ECI and maps these into the same binary economy-product matrix as ECI and has, for the same reason as ECI, only been evaluated for economies. Data for recent years has been made available through the World Bank[313]. The economy-product matrix (see figures below) illustrates the macroeconomic development dilemma of specialization versus diversification. The development pattern predicted by Ricardian economic theory predicts that economies should specialize in those products for which they have competitive advantage. A world composed of such highly specialized economies would, however, not be very resilient. If, e.g., the economy producing the first product (in the first column from the left in the left figure below) is struck by a disaster, the whole world suffers from undersupply of that product. The observed reality shows a picture of diversification (on the right in figure below). As a matter of fact, developed economies produce almost any product, which makes them resilient, whereas underdeveloped economies produce only few, often ubiquitous products, which shows their lack of economic resilience.

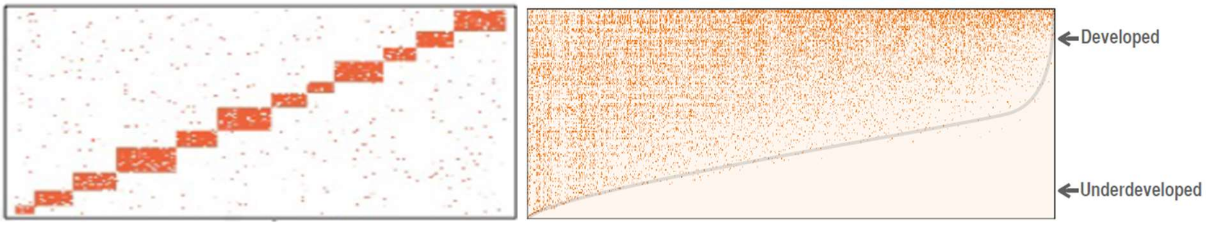


Figure 126: Specialization predicted by Ricardo (l) vs diversification as measured empirically (r)

Source: Pietronero and others

Economic fitness (EF) of an economy is calculated in iterations in combination with the complexity of products of an economy, whereby complexity of products serves to weigh fitness of the economy at each iteration. For the details and the interpretation of the results, and the extent to which EF can be used as predictor for GDP, see the referenced source. Economic fitness of APEC economies is shown in figure below.

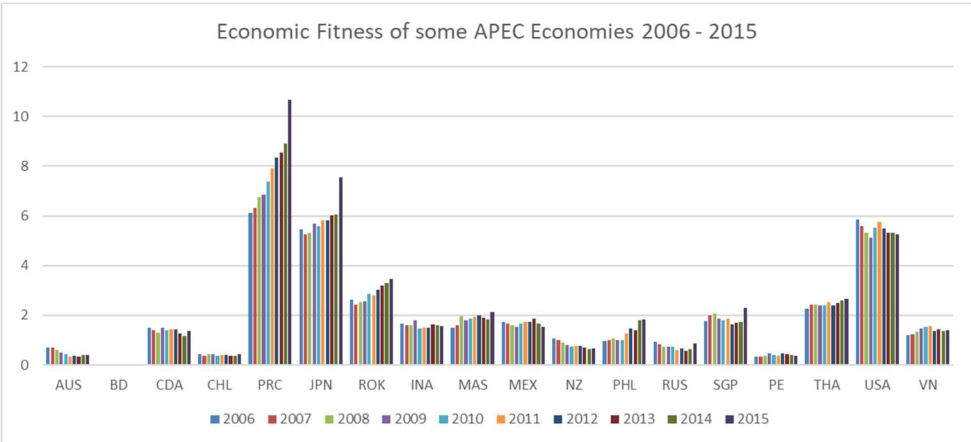


Figure 127: Economic fitness of APEC economies 2006 – 2015

Data source: World Bank[314]

The methodology which is underlying the calculation of economic fitness might still have potential for further development and refinement. It has been proposed to replace the somewhat arbitrary step of creating the binary economy-product matrix by a method that employs the maximum entropy principle[315]. The obtained results should still be discussed further and are in general like EF but show significant deviations in the details.

The preceding paragraphs describe indicators for general economic resilience. Besides these general indicators, specific indicators, standards, regulations, or technical devices have also been proposed for specific economic sectors or situations.

Within APEC Energy Working Group, resilience is the focus of the Energy Resiliency Task Force (ERTF). APEC Energy Ministers Meeting that took place in Cebu, the Philippines, in 2015 stated in EMM Declaration: “We welcome the new APEC Initiative for Enhancing the Quality of Electric Power Infrastructure taking into consideration not only resilience to extreme weather events but also lifecycle costs, environmental impact, responsiveness to changing market circumstances and business continuity.” This initiative started to be concretized in a workshop in 2018 on Promoting Resilience in the Energy Sector[316]. Further work is planned in this direction.

Individual APEC economies have also enacted measures to increase resilience of their energy infrastructures. The Chinese National Energy Administration (NEA) has recently published Guidelines for the Power Industry Preventing and Responding to Typhoon Disasters[317]. These guidelines aim at comprehensively improve power system capacities for prevention from and response to typhoons, and at minimizing the impacts of such disasters. The measures to be implemented consist of optimizing power system planning, tightening anti-typhoon standards, enhancing power grids, and maintaining power supply reliability. The NEA requires all power generation companies to strictly implement practices and measures to prepare for typhoons and other severe natural disasters. Specific recommendations are given for specific energy producing sectors.

Within APEC Energy Working Group, a project has started 2015 on developing solar powered emergency shelter solutions (SESS) as an energy resilience tool for natural disaster relief in APEC community[318]. This kind of tool is part of the disaster response of communities and improves the life immediately after disasters. The innovative aspect of this project is to use the synergy between decentralized solar-powered energy production and the reality of communities that are cut off from outside after disasters such as earthquakes and floods and are therefore obliged to various degrees of self-organization. The first phase of the project has been terminated in 2018. As a result, two alternative design concepts have been proposed.

The simpler one (rainbow home) can be deployed very easily as individual shelter and combined to emergency community spaces. The rainbow home arrives as a ready-made kit that can be deployed easily without need of special equipment. Several sizes are planned. The smallest one is designed as living space for 4 to 6 family members. If several modules are connected, they can be used to shelter correspondingly bigger groups of people. Besides the basic small shelters, bigger modules are planned which can serve as community facilities, such as sanitation facilities, cooking facilities or emergency health facilities allowing to make urgent medical interventions. To ensure energetic and connective autonomy of the rainbow home modules, their exterior surface contains thin film photovoltaic panels. They are equipped with an electricity control module, batteries, an off-grid inverter, connectivity for LED lamps, digital communication such as cell phones, laptops, radios, or special electric equipment. The modules are designed to use passive solar heating as well as active solar cooling. From these specifications, it can be concluded that the utilization of the rainbow homes is mainly adapted to hot, warm, or temperate climates. The rainbow home is not destined to become a permanent residence. It offers, therefore, only limited protection against specific natural hazards.

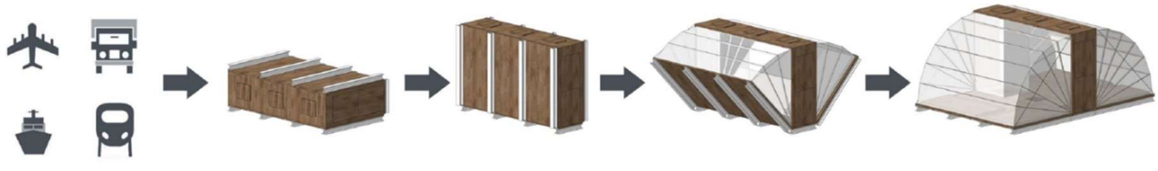


Figure 128: SPESS rainbow home and its deployment

Source: APEC[319]

The second, more sophisticated SPESS design is the harbour design. The structure of the harbour design is made of wood. Monocrystalline solar panels are placed on the roof. Interior walls can be added so that the shelter becomes a small apartment house for two families, including a common bathroom, restroom, and kitchen. Collection of rainwater and storage in an underground cistern are both planned. The planned time horizon of utilization of the harbour design is two years and more, with the possibility to make it become a permanent home. If it is to become a permanent home, the harbour design should be adapted accordingly, e.g. by connecting it to a wastewater facility. Considering the lessons to be learnt from resilience to specific disasters (see sections 3.2. below), the 10cm uplifting above the ground floor should be increased to the height of the expected flood (e.g. 1 or 2 meters) if the settlement is e.g. designed to be placed in regions with flood occurrence. As from its structural properties, the harbour design is not adapted to become a permanent home in regions where cyclones, typhoons or hurricanes are a major occurrence, nor is it designed to give protection against wildfires or tsunamis, as it would not satisfy resilience against any of these disasters.

Figure 129: SPESS harbour design

Source: APEC

3.1.5. Integrated Governance for Sustainability and Disaster Resilience

This section aims at identifying some elements of a combined governance for sustainability and disaster resilience of cities. It will first look at some existing frameworks that describe governance in the double context of sustainability and disaster resilience, to which the lessons learnt from governing complex adaptive systems (CAS) will be added. It will then state the principles of a governance system that combines sustainability and disaster resilience by means of a synthesis of both, the SDG indicators after refinement and the UNDRR Disaster Resilience Scorecard for Cities. It will be shown that this governance system mimics the governance system of the human body which has been described above in section 3.1.1.

A simple framework for resilience and sustainability has been elaborated for the energy-water system, see the figure below. This kind of framework might be useful for addressing specific energy and water issues, but it fails clearly to represent the substantive synthesis between sustainability and resilience defined in the official UN documents quoted above.

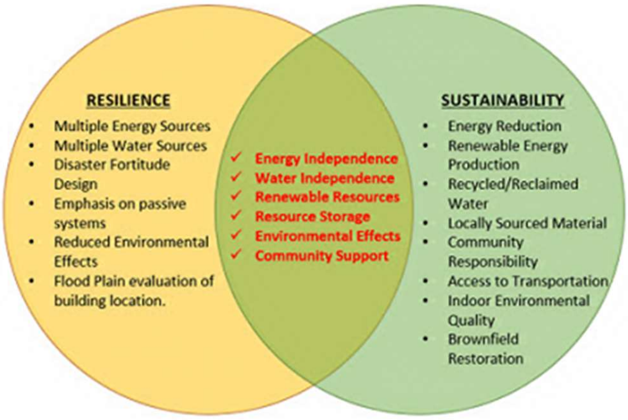


Figure 130: Complementarity between resilience and sustainability

Source: Echotape[320]

A more elaborate integration, mapping the areas of urban planning, energy, water, and solid waste management into the areas of policy, institutions, physical systems, stakeholders, and financial aspects has been elaborated by Suzuki at the World Bank in 2010. It explicitly states the important variables which affects cities and those on which cities can have impact. While showing more clearly the point of view of cities, it is dates from before the year 2015 when the current 2030 Agenda for Sustainable Development was adopted by the UN General Assembly and does not yet reflect these developments, nor does it reflect the fact that the governed systems are complex adaptive systems (CAS).

DIMENSIONS	URBAN	ENERGY	WATER	SOLID WASTE
Policy, legislation and regulations	Land use zoning for residential, commercial, and institutional properties	Energy and emissions inventories and targets Fuel security Air quality standards	Roadway design standards for drainage	Litter prevention programs Materials recycling programs
Institutional context	Metropolitan coordinating institutions	Reform and regulation Conservation programs	Reform and regulation Conservation programs	Reform and regulation Conservation programs Enforcement programs
Physical systems, technology, and spatial planning	Master planning of non-motorized transport facilities, accessibility, amenities, and urban furniture Public spaces	Fuel and vehicle standards Inspection and maintenance Location efficiency Fleet management and efficiency programs	Storm water runoff Production and disposal of infra-structure, vehicles, and systems	Production and disposal of infrastructure, vehicles, and systems Location of collection and disposal facilities
Stakeholder dynamics	Special events to change behaviors and spur investment			
Economic and financial aspects	Savings through coordination	Savings through coordinated utility development (power lines, lighting)	Savings from coordinated road construction	Savings through coordination

Figure 131: Integrating urban policies

Source: Suzuki, World Bank[321]

Similar to the above approach, a governance framework for communities has been set up along the various lines of action to which city governments can be empowered (see figure below). The corresponding actions are shown in eight dimensions that can be grouped two by two. The legal authority to undertake DRR action and the authority to develop plans and policies are commonly part of integrated urban planning, the authority to develop and control budgets as well as the authority to develop partnerships are part of the budgetary process; the authority to access and build data as well as to have adequate and capable staff are part of the early warning/emergency response system, and the possibility to own or operate assets or services and the responsibility to carry out the corresponding action are part of the infrastructure management. This framework shows the empowerment (or lack thereof) of cities to manage sustainability and disaster risk reduction, but sustainability and disaster resilience are indistinguishably merged. Furthermore, the nature of cities as CAS is not adequately represented.

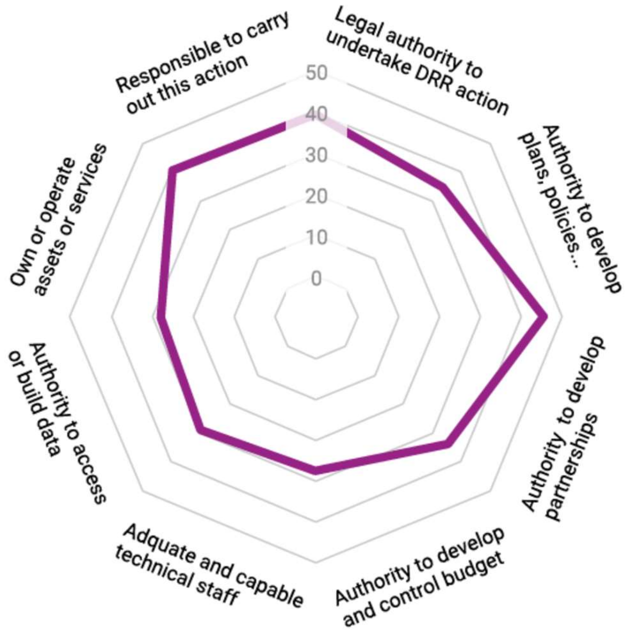


Figure 132: Eight fields of urban DRR empowerment

Source: Gencer and UNDRR 2017

A governance system addressing specifically the needs of governing complex adaptive systems (CAS) has been gradually elaborated and improved for the past 15 years at the International Risk Governance Center IRGC. Risk governance is not synonymous with sustainability nor with disaster resilience. IRGC defines risk governance as the identification, assessment, management and communication of risks in a broad context, including the totality of actors, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analysed and communicated, and how management decisions are taken[322].

IRGC defines now risk governance as a process composed of 7 interlinked steps[323]:

1. Explore the system in which the organisation operates; define the boundaries of the system and the organisation's position in a dynamic environment
2. Develop scenarios, considering ongoing and potential future transitions
3. Determine goals and the level of tolerability for risk and uncertainty
4. Co-develop management strategies to deal with each scenario and the systemic risks that affect or may affect the organisation, and to navigate the transition
5. Address unanticipated barriers and sudden critical shifts that may come up during the process
6. Decide, test, and implement strategies
7. Monitor, learn from, review, and adapt.

Figure 133: Elements of the systemic risk governance guidelines

Source: IGRC[324]

Compared to management cycles described earlier in section 2.2.3., the systemic risk governance cycle is not actually a cycle, as steps can be repeated, and the direction can be reversed if necessary. It is much more explorative, creative, and iterative, having a much stronger focus on maximising the absorption of new information by the system. IRGC does not intend to build a theory of systemic risks but rather to provide practical guidelines that organizations can adapt to their specific needs and objectives. One of the recommendations of the IRGC is that organisations should appoint a "navigator" or process manager for navigating transitions and the systemic risks that accompany them, especially the conflicting stakeholders' objectives and views, as well as[325]:

- Bringing new knowledge to the organisation
- Validating and legitimising the technical methods and approaches used
- Ensuring that scientific concepts are translated into understandable concepts
- Working to break silos
- Monitoring performances
- Organising capacity-building for staff
- Communicating internally and externally
- Reporting and reviewing

The function of the navigator is like the more traditional function of Chief Risk Officer (CRO) that exists in large companies[326] or the Resilience officer proposed by the Resilient Cities framework.

Resilience has recently become a special focus topic of research at IRGC. Two resource guides on resilience have been published in 2016 and 2018, respectively, and a more recent guide on Resilience, critical infrastructure, and insurance in 2019[327].

The IRGC guidelines are flexible and adaptable to the governance of cities which can be understood as complex adaptive systems (CAS). While adapting these guidelines to cities, it should be borne in mind that this adaptation needs to take care of the double context of sustainability and disaster resilience.

This is now the right place to outline the requirements of a governance system that combines sustainability with disaster resilience by means of a synthesis of both, the SDGs indicators after refinement and the UNDRR Disaster Resilience Scorecard for Cities. The definition of governance used in this section is to be understood as systemic risk governance of complex adaptive systems (CAS) as outlined in section 3.1.1. that integrates aspects of network sciences. Network science teaches that overall network resilience can be improved if each of the network's sub-systems strengthens resilience. It is, therefore, necessary but not sufficient to look at resilience of sub-systems. Resilience of governance systems emerges from addressing systemic risks of the system seen as a whole.

Two dimensions of this combined governance are:

- Substantive definition of sustainability as made by the SDGs, its targets and indicators. To the extent that this governance system shall be applicable to cities, the governance system should specially concentrate on those SDG indicators that are applicable to cities. This selection will be made in sections 4.2.
- Substantive definition of disaster resilience of cities based on the 117 assessment criteria of the detailed analysis of the UN DRR Disaster Risk Scorecard for cities.

Recall that making a synthesis between two items does not consist of merging the two items; on the contrary, even in a synthesis they both retain their distinct and separate nature. Section 2.3.3. has already shown that this synthesis can in principle be made by considering disaster risk reduction as an instrument for attaining sustainability as a goal.

APSEC (2018) has described sustainability as conquest of time and shown the H-index to be the basic measure for sustainability. By opposition, resilience addresses short term necessities before, during and after disasters and other emergencies, as well as building internal and external buffers against disasters after they occurred. Therefore, the idea that disaster resilience should deliver the instruments to attain the goal of sustainability makes sense. Disaster resilience includes the fight against short term emergencies which absorb the attention of all members of socio-economic systems to such an extent, that longer term goals might be put on hold or forgotten altogether.

Without disaster resilience, sustainability is fragile, and without sustainability, disaster resilience lacks the long-term perspective.

As will be shown in the sections further down, sea level rise may become the dominant long-term risk for cities.

The figure below, combining figure 86 with figure 119 shown earlier, gives an integrative illustration of how these two concepts can be made complementary to reach a common understanding about their respective roles along the lines just sketched.

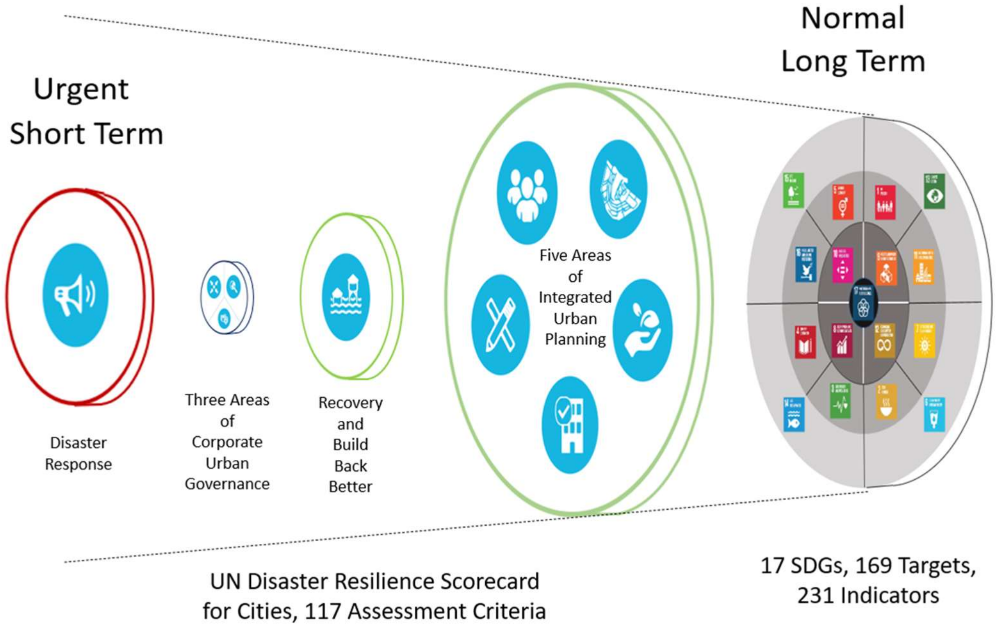


Figure 134: Integrative approach for sustainability and disaster resilience

Source: APSEC

The above figure considers the explicit definitions of sustainability and disaster resilience as adopted by the competent UN authorities. On a more theoretical basis, showing the distinct nature of resilience and sustainability can best be done by mapping them into a diagram where e.g. the horizontal axis designates disaster resilience and the vertical axis designates sustainability. This reflects the idea that attaining sustainability will ultimately depend on fulfilment of disaster risk criteria.

Suppose that both, sustainability and disaster resilience are each measured on a scale between 0 to 3, whereby 0 is the lowest and 3 is the highest score. The figure below shows nine fictitious cities named A to I whose disaster resilience and sustainability scores are mapped into such a bi-dimensional diagram.

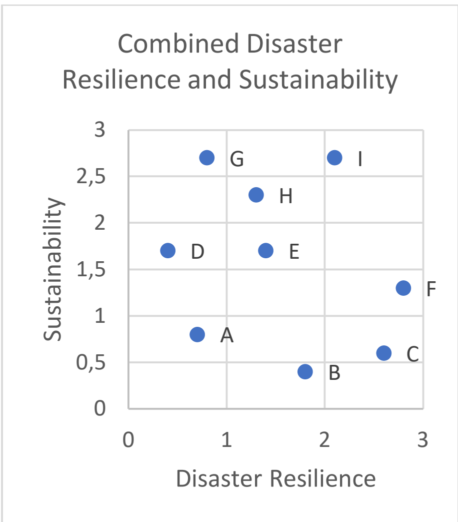


Figure 135: Combined disaster resilience and sustainability diagram of nine fictitious cities

Source: APSEC

In this diagram, the fictitious communities C and F have both chosen to become highly resilient yet show relatively low sustainability scores. These two communities put high efforts to shield themselves against disasters of all kinds but care much less about the longevity of their systems in terms of resource use. Their high disaster resilience may be attained at the cost of keeping low circularity of resource use. On the other hand, communities D and C show higher sustainability scores which means that they make efforts to evolve towards circularity of resource use, but this comes at the cost of low disaster resilience. They may both be severely hit or even wiped out altogether by disasters. Community A is neither resilient nor sustainable, while community I is both, disaster resilient and sustainable.

The above diagram can also be interpreted as mapping communities' scores in climate adaptation (i.e. resilience) versus climate mitigation (i.e. sustainability). Depending on their physical location, some communities (e.g. the fictitious communities C and F above) may be less affected by climate change than others and may also be less exposed to other disasters than other communities. These communities may have a certain tendency to increase their climate adaptation (i.e. disaster resilience), which they can do at relatively low cost, and to take relatively few measures to mitigate climate change (i.e. become more sustainable), which for them might be relatively more expensive.

In sum, communities that are only making efforts in disaster resilience will not participate in the collective efforts to become sustainable, and communities that only focus on sustainability may be fragile and take damage at the next disaster. Hence both, disaster resilience and sustainability need to go together.

This bivalent governance that combines improving both, disaster resilience and sustainability, is found in many animals that are endowed with highly complex nervous systems, including in human beings. Evolution acting during millions of years has favoured the development of both aspects simultaneously in these organisms. The simultaneous action of both seems to have increased the chances of survival of these organisms.

Section 3.1.1. above presented the autonomous balance of the human peripheral central nervous system as the balance between the “fight and flight” and the “rest and digest” modus. Translated to the context of disaster resilience and sustainability, disaster resilience, which addresses emergency reactions, corresponds to the “fight and flight” modus, whereas sustainability, which addresses longevity issues, corresponds to “rest and digest” modus. The combined disaster resilience and sustainability diagram above has striking similarity with the autonomic balance diagram presented in section 3.1.1.

A further remark should be made concerning the differentiation between disaster resilience and sustainability.

- Theoretically, in the “flight and fight” mode, the focus lies on maximizing physical performance. In case of acute danger, all resources are mobilized to fight a danger or escape it. This is a mode which maximizes metabolic flows and physical output. A kind of macroeconomic analogy of metabolic flows is the GDP, which in its present-day definition, is almost a pure flow indicator that incorporates only very limited amount of information on variation of stocks in its term I (investment flows), see section 2.3.4. above. However, GDP or value added is mentioned in the SDGs, not in the Disaster Resilience Scorecard where the theory would expect it.

- Still according to theory, in the “rest and digest” mode, the focus lies on building up reserves or stocks that can be used or drawn down in emergency situations. The macroeconomic analogy is the sum of the different capital stocks described in the

System of Environmental and Economic Accounts (SEEA) which is reflected in the H-indicator, see *APSEC (2018).* However, the five capital stocks are more clearly addressed in the Disaster Resilience Scorecard, namely in the five areas of integrated urban planning, than in the SDGs where the theory would expect them (even though they are also found in some SDG indicators).

- If sustainability were consistently defined in terms of capital stocks and disaster resilience in terms of flows, disaster resilience instruments in terms of input and output flows could always be identified for any type of stock. This would ensure that instruments are available to attain any sustainability target defined in this manner, thereby satisfying the law of requisite variety, see section 2.3.3.

- The lesson learnt from the above is that the SDGs and the Disaster Resilience Scorecard do not exactly respect the theoretical distinction between sustainability and disaster resilience. The SDGs and the Disaster Resilience Scorecard are like Siamese twins which, in their present formulations, are not totally separable from each other.

- From the governance of the human body, it can be understood that the "fight and flight" and the "rest and digest" modes should ideally be in tight equilibrium. If one of them plays a preponderant role or governs alone, there is malfunction.

The integrated governance for sustainability and disaster resilience has been introduced into this report mainly because of the COVID-19 pandemic. This pandemic demonstrates the existence of a real risk that the focus of governing bodies and institutions may shift to short term measures for fighting against the epidemic, whereby long-term sustainability goals might be postponed or forgotten. The integrated governance should help avoid this from happening.

This theoretical analysis should not be interpreted to be a proof of the existence of causal links between disaster resilience instruments and sustainability targets. Rather, it should be interpreted as hypothesis that should be further investigated by more evidence. It also remains to be spelled out what the integrated governance for sustainability and disaster resilience means in terms of setting up the corresponding governing organs in socio-economic communities. This will be part of a separate study.

3.2. Integrating Disaster-Specific Resilience into Urban Planning

3.2.1. Integrating Climate Resilience

The preceding sections have only touched upon the general aspects of resilience, independent of specific disasters. As such approach totally fails to describe the real disaster-specific resilience, it is necessary to describe measures of disaster-resilience in response to each type of disaster. This is what will be done in the following sections.

As a preliminary remark, it should be recalled that cities are meso-level socio-economic Complex Adaptive Systems (CAS). They are part of a nested system of CAS, comprising on the one side of the size spectrum the climate as macro-level CAS, and on the other side of the size the spectrum the micro-level systems such bacteria, biological viruses and computer viruses as micro-level systems. Looking at the vulnerabilities of all the nested CAS, the least vulnerable may well be the macroscopic level (i.e. the climate) and the microscopic level (bacteria, biological viruses, computer viruses). All the levels in between, comprising cities as well as all other socio-economic systems and their engineered components, but also ecosystems and multicellular biological organisms, are at much greater risk compared to these two extreme levels.

Cities are less affected by climate change than rural areas. Nonetheless, they are well advised to learn from worldwide climate resilience experiences and to prepare themselves for climate-related disasters. If e.g. sea level rises due to climate change, cities will be heavily affected.

Climate resilience is the response against a very broad category of disasters. Climate-related disasters will be considered in three parts:

- Disasters originating from inland waters,
- Disasters originating from coastal flooding (including tropical windstorms), and
- Disasters originating from extreme temperatures.

Addressing disasters from inland waters, SDG 6.5 states "By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate". This comprises two distinctive parts: integrated river basin management (i.e. surface water management), and groundwater management.

Integrated river basin management includes all aspects of freshwater, most importantly drinking water and water for households, water for agriculture, industry and services, water for hydroelectricity or for thermal electricity production, wastewater treatment, but also water for navigable waterways. This last aspect creates a link to TOD. Most ancient cities and cultures have originated as a kind of TOD around a river, using the river as preponderant means of transport. It is only recently that other technologies, especially railway-based technologies, have become the backbone of TOD.

Hydrological risks from inland waters are the risks related to freshwater management. The corresponding main disaster types are riverine floods, flash floods, droughts and landslides. Locally and for specific cities or rivers, other more specific disaster types may be relevant, e.g. disturbances in river sedimentation, subsidence (see *APSEC (2018)* for more details), and eutrophication of water.

The most important sustainability dysfunction of most river basins in the world is the general lack of circularity of the water flow system in upstream regions, leading to excessively high offtake in upstream regions and consequent low remaining rest water in the downstream regions, causing rivers to nearly dry out before they reach their estuary. With higher average temperatures, the evaporation of lakes and rivers increases, exacerbating the problem. Furthermore, insufficient water purification in upstream regions results in pollution of the river which causes further stress to downstream regions.

Many river basins worldwide have established structures and principles for river basin management. An overview can be seen in the Handbook for Integrated Water Resources Management[328]. More recently the SDGs (2015) contain the following targets and indicators relating to water:

3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	3.9.2 Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services)

4.a Build and upgrade education facilities that are child, disability and gender sensitive and provide safe, non-violent, inclusive and effective learning environments for all	4.a.1 Proportion of schools with access to (a) electricity; (b) the Internet for pedagogical purposes; (c) computers for pedagogical purposes; (d) adapted infrastructure and materials for students with disabilities; (e) basic drinking water; (f) single-sex basic sanitation facilities; and (g) basic handwashing facilities (as per the WASH indicator definitions)
Goal 6. Ensure availability and sustainable management of water and sanitation for all	
6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	6.1.1 Proportion of population using safely managed drinking water services
6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	6.2.1 Proportion of population using (a) safely managed sanitation services and (b) a hand-washing facility with soap and water
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	6.3.1 Proportion of wastewater safely treated
	6.3.2 Proportion of bodies of water with good ambient water quality
6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	6.4.1 Change in water-use efficiency over time
	6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	6.5.1 Degree of integrated water resources management implementation
	6.5.2 Proportion of transboundary basin area with an operational arrangement for water cooperation
6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	6.6.1 Change in the extent of water-related ecosystems over time
6.a By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies	6.a.1 Amount of water- and sanitation-related official development assistance that is part of a government-coordinated spending plan
6.b Support and strengthen the participation of local communities in improving water and sanitation management	6.b.1 Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management
11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations	11.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population
	11.5.2 Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters

15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type
15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species	15.8.1 Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species

Table 17: SDG targets and indicators relating to water

Source: APSEC based on UN SDGs

Water issues are mentioned in the SDGs not only by specifically setting integrated river basin management as target (6.5), but also in postulating the reduction of disfunctions of the water systems to human health. Among these are the substantive reduction of both, toxic waste and water-related disasters to human lives. On the positive side, the SDGs postulate provision of basic drinking water in schools (4.a.1). Furthermore, SDGs underline water as the medium for water-based eco-systems (15.1 and 15.8). This multiple role of water shows the multiple synergies water has with both, disaster resilience and sustainability.

Integrated water basin management is especially important in water-scarce river basins, but it is vital in so-called endorheic water basins. Endorheic water systems are inland basins whose water does not flow into an ocean. They cover large parts of Asia, Africa, Australia and Northern America (see grey areas in map below). Their climates belong in majority to the dry climates, comprising arid and semi-arid (steppe) climates[329]. With further increase of average temperatures due to climate change, they are likely to become full-scale deserts. For endorheic basins, integrated river basin management is a question of survival. As they are in general very sunny areas, all solar energy-based technologies can have a bright future in these areas, provided sustainable water management allows keeping people in these places. Some similar concepts for cities in arid regions can be found in Cities Alive – Rethinking Cities in Arid Environments (2018)[330].

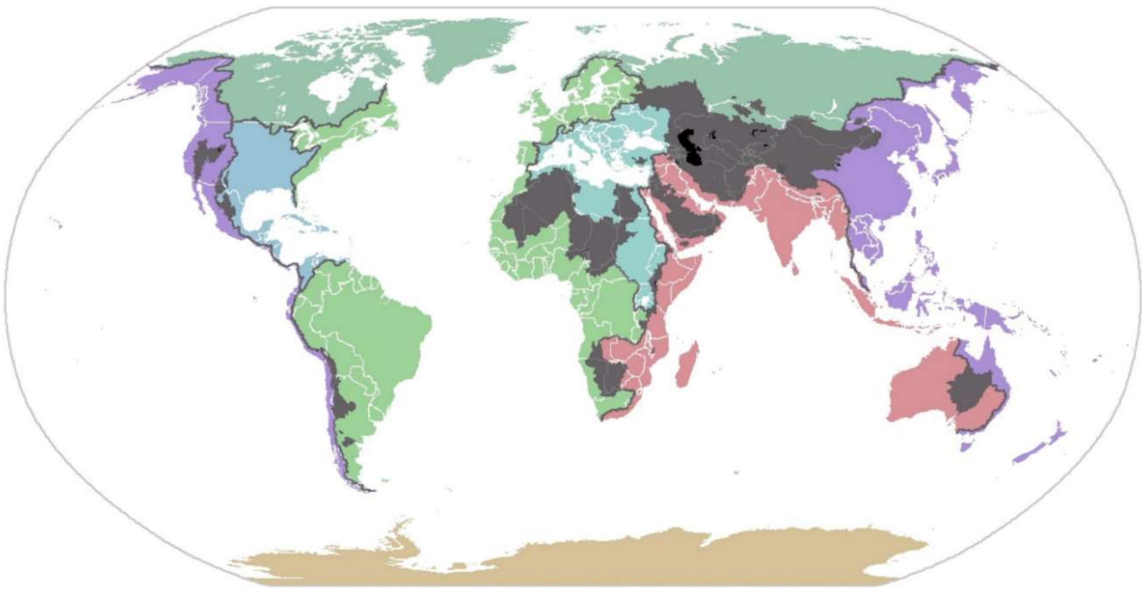


Figure 136: Ocean drainage basins and endorheic basins

Source: Water fandom[331]

The shrinking of the Aral Sea stands as an example of an over-exploited endorheic water system. The reason for the shrinking of the Aral Sea has been water-intensive upstream cotton monoculture. The Aral Sea is one of the large Central Asian endorheic basins. The Caspian Sea is another large endorheic basin. Since the mid-1990s, the Caspian Sea has been losing water. Its water level has lowered by 1.6m. The process is caused by higher evaporation, facilitated by higher average temperatures due to climate change[332].

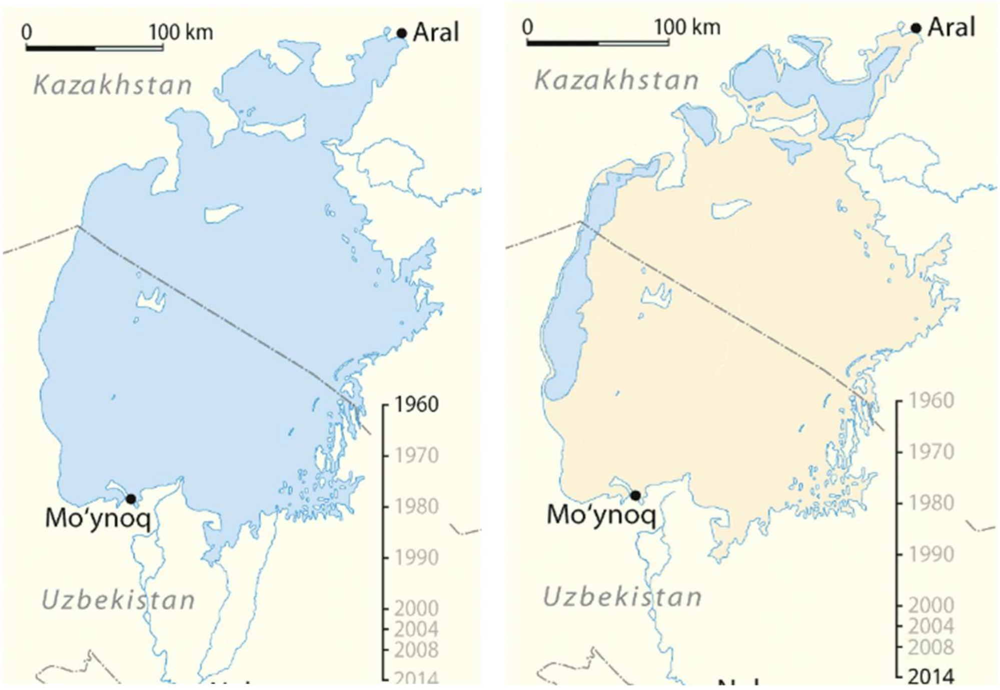


Figure 137: Shrinking of the Aral Sea 1960 – 2014

Source: Portandterminal[333]

Connecting urban planning of any type, including TOD, with integrated water basin management represents one of the most fundamental and efficient ways to connect the cities to their hinterland. This nexus may comprise water, but also energy. More than 90% of the world's power systems rely on water, either to produce electricity (hydropower) or to provide the cooling source for thermal electricity (nuclear, coal-fired) production[334]. While hydropower returns the water to the basin after the turbine, thermal electricity cooled by cooling tower withdraws around 2000 litres of water per MWh[335] or around 500 litres per second for a 1GW thermal power plant. In some regions, thermal electricity plants are the largest water consumers. From the point of view of water management, it would increase overall water-resilience to locate all thermal power plants near seashores for cooling. As for the trend to place PV in lakes, the technology is now mature. For avoiding conflict with aquatic eco-systems, floating PV is designed to satisfy aquafarming specifications[336].

The water basins of islands or peninsulas are relatively small. The small size makes them particularly vulnerable. Islands and peninsulas are water-scarce, therefore the interest to implement integrated water basin management is high. Furthermore, due to the Ring of Fire around the Pacific Ocean, the Pacific riparian water basins of many APEC economies happen to be comparatively steep and small. This is the case in Chile, Peru, Mexico, the US and Canadian West Coast, but also Viet Nam and the Australian East Coast. In these regions, there is a great interest to implement water basin management, in particular if they are water scarce.

APEC's large and shallow river basins are found in China, Russia, in the US and Canadian Atlantic Basin, around the Mekong and Chao Phraya rivers (Thailand) and the Murray-Darling basin of South Australia. In these basins, integrated water basin management may take a dimension that exceeds the scope of planning of individual cities. Reaching agreement about water issues in these water basins may be more difficult, but the result may still be rewarding. Many of these basins have known floods in their histories.

As an example of flood management and prevention, take the Pennsylvania Emergency Management Agency PEMA[337]. The agency in charge of emergencies is the FEMA (Federal Emergency Management Agency). Pennsylvania, the most common hazard is flooding, the emergency planning of PEMA is, therefore, largely concentrating on flood prevention and management and has aspects of a sectoral planning.

Floods are usually not a local phenomenon but impact a region or a river basin which may contain several cities and towns. Where local authorities are involved in flood prevention and management, they are in close cooperation with their region and the neighbouring affected cities or towns.

PEMA defines hazard mitigation[338]: Mitigation is another way to say "relieve" or "alleviate". The general idea is to make a dangerous situation less risky. In emergency management, hazards are natural, man-made, or technological disasters. Hazard mitigation means reducing, eliminating, redirecting or avoiding the effects of those hazards. The standard definition of hazard mitigation that is often used by FEMA and PEMA is:

- Any cost-effective action taken to eliminate or reduce the long-term risk to life and property from natural and technological hazards.

The phrase "cost-effective" is added to this definition to stress the important practical idea that, to be beneficial, a mitigation measure should save money in the long run. If the cost of a mitigation project is less than the long-term costs of disaster recovery and repair for the project area, the mitigation is considered cost-effective. Nationwide, FEMA estimates that for every $1 spent on mitigation, $4 is saved.

In Pennsylvania, the most common mitigation project is acquisition and demolition of flood-risk homes or "buyouts". Acquisition is considered the "best" mitigation because it eliminates the hazard of flooding in a risk area – no homes, no losses. Since 1996, some 1400 homes and an estimated 3500 people have been removed from dangerous flood areas through mitigation projects.

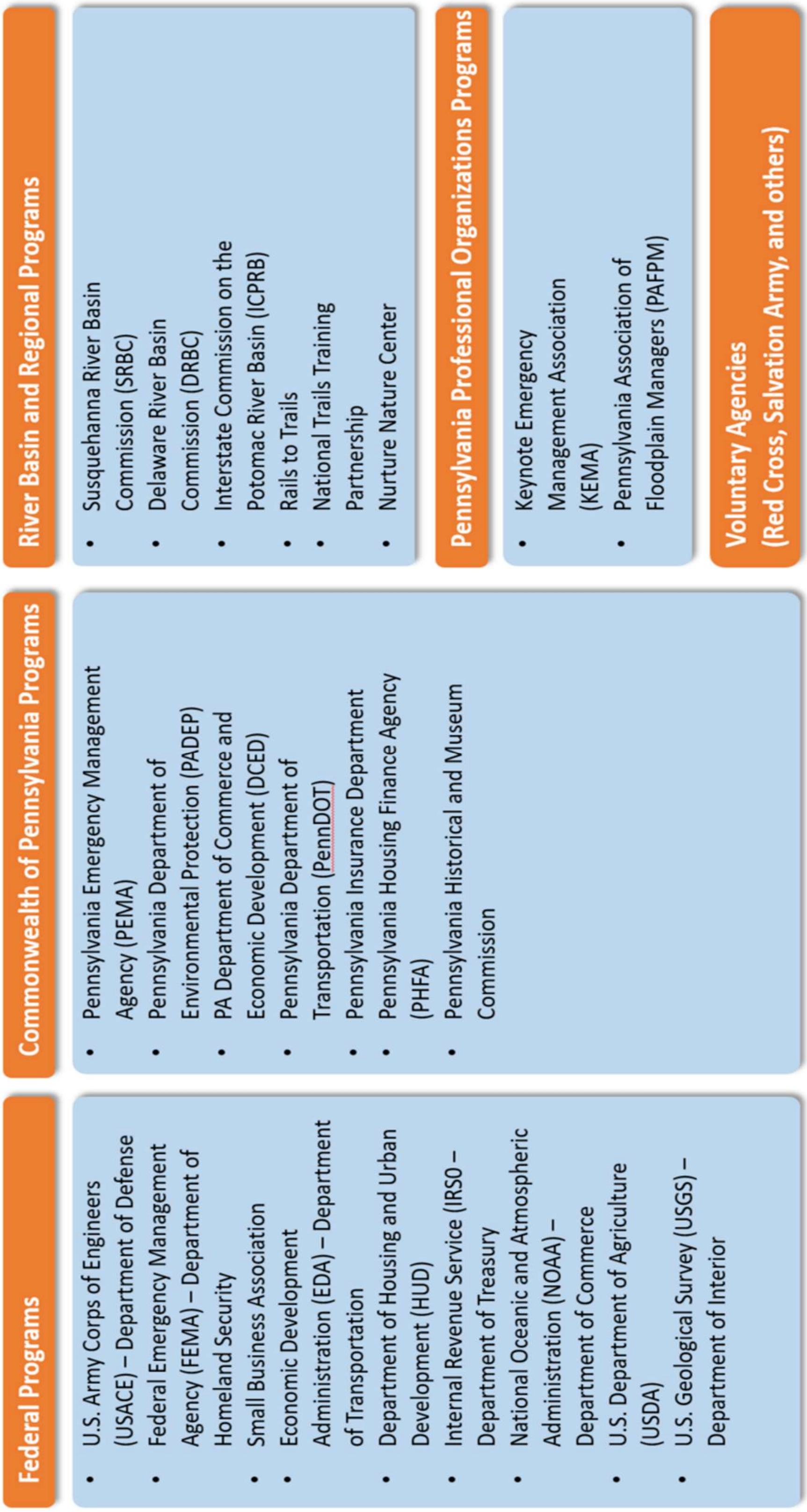


Figure 138: Agencies involved in flood disaster management in Pennsylvania

Source: APSEC based on the Pennsylvania Interagency Flood Mitigation Program Guide[339]

Other mitigation projects in Pennsylvania include home elevations and small flood control projects, though these are fewer in number than acquisition projects. Also, these types of mitigation activities are not as effective because homes and businesses remain in risk areas and can still be damaged in a disaster.

The Pennsylvania Interagency Flood Mitigation Program Guide lists without great technicality the different federal, state-level and local agencies and programs that become active in case of flood disaster, together with their respective mission statements and the kinds of specific activities or programs each of them has in relation to flood disasters.

The second aspect of management of freshwater resources is groundwater management. The depletion of groundwater aquifers is a matter of fact. This can be observed by satellite measurement. A study published in 2015 shows that a third of the world's biggest groundwater basins are in distress and suffer from overuse, whereas less than half of the basins are replenishing [340]. The replenishing groundwater basins are often far away from cities. Regeneration of groundwater storage could be actively promoted by draining water to porous (e.g. sandy) soils. Groundwater depletion creates soil subsidence. More problematic about the groundwater issue is that the quantity of groundwater remaining in the soil is largely unknown. Whenever groundwater is pumped for use, estimates should be made about remaining stocks to avoid unexpected disruption. In general, more needs to be done to estimate the risk of water system failure[341].

Responding to problems of the freshwater cycle in a holistic manner, China has created the concept of sponge city. The main idea is to favour surface water penetrating the underground so that groundwater resources can be replenished, and surface flooding diminished. The Chinese city of Chengdu decided in 2015 to implement the concept of sponge city.

Figure 139: Concept of sponge city

Source: City of Chengdu[342]

To summarize, the key principles that guide river basin management and groundwater management are recapitulated in the table below. The table states objectives, measures, and synergies with other measures.

Objective	Measure	Remarks / Synergies
Determine comprehensive water balance	Real-time water inflow and outflow data form basin (geographic and temporal distribution, trend)	Early Flood and Drought Warning System Synergy with smart city
Provide for high water quality	Continuous measure of water quality and pollution	Synergy with smart city
Flood management and drought mitigation	Build adequate water storage capacity and hydro-engineering infrastructures	Synergy with urban water supply
Minimize settlement in flood-prone areas	Create a flood cadastre, buy out homeowners in places that cannot be made flood-resilient	
Manage interregional balance	Link water storages by underground pressure tunnels, allow pumping and storing water for flexible water storage and electricity supply	Synergy with renewable energy
Minimize evaporation	Prefer surface water storage in cold upstream basins rather than in warm downstream basins.	
Minimize evaporation	Prefer water storage in form of groundwater rather than surface water. Establish a cadastre of surface areas allowing penetration of surface water into ground water (e.g. sandy soils), and drain water towards these areas	Synergy with sponge city
Minimize evaporation	Install floating PV stations on lakes and artificial water basins	Synergy with renewable energy
Minimize evaporation	Avoid placing thermal power stations near inland waterways, place them at ocean shores instead	Synergy with energy production
Avoid systemic risk of dam failures	Where cascades of dams are built, use highest standards	
Optimize flood management	Install variable water level regulators at the outflow of natural lakes, allow natural lakes to participate in flood management	
Avoid unnecessary ecological damage	Define minimum water flows below dams	Synergy with use of waterways for transportation
Avoid splitting aquatic ecosystems	Install fish ladders allowing fish to overcome dams	
Satisfy agricultural water needs	Dynamic planning of agricultural irrigation needs	Synergy with smart city
Water-intensive activities	Adapt quantity and location to long-term availability of basin	
Re-use of grey water	Provide for urban or building-scale grey water system	
Maximize wastewater treatment	Generalize wastewater treatment	Synergy with energy production

Table 18: Key principles of integrated freshwater management

Source: APSEC

The second part of the analysis of climate resilience comprises resilience against coastal flooding. This is different from inland flooding as it is not linked to water basin management. It is, however, related to tropical windstorms called cyclones, typhoons, or hurricanes during which several elements coincide, namely high sea waves called storm surges (the deadliest and most destructive part), strong wind (>118km/h, see section 1.2.2.) caused by low atmospheric pressure, and heavy rainfall. A fourth cause, namely spring tide combined with an estuary-like coastline, can make the effect even worse. In cases storm surges coincide with spring tides, it becomes a storm tide. Storm tides are the deadliest and most destructive effects of hurricanes.

Measures are being taken by authorities to establish flooding cadastres and establish early warning systems and evacuation plans for risk-prone areas.

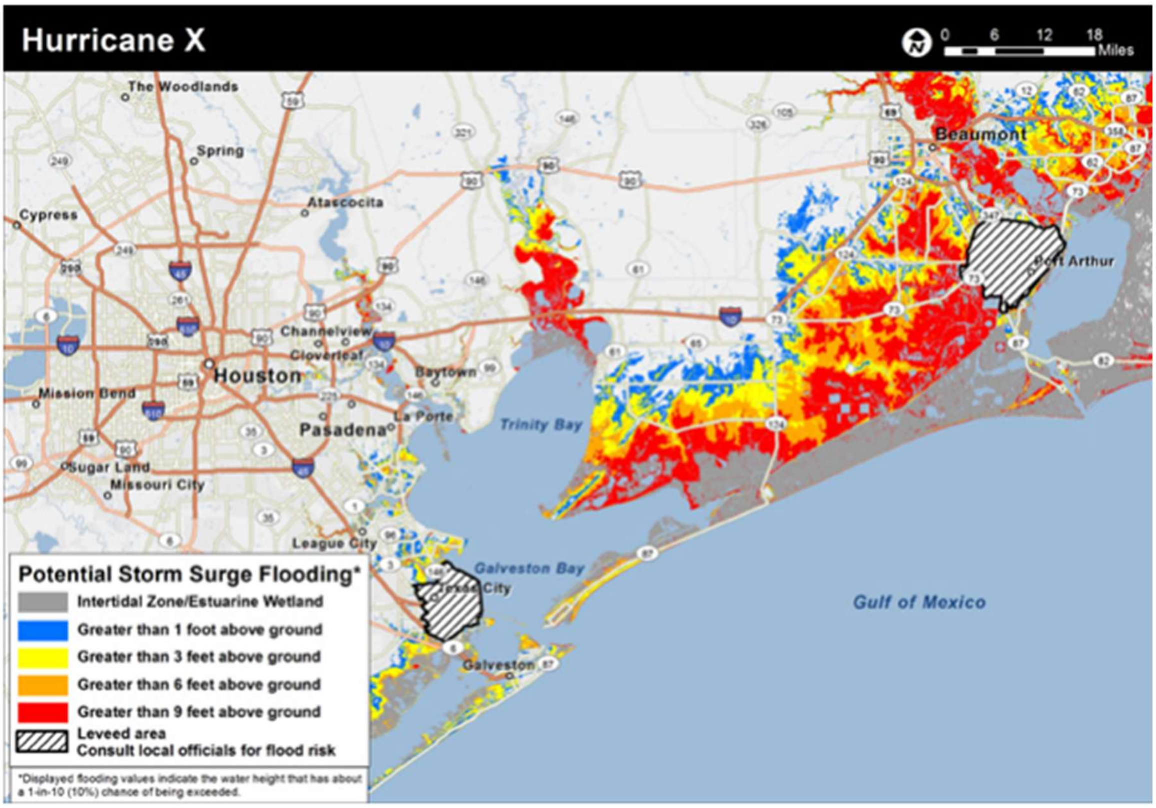


Figure 140: Potential storm surge flooding in Houston

Source: US National Oceanic Atmospheric Administration NOAA[343]

Such measures are all in all just an embryo of a comprehensive response to coastal flooding. In fact, there are five possibilities of action to be considered:

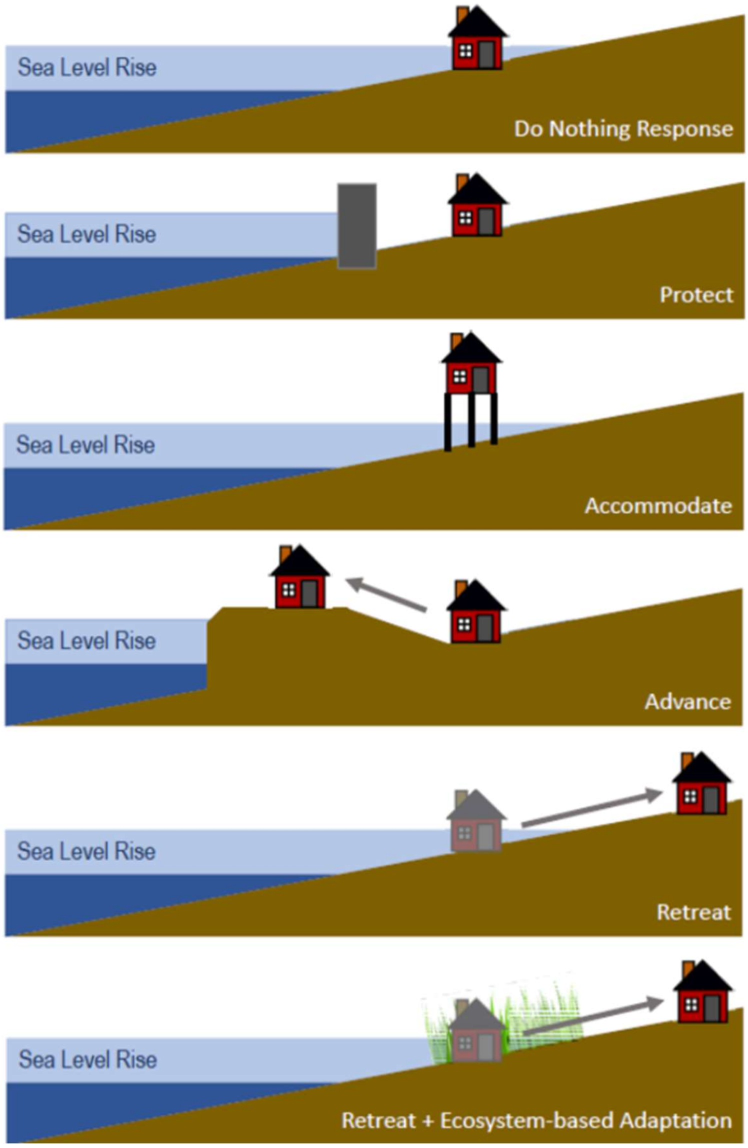


Figure 141: Strategies facing sea level rise

Source: National Resources Defence Council 2019[344]

Mitigation of tropical windstorms and coastal flooding should take a long-term approach as the risk is increasing anyway. Unfortunately, option 1 (do nothing) is still prevailing in many cities. Some cities (e.g. Louisiana) have started protecting themselves (option 2). Also New York has elaborated a large set of measures, some of which might prove insufficient in the more distant future[345]. In the long term, options 5 and 6 are more realistic. Studies have been made to determine the use of biological shielding such as mangroves or similar vegetation on land[346] or coral reefs in the sea[347] as protection. But besides these, cyclone-specific building measures should be added. Above all is essential to realise that tropical windstorms have similar destruction potential like earthquakes and can transform entire cities into debris (see figure below). The hydrostatic pressure coming from sudden rise of groundwater can move insufficiently fixed houses.

Figure 142: Earthquake-like damage by Typhoon Ketsana, 28 September 2009, the Philippines

Source: Reuters

It is therefore logical to suggest that any new housing or new infrastructure built in areas struck by tropical windstorms should be made cyclone-resistant by design. Moreover, tropical windstorms also transform insufficiently fixed objects into flying or swimming debris. Cyclone preparedness should, therefore, also provide provisions on city scaping. Preparedness measures should also include removing potential flying or swimming debris from open spaces by placing it inside buildings or fixing it (e.g. for cars).

Cyclone-resilient architectural design is still in its infancy. It takes account of high wind speeds and flooding. For this reason, it involves round-shaped buildings which may be raised above ground to allow flooding[348]. Special attention is given to doors and windows, allowing them to withstand high air pressures. Design is made so that the building can specially withstand tropical windstorms coming from the dominant direction of such winds.

Figure 143: Design characteristics of tropical windstorm-proof single-family home

Source: Deltec[349]

APEC Economic Leaders endorsed the APEC Disaster Risk Reduction (DRR) in 2015, see *APSEC (2018)*. One of its key elements is build back better after a disaster. In this sense it would be useful to start planning cyclone-struck areas with a modern integrated urban planning concept which could integrate principles for cyclone prevention. Simultaneously, such new settlements would be planned as higher density neighbourhoods with multi-storey buildings designed to be cyclone-resistant from the start. Such neighbourhoods could use existing synergies with sustainable energy and simultaneously diminish dependence from fossil fuels. To fight water intrusion on the first floor, buildings may be equipped with pumps driven with locally generated energy[350]. Such buildings should fully integrate smart technologies. Where waterways are a conceivable option, these might be used as backbone for transit.

The table below sums up the main principles to reduce coastal flooding. It does not exclude any of the options presented further above, except option 1, as doing nothing is not advised. Some measures mentioned in this table have already been mentioned in table above under integrated river basin management. They also have validity for coastal flooding.

Objective	Measure	Remarks / Synergies
Determine comprehensive water balance	Real-time water inflow and outflow data form basin (geographic and temporal distribution, trend)	Early Flood and Drought Warning System Synergy with smart city
Provide for high water quality	Continuous measure of water quality and pollution	Synergy with smart city
Avoid unnecessary cyclone risk	Create a flood cadastre and buy out homeowners in places that cannot be made cyclone-resilient	
Make buildings cyclone and hydrostatic resistant	Improve cyclone building codes and enforce them in cyclone-resilient areas	Synergy with sustainable energy and with earthquake resistance
Cyclone-resilient cityscape	Wind and flood resilient city design and engineering	

Cyclone preparedness	Remove potential flying debris immediately before cyclones	
Maximize freshwater flow into groundwater	Establish a cadastre of surface areas allowing penetration of surface water into ground water (e.g. sandy soils), and drain water towards these areas	Synergy with sponge city
Improve early warning	Adapt the Saffir-Simpson scale to the local coastal topography to create a local impact scale for surge waves	Possible synergy with tsunami resilience

Figure 144: Key principles for preventing tropical windstorms

Source: APSEC

The analysis of the third part of climate risk comprises extreme temperatures, especially heat waves. Wildfires can also be addressed in this category. Extreme temperatures are at first instance being addressed by adequate insulation. Whether extreme cold or extreme hot temperatures, insulation is the backbone for extreme temperatures. This must usually be combined with heating or cooling systems. In many APEC regions the climate is either hot, requiring only cooling, or cold, requiring only heating. In some temperate climate regions, both are required, depending on the season.

The impact of freeze and heat wave threats on human settlements should be assessed with the help of the Köppen-Geiger climate zones classification. The Köppen-Geiger climate classification distinguishes between five major climate types and thirty climate sub-types[351]. The geographical distribution of these climate types and sub-types is shown in the figure below. The detailed description of each climate type and sub-type is given in Annex 2.

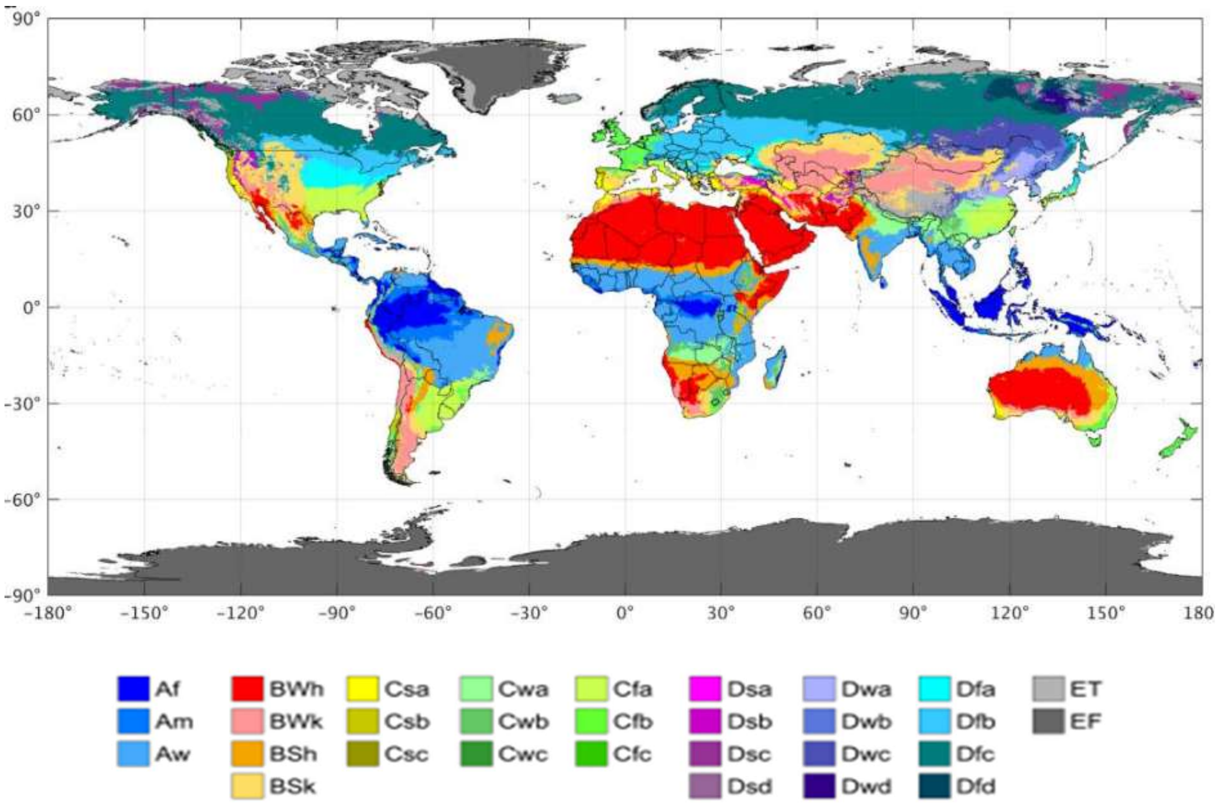


Figure 145: Köppen-Geiger climate classification regions 1980 – 2016

Source: Scientific Data[352]

Table below mentions some of the important APEC cities that are classified in each climate-subtype during the period 1980 – 2016. Some extreme climate types host no APEC cities (e.g. ET and EF).

1st	APEC cities (examples)	Requirement
A	Tropical	
AF	Singapore, Kuala Lumpur, Balikpapan, Davao, Innisfail, Ishigaki, Lae, Medan	cooling
Am	Jakarta, Miami, Cairns, Qionghai, Taitung	cooling
Aw	Bangkok, Ho Chi Minh City, Cancun, Darwin, Surabaya, Sanya, Kaohsiung	cooling
B	Arid	
BWh	Alice Springs, Phoenix, Las Vegas, Lima, Bakersfield	cooling
BWk	Turpan	both
BSh	Honolulu, Monterrey	cooling
BSk	Denver, Ulan Ude, Shijiazhuang, Zacatecas	heating
C	Temperate	
Csa	Sacramento, Perth, Adelaide	both
Csb	San Francisco, Santa Barbara, Seattle, Victoria, Devonport	both
Csc	Balmaceda, Spirit Lake	heating
Cwa	Mackay, Haikou, Zhengzhou, Chengdu, Hong Kong, Ha Noi, Guadalajara	both
Cwb	Da Lat, Kunming, Mexico City, Cusco, Cajamarca	both
Cwc	Puno	heating
Cfa	Brisbane, Sydney, Atlanta, Dallas, Washington DC, Shanghai, Taipei, Tokyo	both
Cfb	Auckland, Wellington, Christchurch, Melbourne, Hobart, Valdivia	both
Cfc	Miena, Charlotte Pass, Punta Arenas, Unalaska	heating
D	Cold, Continental	
Dsa	Salt Lake City	heating
Dsb	South Lake Tahore	heating
Dsc	Anchorage, Brian Head	heating
Dsd		heating
Dwa	Beijing, Harbin	both
Dwb	Heihe, Vladivostok	heating
Dwc		heating
Dwd		heating
Dfa	Naomori, Nagano, Chicago, Minneapolis, Volgograd	heating
Dfb	Moscow, Novosibirsk, St. Petersburg, Ottawa, Quebec, Edmonton	heating
Dfc	Fairbanks, Archangelsk, Frazer	heating
Dfd	Yakutsk	heating

Table 19: Examples of APEC cities located in the various climate subtypes

Source: APSEC

The table also indicates whether the city requires heating or cooling systems or both, depending on the season. Such indication does not mean that heating or cooling is installed in all the cities listed under that specific climate sub-type. Shanghai is e.g. known not to have a heating system in all buildings. In Washington DC which has a similar climate sub-type but lies more north and, therefore, gets more often snowfall than Shanghai, it would not be conceivable to live without heating.

Climate change modifies temperature and precipitation in both ways, average and intra-annual variability[353]. Thus, during the 20th century, the area of the polar frost climate (EF) has diminished by more than 12%, and the area of arid or type B climates has increased by 4%. The area of savannah climate subtype Aw has increased by more than 20% during the 20th century. A large intra-annual volatility up to 40% is observed among most climate sub-types. This means that climate sub-types may often change in a given location during a year.

The above may illustrate that for city planning, climate change in the medium term BAU scenario up to 2030 does not mean having more air conditioning and less heating, but it means having more of both, cooling and heating. As an example, the West-Siberian region where the 2010 heat wave took place (see section 1.2.1.) has continental warm summer climate sub-type without dry season (Dfb). This region would certainly not be able to live without heating in winter. The 2010 heat wave was exceptional in this climate sub-type precisely because it usually does not have hot summers, contrary to the Dfa climate subtype which is characterized by hot summers.

In the longer term (2070), climate change in a BAU scenario destroys the temperature niche in which human population has lived in the past 6000 years. Population has traditionally been living in two temperature segments, 11°-15°C and 20°-25°C mean annual temperature (MAT), whereby the lower temperature segment was heavier populated than the higher one. In 2070 and in BAU scenario with absence of climate migration, this is projected to change, whereby the number of people living in the higher temperature segment will be larger than those in the lower one, and the majority of world population will live in MAT > 29°C, a temperature range that today is found only on 0.8% of the global terrestrial surface.

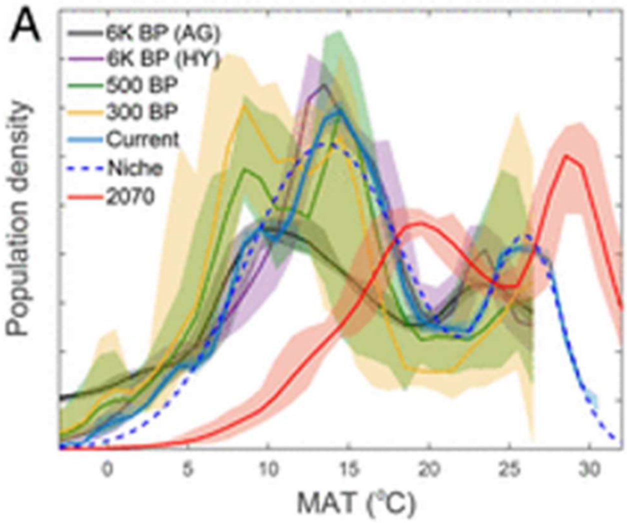


Figure 146: Projected effect of temperature increase by 2070 on today's inhabited areas

Source: Marten Scheffer and others[354]

The above BAU scenario would oblige practically all cities of the world to provide for space cooling as a standard. In the interest of limiting climate change, such new space cooling should be provided by passive house technology or solar power. More importantly, the countryside would even more suffer from such excessive temperatures. This would endanger the food productivity in many regions. In less arid regions, where crops can still be grown, crops should be protected from direct sunshine to prevent heat damage. Large PV could be the means of choice to achieve this protection, possibly in combination with rain collecting devices to improve irrigation. This can increase the combined electricity-crops yield by 60%. In water-scarce coastal areas where freshwater availability for irrigation is not sufficient, the practice of cooling and moisturizing greenhouses might become a standard to protect vegetable growth.

This type of agriculture is practicable already today in some arid coastal areas where it is cooled with sea water and combined with desalination. Production costs might be substantially higher than for open agriculture. Again, in the interest of limiting climate change, cooling and moisturizing greenhouses should be powered by solar energy.

Figure 147: Combined PV and crops culture (l); PV-powered seawater-cooled greenhouse (r)

Source: Fraunhofer ISI[355] (l) and Siemens (r)[356]

The key planning measures to improve resilience to extreme temperatures are listed hereafter.

Objective	Measure	Remarks / Synergies
Generalize space cooling	Generalize passive housing and solar-powered HVAC	
Thermo-resistant building envelope	Improve thermal insulation through building codes and passive design characteristics	Combine with fire-resistant building envelope in endangered zones
Increase share of local renewable energy	Rooftop PV, building-integrated PV, micro-grids, battery energy storage in building blocks	Synergy between adaptation and mitigation Role for city planning
Energy-efficient solar heating and cooling as a function of local climate	Solar-powered district heating/district cooling centred around transit hubs	Central role of city planning
Cooling cities	Heat reflective paint	
Passive city-scaping as function of local climate	Contribution of design and vegetation	
Resilient crops production	Combined PV and crops culture	On countryside for food resilience
Resilient vegetable production	PV-cooled greenhouses for vegetable culture	On countryside for food resilience

Table 20: Key principles for resilience against extreme temperatures

Source: APSEC

The problem of wildfires is linked to the problem of heat waves but requires special analysis. It is not yet very high on the agenda of community-scale planning. Two APEC economies, namely the United States and Australia, have been heavily struck by wildfires in the last years and lost lives and wealth.

Fire-resilience has three components: land management, vegetation management and building codes[357].

The land management component essentially regulates or forbids building in forest areas that bear fire risks, possibly combined with a buy-out program of existing houses. Fire emergency plans usually provide for evacuation of population in case of approaching wildfire. Evacuation is the preferred safety measure as no construction material is up to now guaranteed fire-proof. Concrete is already fully oxidised and cannot burn, but above 1200°C, it starts to disintegrate by losing its bound water in the chemical reaction $Ca(OH)_2 \rightarrow CaO + H_2O$. In case concrete is reinforced by steel bars, concrete may also lose its load capacity by the thermic dilatation difference between steel and the other components. Such effects have caused the collapse of the World Trade Center towers during the 9/11 events. Burning tunnels from which heat cannot be evacuated generate extremely high temperatures and consecutive severe damages.

The temperatures of wildfires depend on the flame height. Flames of 50m height may reach temperatures of 1200°C[358], but the main characteristic of wildfires is their rapid spread and comparatively short duration at one single point. Even during short times, thermal radiation can be so strong that objects inside houses may be set on fire through closed windows.

Pursuant to the logic to build back better, the United States and Australia have both had the occasion to start making regulations about fire-resistant housing and release new building codes for regions with risk of wildfire[359] [360]. Building codes should, however, be seen as complementary to land zoning providing for strict regulation or prohibition to build in forest areas that can bear fire risks.

Concrete houses with high thermal insulation, combined with special protection of windows and doors, are required to resist against this type of external impact. Some points to diminish wildfire damage of individual housing are[361]:

- Clear surroundings of combustible material, make way for fire fighters
- Firewall the house and provide an ember resistant exterior
- Install exterior window protection by roll-down metal protections
- Install fire-resistant doors, garage doors, louvers and vents on the roof
- Install sprinklers or other automatic fire-extinction devices

3.2.2. Integrating Resilience against Disasters of Geological Origin

Disasters of geological origin include earthquakes and the associated tsunamis, as well as volcanic activity. Earthquakes are tipping points in the movement of tectonic plates. The tectonic plates move very slowly but accumulate high quantities of energy if their movement faces resistance from neighbouring tectonic plates. This energy is released at the moment when earthquakes materialize.

Earthquakes are nearly impossible to predict. Some very short-time prediction is possible by the fact that earthquakes are composed of four different types of waves, namely two body types and two surface types. The body types of waves (called primary P or longitudinal and secondary S or rope-swing waves) travel faster and cause less harm to buildings than the two types of surface waves (Rayleigh R and Love L waves). As the body waves are weak, they can often only be seen on seismographs. The surface waves can be very destructive especially if the up-down Rayleigh movement combines with the lateral Love movement. In practice, this way of predicting earthquakes is almost useless for regions immediately above the epicentre of the earthquake where the destruction is largest, as the time difference between the arrival of these different types of waves is too short. At 200km distance, the warning time is about 30 seconds, at 1700km about 250 seconds.

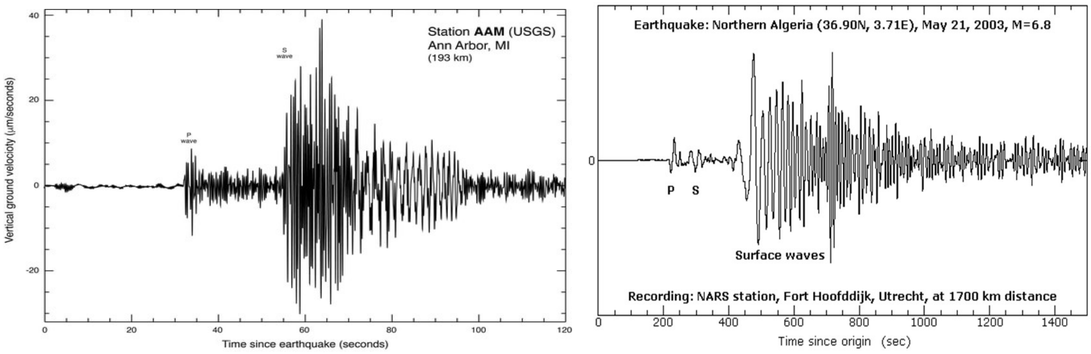


Figure 148: Earthquake precursors at 193km and at 1700km distance

Sources: Mlive[362] and Preceden[363]

Other indirect ways to predict earthquakes are the change of elevation of land surface, fluctuations in ground water levels, changes of the magnetic field or of the electrical resistance of the ground, and the release of gases[364]. According to many observations, animals show abnormal behaviour before earthquakes. This relationship has been investigated[365] but is still too little understood to be used as reliable predictor.

It is not really earthquakes that kill people, but buildings. Therefore, the focus of any strategy to diminish human and economic losses should rely on making buildings and other infrastructures earthquake-proof. In some APEC economies there is a long-standing tradition of earthquake resistant buildings. Japan, China and Korea have tower-like pagodas that survived for more than a thousand years, including during many earthquakes. The Horyu pagoda in Japan dates from the 7th century[366], a pagoda at the Songyue monastery in Henan Province, China, dates from the Wei dynasty (4th to 6th century), and a pagoda of the Chongrim temple in Puyo, Korea, dates from the 7th century[367]. In the case of Japanese pagodas, the secret of earthquake resistance is the flexibility allowing each floor to swing in the opposed direction of the floor below it, a swinging pattern that makes the pagoda look in an earthquake as if it were performing a snake dance. To limit this type of uncontrolled swinging to a predefined level, the pagoda contains a central spine called shinbashira that is fixed in the upper part of the pagoda and can swing freely, thereby acting like a damper for the whole pagoda in case of earthquakes or strong winds[368]. The famous architect and structural engineer Kiyoshi Muto has adapted these principles in the 1960s to build the first skyscrapers in Japan.

Since 1981 Japan has successively introduced techniques in its building codes to make modern buildings earthquake proof. The basic earthquake resistance (taishin) is required by law. It provides for beams, pillars and walls that are thicker to provide more strength against earthquakes. This method is suitable for low-rise buildings. The vibration control (seishin) is not required by law but recommended for high-rise buildings. It provides for dampers to absorb some of the energy of the earthquake and reduce the shaking by some degree. An entirely new approach is the base isolation (menshin). This method is also facultative but is often used in high-rise buildings as it offers the best earthquake protection. It consists of isolating the building from the soil, i.e. allowing the soil to move freely beneath the building while keeping the building immobile by its own inertia.

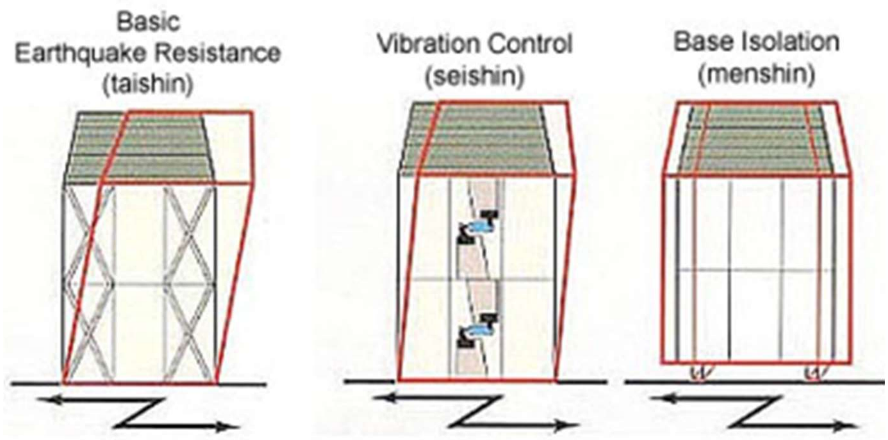


Figure 149: Earthquake resistant construction methods used in Japan

Source: Japanpropertycentral[369]

Earthquake proof construction for high-rise buildings is especially important in APEC where high-rise buildings play a more important role than in any other part of the world, as has been shown in *APSEC (2018).* The techniques described above are also used in other APEC economies. The Taipei 101 building has a tuned mass damper to reduce the sway of the building in case of earthquakes[370]. The base isolation technique is also used e.g. in the Philippine Arena in the roof structure which has been conceived to withstand strong transient forces as they happen in earthquakes and typhoons[371]. Base isolation technique is also used in Apple's new headquarter building complex in Cupertino, California. This complex is not fixed on the soil but lies freely on 692 stainless steel saucers. In case of an earthquake, the soil beneath the building can move by as much as 1.2m in any direction so that the building will move less. The figure below shows a saucer in the normal situation at the centre, while in the left picture the soil has moved to the left and in the right picture it has moved to the right, both without moving the building.

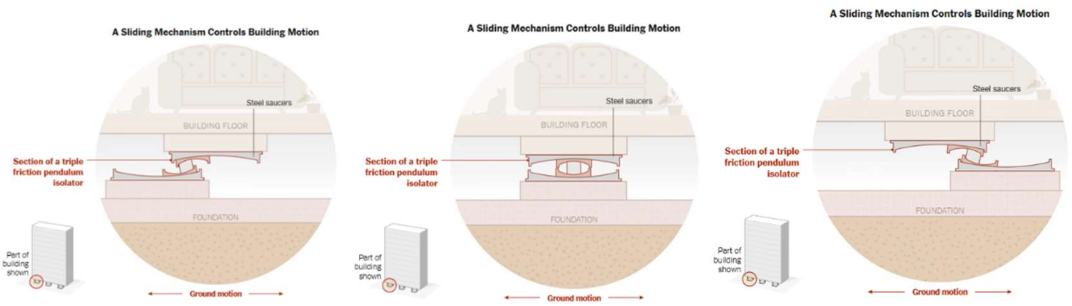


Figure 150: Building resting on saucers moving laterally during earthquake

Source: New York Times[372]

Seismic upgrading of existing reinforced concrete buildings is possible and is sometimes being advocated in combination with thermal upgrading. Advanced materials such as textile reinforced mortar can be applied to external building surfaces to increase earthquake resistance. Simultaneously insulation material can be fixed to improve the thermal performance of buildings. The combination of both is more economical than each upgrade separately[373].

Earthquakes have also been produced by human activity, mostly in connection to geological exploration of energy resources[374]. Fracking may have produced a magnitude 5.6 earthquake near Oklahoma by injection of high-pressure water, as well as many other events of magnitude 3. The problem is that these occur outside traditional seismic areas and hence local building codes are not adequate. This earthquake risk which is borne by local estate owners should be transferred to the fracking companies.

For earthquakes it may be difficult to find technical solutions that prevent any damage to cities. Therefore, it is essential that the discussion about resilience focuses also on measures of restoration after earthquakes. Resilience was defined in section 3.1.1. as the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management. Indeed, if there is any type of disaster where the notion of resilience is to be interpreted in the whole breadth of this definition, it is big earthquakes.

The Kobe 1996 earthquake can serve to illustrate the damage and restoration in a context of a highly developed and in many aspects well prepared economy. Before the earthquake, Kobe was not seen as a place of particularly high risk for earthquakes. People apparently had moved to Kobe in the years before the earthquake because of perceived lower earthquake risk[375]. The 1996 earthquake, therefore, came as a surprise and caused heavy damage as its epicentre was at only 16km below surface. The originally determined magnitude of 7.2 has been revised to 7.3 by the Japanese meteorological agency after a review in 2001[376]. It happened in early morning hours of 17 January 1995 when most people were still sleeping. 5297 persons died[377], of which 4571 in Kobe[378], where two persons went missing and 14’678 were injured. Total direct damage was estimated at approximately 6.9 trillion yen. 120’000 buildings were destroyed and 400’000 damaged, most of them wooden buildings dating from the period between 1945 and 1981, mostly before anti-seismic norms have been adopted. 7’000 buildings or about 80ha floor area were burned. Many fires could not be extinguished because the water system was broken down. As a result, 240’000 persons became homeless and received provisional accommodation in 600 shelters as of 18 January.

Among the infrastructures, 85% of schools as well as most cultural buildings were damaged. The traffic system was severely affected. Two expressways collapsed partially, subsidence and cracks blocked many roads. Severe damage also occurred to railway systems and to the access roads to the port. In the port, almost all container berths and wharves were inoperable. Main municipal utilities occurred partial or total failure: Power (100%), phone (25%), water (almost 100%), gas (80%), sewage (3/7), waste treatment (100%).

The restoration process of some basic infrastructure after the earthquake can be summarized as follows: Power (9 days), phone (14 days), water (1 month), sewage (3 months), gas (3 months).

During the first two months after the earthquake the authorities issued a moratorium on construction. The moratorium should give time to revise land planning and make any immediate improvements required. The quick debris removal was to be completed after 1 year, the quick restoration of infrastructure in 2 years, providing the basis of all kinds of recovery activities. Within 5 years, all temporary shelters for victims were to be closed and victims to be moved to permanent housing. Building codes were to be released guaranteeing higher seismic performance. The economic activity might have undergone fluctuation as shown in the chart below. Some activities such as steel mills were needed during reconstruction. Some activities (sake breweries) never recovered their original markets again.

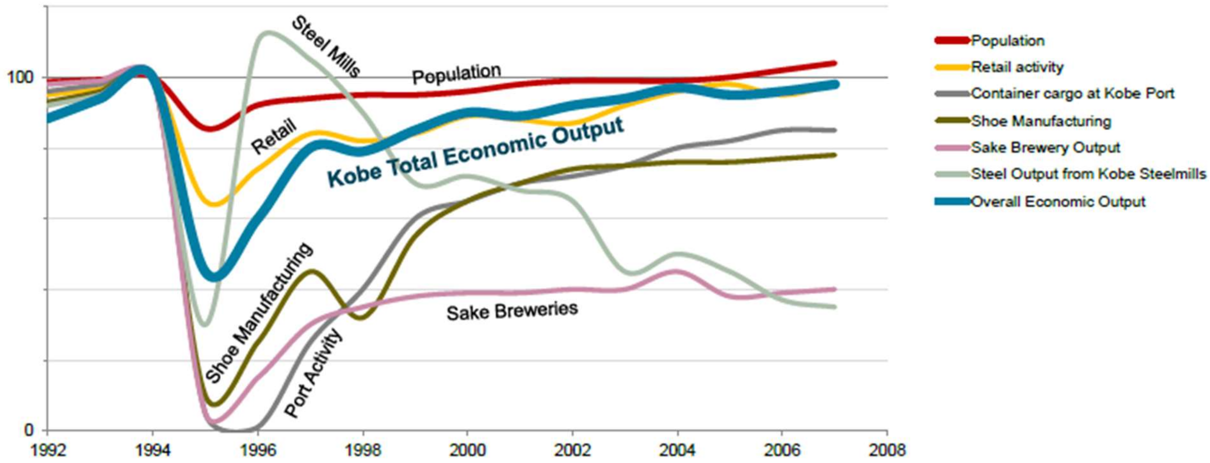


Figure 151: Economic effect of Kobe earthquake 17 January 1995

Source: Copburn 2015[379]

The above illustrates that even so-called resilient communities might be severely affected by specific disasters. The key measures for earthquake resilience are summarized in table below.

Objective	Measure	Remarks / Synergies
Produce lifesaving and sustainable buildings	Promote building codes for 100-year planned life span of all new buildings in APEC cities that are in earthquake regions	
Combine seismic with energetic upgrade for existing buildings	Integrate combined seismic and energetic upgrade into building codes	Synergy with energy efficiency
Increase earthquake resistance of bridges, especially transit system bridges	Promote worldwide best practices for bridges	
Risk transfer of artificially caused earthquakes	Causal liability and insurance by fracking companies	

Table 21: Key measures for earthquake resilience

Source: APSEC

Tsunamis are created by underwater earthquakes of magnitude higher than 6.5. Not all these earthquakes create tsunamis. It was shown in section 1.2.2. that tsunamis are high uncertainty events, making them even more difficult to predict than earthquakes. The maximum height of the tsunami is in direct relationship with the magnitude of the earthquake. The figure below gives the theoretically predicted maximum height of tsunamis (red line) and earthquake magnitudes as well as documented height (blue marks) of tsunamis. The maximum local tsunami height can be higher than in that figure, depending on local coastal shape. The same has been observed above in section 1.2.2. under coastal flooding where the locally observed height of the storm surge can be higher than the predicted height, depending on the local form of the coast. Estuaries create higher waves also in the case of tsunamis.

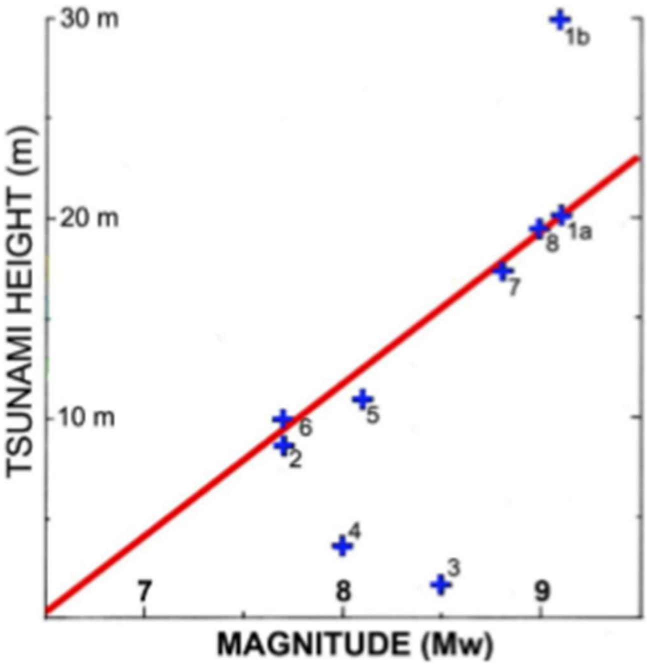


Figure 152: Tsunami height as function of earthquake magnitude

Source: Morner[380]

The events shown in the above figure correspond to:

1) the 2004 Indian Ocean event with a wave height of 20 m and magnitude Mw 9.1
2) the Java 2006 event with a wave height of 8.6 m and a magnitude of Mw 7.7,
3) the Bengkulu 2007 event with a wave height of 1.65 m and a magnitude of Mw 8.5
4) the Peru 2007 event with a wave height of 3 - 4 m and a magnitude of Mw 8.0
5) the Samoa 2009 event with a wave height of 11.9 m and a magnitude of Mw 8.1
6) the Mentawai 2010 event with a wave height of 10 m and a magnitude of Mw 7.7
7) the Chile 2010 event with a wave height of 17.2 m and a magnitude of Mw 8.8 and
8) the Tohoku 2011 event with a wave height of 19.5 m and a magnitude of Mw 9.0.

While typhoons rarely produce storm surges higher than 10 meters, earthquakes above 7.5 can produce tsunamis higher than 10 meters, reaching 23 meters for the strongest recorded earthquake (Valdivia, Chile, 1960). Tsunamis have minimal amplitude over open seas but amplify near the coasts due to their slowing down. The tsunami speed depends on the depth of the basin in which the earthquake takes place and can be calculated using an online calculator[381]. The deeper the basin the faster the tsunami. At 5500m depth of the Pacific Ocean, the tsunami has little amplitude, and its speed is around 836km/h, at 900m depth the speed decreases to 340 km/h, and at 20m depth to 50km/h, each time with a corresponding increase of amplitude or wave height. Once on land, the speed of tsunami waves has been estimated to be between 20 and 35km/h (or 6 to 10m/s)[382].

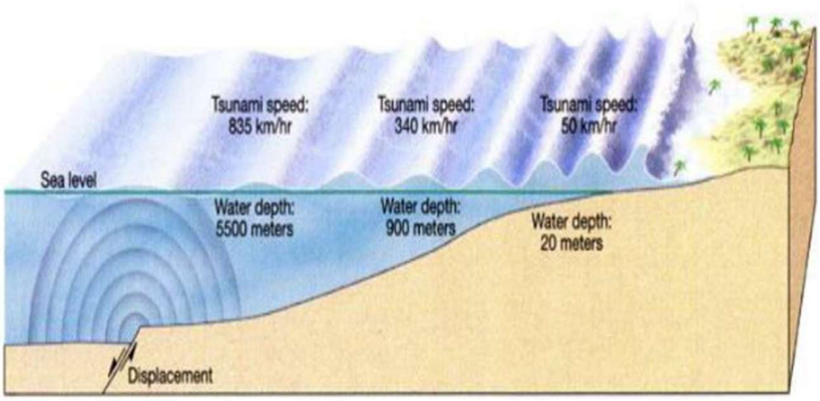


Figure 153: Tsunami build-up

Source: Kivlehan[383]

Tsunamis are the most challenging type of all disasters. Therefore, protection against tsunamis requires combination of all available means. To these belong the same methods as mentioned earlier for coastal flooding: Coral reefs and mangroves swamps or other types of forests diminish the primary impact of tsunami in both, destructive force as well as inundated land area, but neither of them will prevent a tsunami from entering. Supplementary protection against tsunamis are protective walls such as the 30'000 km walls built by Japan[384][385]. Since the 2011 Tohoku earthquake, Japan has been discussing extending similar protection by adding 440 more protective walls around the Fukushima district[386]. Protective walls may fail if they are not sufficiently high. In September 2010, the city of Kamaishi at the north-eastern coast of Japan completed a protective wall, but the March 2011 tsunami was 4m higher than the wall, hence the tsunami destroyed or displaced more than three quarters of the wall (62 out of 79 elements)[387]. Consequently, the tsunami flooded the city, even though it did so with 6 minutes delay and 40% height reduction[388]. Supplementary measures, especially vertical evacuation, are required to protect the population. Vertical evacuation enables population to seek refuge in upper parts of buildings. Vertical evacuation requires that the building structures themselves are comfortably higher than the tsunami. Besides that, such structures must be sufficiently strong to withstand not only a high magnitude earthquake but also the tsunami that follows. Besides Japan, the USA has also created guidelines for the design of structures for vertical evacuation from tsunamis[389].

The 2011 tsunami which was the largest ever recorded tsunami in Japan, has brought about an adaptation of the resilience paradigm[390]. Before 2011, the objective had been to protect the population mainly by seawalls, while maintaining vertical evacuation, ample disaster training and early warning in flood-prone areas. The 2011 earthquake was of magnitude 9, whereas the highest possible magnitude had been evaluated at 8.5. The first calculations made in the minutes after the earthquake pointed to a 7.9 magnitude event. Correspondingly, tsunami warnings of 3m to 6m were issued. People outside risk-prone areas felt safe and did not see any reason to evacuate, and this increased the number of deaths. The policy adaptations made after the 2011 tsunami still provided for prevention by protective walls (newly called level 1), but only for 150-year tsunamis. Prevention by seawalls is clearly not regarded as sufficient anymore. Mitigation (newly called level 2) and vertical evacuation become comparatively more important and are even regarded as the main strategy for extraordinary high tsunamis of rarer occurrence such as the 2011 one.

The new philosophy can e.g. be seen in the cross-sectional plan of measures adopted by the city of Sendai. The coastal breakwater is only the first element of the security design.

Behind follows a disaster prevention forest, a park, an elevated road, an evacuation centre, a second elevated road, and finally the residential area.

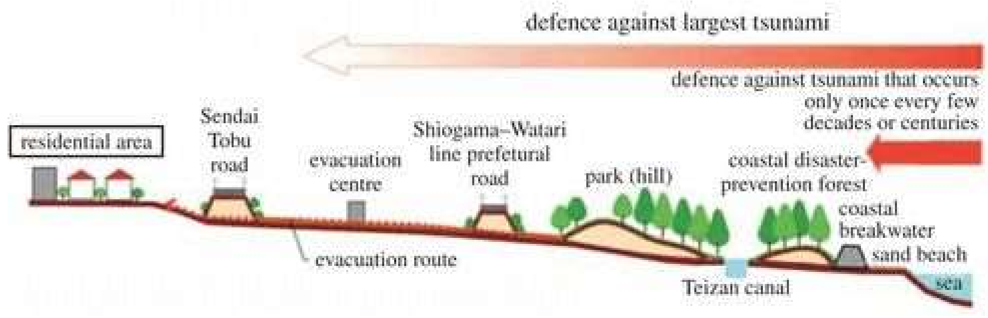


Figure 154: Tsunami prevention elements of Sendai after 2011

Source: Koshimura[391]

The 2011 earthquake and tsunami have also brought adaptations to the Japanese power mix, especially its nuclear power[392]. Of the 54 nuclear power plants that were operational in 2011, 21 are to be decommissioned. Of the 33 remaining ones, nine are back in operation at the beginning of 2020, of which eight are at the west coast. A further 16 have applied for compliance for National Regulatory Authority (NRA) standards. Of these, up to now, five plants meet basic design requirements and two more meet basic and detailed design requirements. The future of the eight others is still undecided. Three new plants are under construction.

The 2011 events may also lead to reconsidering geothermal energy. Japan's geothermal potential is estimated at 24GW for temperatures over 150°C, and at 8.5GW for temperatures between 53°C and 120°C[393]. In 2014 the first geothermal power plant opened since the 2011 earthquake[394].

Early warning systems are a crucial element of tsunami mitigation. For the Pacific basin, a first early warning system caused many false alerts and was replaced in 2003 by the Deep-ocean Assessment and Reporting of Tsunami (DART) system[395]. The 2004 tsunami in the Indian Ocean initiated the creation of tsunami warning systems in the Indian Ocean, but also the Caribbean, the North East Atlantic and the Mediterranean[396].

To sum up, tsunami-resistant buildings should have the following characteristics:

- They must be heavy (i.e. made of concrete and steel) in order to withstand the pressure of the water in both directions, inward and outward. This pressure depends on the height of the tsunami. The lateral pressure of a 2m tsunami on a vertical wall is estimated to be equivalent to 2t/m^2, a force that only reinforced concrete buildings can withstand[397].
- Furthermore, these buildings must be firmly anchored in the ground. During the 2011 tsunami at least eight multi-storey concrete houses were tossed over without breaking apart for the simple reason of not having been sufficiently anchored in the ground[398][399]. This means that the base isolation technique described above for earthquake-resistant structures is not advised in regions where tsunamis are likely to occur.
- Ideally buildings should be turned by 45°, showing an angle towards the seaside to avoid frontal building exposure to the tsunami.
- It is not realistic to design these buildings as submarine-like water-tight structures. This means that tsunami water will normally break through ground floor doors and windows and flow through the building in both directions, inward and outward. Up to

the expected level of flooding, buildings should be able to stand only on columns. Open multilevel parking houses or similar structures can be useful for vertical evacuation.

- Such water flow erodes the building structure at each edge of each carrying structure. Such erosion can be minimized by using round supporting columns instead of square columns.
- Buildings must resist floating debris such as barges, fisher boats, buses, vans, cars, and neighbouring houses or parts thereof. Openings of such buildings should be sufficiently small to keep large objects outside to prevent harm to the building's bulk columns.
- Each resisting building increases the stress on neighbouring buildings because it displaces water which then will flow towards the nearby buildings. If a waterfront is designed, each of its elements should be stronger than if each element was designed individually.
- Whenever possible, soil under and around the building should be stabilized. Sandy soils in a tsunami behave like water and may cause buildings to slide and displace.

Volcanic eruptions are the third type of disasters of geological origin. Compared with other disaster types, volcanic eruptions cause less deaths in APEC cities, but the GDP loss can be considerable. Section 1.2.2. showed how they affect APEC cities. Volcanic activity is of medium confidence (see section 1.2.2.) having 50% of correct prediction.

Volcanic eruptions may be accompanied by earthquakes, fires, landslides, floods, or tsunamis. Volcanic eruptions are still not very well predictable, but the eruption of Mount St. Helens in 1980 has accelerated research for creating early warning systems for volcanic eruptions. The Mount St. Helens eruption was the first occasion to record a heavy landslide along the steep volcano flank. Nowadays, satellite observation[400] combined with artificial intelligence can detect sub-centimetre earth movements. Thus, immediately before the Anak Krakatau eruption in 2018, specific vertical as well as horizontal movements of land masses around the volcano have been measured by satellite. Nonetheless, when the volcano did erupt on 22 December 2018, the collapse of one of its flanks into the sea surprised observers. The tsunami that followed the eruption caused 453 deaths, mainly on other Indonesian islands that were far beyond the security perimeter of the volcano itself.

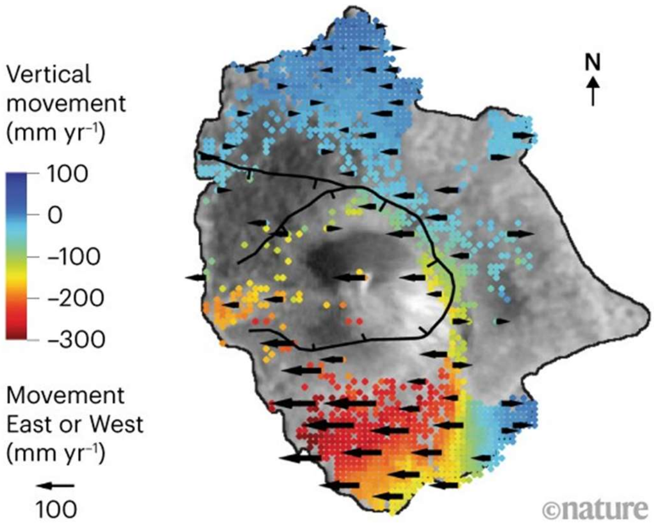


Figure 155: Movement of land masses preceding the Anak Krakatau eruption in December 2018

Source: Nature[401]

Eruptions comprise lava, pyroclastic material or hot ashes like the ones that set aflame and buried the city of Pompei in year 79 AD, and gases. The most dangerous form of lava is the glowing avalanche, an extremely hot liquid (1200°C) running down the flanks of the volcano and reaching out 10km to 40km. Gases also help predict volcanic eruptions. By far the most abundant gas released by volcanoes is water vapour which is totally harmless to biological organisms[402]. Besides that, volcanoes release CO_2. The annual amount of CO_2 released globally by volcanoes into the atmosphere is between 180 million and 440 million tons which corresponds to around 1% of anthropogenic CO_2 emissions. One case is known in Cameroon in August 1986 where the Nyos volcano lake suddenly emitted such high CO_2 quantities that 1700 inhabitants and all their animals were killed in a surrounding of 25km[403]. CO_2 is colourless and heavier than air. It collects in basins until wind blows it away. Volcanic gases also contain SO_2. This is the colourless but smelly gas that irritates eyes and throat and causes smog. Besides that, volcanoes release H_2S, another colourless but quite toxic gas smelling of rotten eggs, as well as three forms of hydrogen halides (HF, HCl, HBr) which are highly acidic and cause acid rain. They can poison drinking water as well as agricultural crops.

Figure 156: Cleaning vegetation after Taal eruption, the Philippines, 13 Jan 2020

Source: NPR[404]

The most important urban planning measures around volcanoes are forbidding construction, buyout and relocating homes and activity in areas close to the volcano perimeter, as well as security evacuation in a wider perimeter in case of volcanic eruption. Possibly sanitary measures such as water safety and food edibility checks are necessary. On the positive side, volcanoes are spectacular events that attract tourists. Cities near volcanoes use volcanoes to make a touristic attraction.

Regular monitoring about volcanic activity is made by the Global Volcanism Program of the Smithsonian Institute[405]. It can be complemented by satellite-based observations. The above measures are valid for small and medium sized volcanoes (VEI less or equal to 6). Volcanoes of higher VEI such as the Tambora eruption that created the famous year 1816 without summer are global phenomena that would require a global response. As most of the VEI 7 and VEI 8 volcanoes are in the region of today's APEC economies, APEC could possibly play a leading role in such a global response.

3.2.3. Integrating Resilience against Epidemics

Resilience of cities against epidemics can be called epidemic resilience of cities. It is the equivalent of disaster resilience for the disasters described in the preceding sections. Epidemic resilience of cities should be addressed at three different levels:

- Epidemic resilience of the individual against disease by the promotion of healthy individual lifestyles. The elements of healthy individual lifestyle as well as the difficulty of scientific proof of what makes up healthy lifestyle have been outlined in section 3.1.1.
- Epidemic resilience of the local health system is the resilience of local health facilities against a sudden unmanageable rise of treatment requirements of ill individuals in an epidemic.
- Epidemic resilience of the local economy against economic effects of epidemic prevention and control measures taken in the affected city or by its most important trading partners.

There are obvious links between these levels: The higher the resilience of the individual against a specific disease, the lower the number of ill persons asking for hospital treatment, and hence the lower the stress of that disease on the local health system.

The epidemic resilience of community health systems depends also on two other factors: how the spread of the transmissible disease can be controlled, and what type of treatment is available against that disease. How the second factor influences the first factor is explained hereafter.

The problem with treatment of COVID-19 patients in the first months was that no specific treatment was available, leading to the wide-spread use of the intensive care unit (ICU) as treatment of last resort. The critical element has been the number of beds in local ICUs and the available number of respiratory ventilators. In many cities the number of patients needing placement in ICU threatened to outgrow the number of available places. In this situation, the local health authorities attempted to limit the spread of the epidemic so that the total number of infected persons requiring medical care would not exceed the capacity of the local health system. The figure below can illustrate this. The word “local” must be emphasized in this context. Even though sporadic cases of treating patients in ICUs of other cities were reported, it was in priority the local health system that should treat such cases.

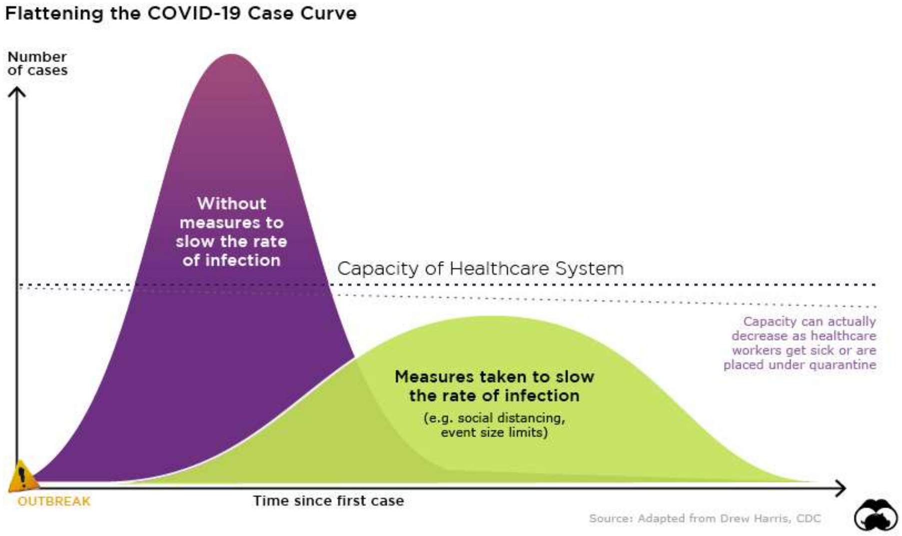


Figure 157: Objective of local health planning: flattening the COVID-19 curve

Source: Rutley, Idea: Drew Harris[406]

In the context of COVID-19, the death rate is expressed as case fatality rate CFR. CFR is the number of deaths divided by the number of confirmed cases. This presupposes that a test has been made and a positive result has been obtained. CFR is related to, but not identical with the mortality rate as stated in the SDGs. SDG 11.5 requests communities to significantly reduce the number of deaths from disasters, and to reduce the direct economic loss from disasters. The *Sendai Framework for Disaster Risk Reduction* sets its targets as number of deaths per 100'000 inhabitants.

COVID-19 has affected so many different aspects of everyday life all around the globe that it must be considered as an epidemic of an entirely new dimension. The new dimension of COVID-19 appears clearly by comparing COVID-19 to the latest similar epidemic that preceded it, namely SARS (2002 – 2003). For SARS, the speed of events (including reaction times of authorities) was much slower than for COVID-19. For SARS, it took four months (16 November 2002 – 12 March 2003) between detection of the first case and the global alert by the WHO[407]. To eradicate SARS, it was sufficient to take measures such as:

- Generalization of face masks in public transport and public places of affected cities
- Soaps and disinfectants for cleaning of surfaces that might carry the virus
- For medical staff: special protective equipment
- Quarantine, isolation and contact tracing for relevant persons
- Selective travel restrictions from infected places
- Awareness campaigns to the public and to specific groups

In contrast, the higher transmission rate of COVID-19 compared to SARS required not only much faster public reaction, but a set of entirely new instruments to get it under control:

- Preventive quarantine or lock-down of entire cities or regions, including for unaffected people and groups
- Setting up emergency hospitals or transforming existing hospitals to specialized COVD-19 hospitals within a matter of weeks

- Preventive closure of all but essential economic activities, cancellation of mass meetings
- Temporary substitution of activities requiring physical contact by online activities such as home office, distant education, online sale
- Generalized physical distancing (wrongly called social distancing, a term that should be banned in the age of internet)[408]

This explains why practically no health system of the world was sufficiently prepared for COVID-19. Even today, it is way too early to give definite answers of how to make community health systems resilient against COVID-19. At this stage, only design thinking for future research can be done. After the Ebola outbreak in Western Africa in 2015, some authors started to describe health systems as complex adaptive systems (CAS) whose resilience is an emerging property. Resilient health systems are said to be aware, diverse, self-regulating, integrated and adaptive[409]. A more recent analysis made during COVID-19 outbreak draws three lessons for a health system to be resilient against an epidemic like COVID-19:

- necessity to be integrated to be able to absorb shocks,
- necessity to prevent the spread of fake news, and
- necessity to trust in government[410].

After the first months of COVID-19 pandemic, the situation concerning COVID-19 treatment has, however, improved in at least one decisive manner: In those cities where the number of recovered cases approaches the number of currently infected cases, the possibility to use human convalescent serum (or passive antibody administration) to treat infected cases becomes possible. Casadevall from John Hopkins School of Public Health, Baltimore, has shown how passive antibody administration has been used during the Spanish flu, MERS and SARS with positive results[411]. It offers less protection than a vaccination but is available immediately as a first treatment and at affordable cost. In most economies, however, cities are dependent on higher level authorizations for introducing this therapy. The conditions are:

1) availability of a population of donors who have recovered from the disease and can donate convalescent serum
2) blood banking facilities to process the serum donations
3) availability of assays, including serological assays, to detect SARS-CoV-2 in serum and virological assays to measure viral neutralization
4) virology laboratory support to perform these assays
5) prophylaxis and therapeutic protocols, which should ideally include randomized clinical trials to assess the efficacy of any intervention and measure immune responses; and
6) regulatory compliance, including institutional review board approval, which may vary depending on location.

As for the transmission rate, the way of how to diminish the reproduction number of COVID-19 below the critical value of a reproduction number smaller than 1 is of prime importance for this rapidly spreading epidemic. Based on experience gained over the first months of COVID-19, the main lessons learnt reside in implementing a combination of the following actions:

- isolating suspected and symptomatic cases
- efficient contact tracing of infected cases
- testing of suspected cases
- physical distancing wherever possible

In the interest of limiting economic impact of measures to the level necessary to effectively stop the transmission of the epidemic, isolating of suspected cases should be immediate and last until either a test has confirmed negativity, or the incubation period is terminated. During isolation, contact tracing should be carried out. The combination of immediate self-isolation and household quarantine with contact tracing strategies gives the largest reduction of the reproduction number[412]. IT based contact tracing methods have started to be used. Whatever their merits, it should not be forgotten that they apply to smartphones rather than to persons. Testing of suspected cases is important, but it is only useful if the suspected person remains isolated at least until the negative test result is known. Moderate physical distancing should be applied in combination with the above measures. In some cases, public COVID-19 interventions have been thoroughly analysed and found efficient[413].

The present section specifically attempts to identify any synergies between creating epidemic resilience and energetic sustainability or smartness in cities or local communities. As a guide for the impact of COVID-19 on global energy policy, the four scenarios published by the World Energy Council (WEC) on 29 April 2020 may serve as analytical help. The WEC describes the four scenarios on the two axes: whether the world will go back to the existing order or evolve towards a new order (x-axis), and whether policies would be incremental or radical (y-axis). Among the key policies are economic stimulus packages which can be assessed along the criteria of being sustainability – oriented.

The “pause” scenario is characterized by a return to the old order, absence of tensions or conflicts and hence evolution by incremental policies. This is a kind of a BAU.

The “rewind” scenario is characterized by emphasis on national security at the cost of cutting supply chains, but a policy environment characterized by incremental policies.

The “fast forward” scenario is characterized by emergence of new local leaderships, which will introduce some radical new policies, especially resilience buffers, but still attempt to remain within the existing order.

The “re-record” scenario is characterized by more generalized bottom-up organization, whose proponents bring about radically new policies driving the world towards a new order.

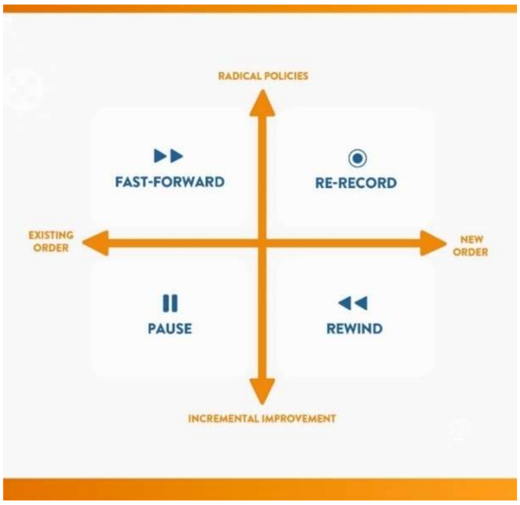


Figure 158: The four WEC scenarios after COVID-19

Source: WEC[414]

It can be expected that energy policies of cities will equally lie somewhere within these four scenarios, whereby the role of cities would be largest in the “re-record” scenario. However, in all scenarios, cities may be called to participate in, and shape economic stimulus packages. The importance of such stimulus packages is that they combine economic stimulus with sustainability targets. This point may be relevant when public support for the automobile sector or the aviation industry or the shipping industry is under discussion.

For the cities, it might be important to build or refurbish infrastructures in such a manner, that they prevent the transmission of airborne epidemic diseases within the built environment. The risk of spreading COVID-19 within badly ventilated interior spaces has been reported[415]. This includes both, interior spaces that have no heating, ventilating and air conditioning (HVAC) as well as interior spaces where the HVAC is primarily designed for energy saving and may, therefore, fail to prevent the transmission of COVID-19[416]. The problem is broader as it concerns not only buildings, but also other interior spaces: During COVID-19, cruise ships were in discussion for failing to protect residents from getting infected. And in broader scope, also planes, trains and buses having HVAC are concerned by this problem, even though in the mass transit systems, the probability of getting infected through direct contact with an infected person or an infected surface might be higher than the probability of getting infected through HVAC.

Following SARS in 2002, research has shown[417] that heating, cooling, humidifying, de-humidifying, cleaning, ventilating, and moving air can all potentially contribute to spreading an epidemic. HVAC are conventionally designed to prevent spread of respiratory droplet of particle size >5μm which are the most frequent transmission mode of epidemics[418]. But HVAC are only rarely designed to prevent the spread of smaller particles such as droplet nuclei and aerosols of particle size < 5μm, including PM2.5. Besides COVID-19, several other transmissible diseases spread by aerosols. Legionellosis, a ubiquitous pneumonia causing disease, may spread by HVAC cooling towers and by warm water systems between 20°C and 55°C[419].

Responding to the challenge of building infrastructures that stop the transmission of aerosol-borne and surface-transmissible diseases, Javier García de Abajo from the Barcelona Institute of Science and Technology and a group of researchers has advocated using UV-C light to eliminate microbiological pathogens from affected interior spaces. UV-C light has been known for a century to have a sterilizing effect. The 1903 Nobel Prize in Medicine was awarded to Niels Ryberg Finsen for this discovery. The interior environments which can be infected by microbiological pathogens are shown in the figure below.

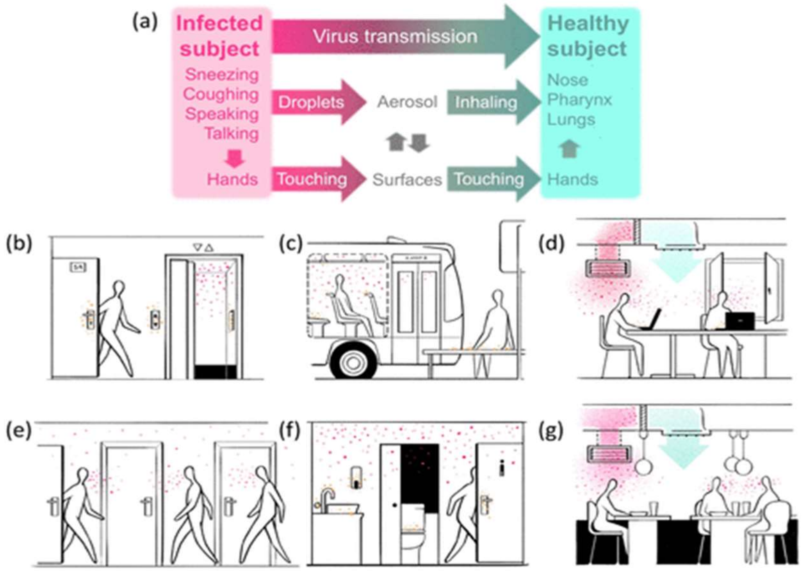


Figure 159: Interior environments affected by aerosol pathogens: elevators (b), public transport (c), offices (d), corridors (e), lavatories (f), restaurants (g)

Source: F. Javier García de Abajo and others[420]

The researchers show that use of UV-C light placed in the above environments can sterilize the air while satisfying the three criteria of fast implementation, scalability and affordability. It can be implemented in a highly energy-efficient manner. UV-C light sources can be placed inside HVAC ducts, thereby sterilizing the air. They can also be directed at contact elements (buttons, handles, handrails).

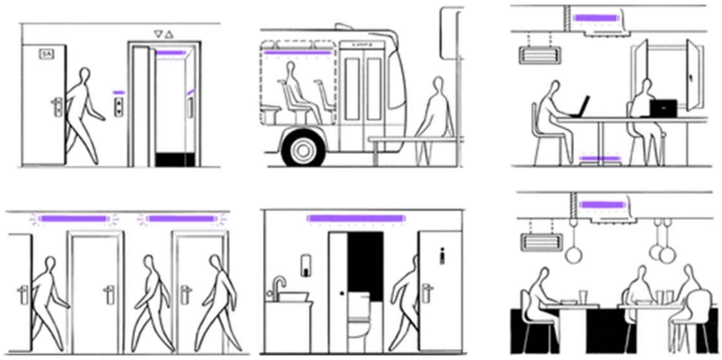


Figure 160: Sterilizing UV-C light placed in the above environments

Source: F. Javier García de Abajo and others

Concerning the contact surfaces, the roll-out of smart technologies can further reduce the number of surfaces (e.g. light switches). Some technologies have already been rolled out (e.g. acoustic or movement-induced light switches that are common in China) while others will develop very rapidly.

Particular attention should be given to making transit systems such as trains and subways free from spreading epidemics. In many cities, ridership during COVID-19 decreased by 80% or more, sometimes due to regulatory measures diminishing transit demand, but also due to fear from users to get infected. Some measures designed to keep transit systems functioning during epidemics are:

- Consider transit systems as system-relevant activities
- Avoid shortening trains or diminishing service as a response to lower demand during epidemics
- Prioritize access for staff traveling in essential or critical activities
- Efficient ventilation with sterilizing effect on microbiological pathogens (e.g. UV-C)
- Frequent cleaning and disinfecting
- Control access so that physical distancing can be ensured
- Use of technologies for tracing if necessary
- Facilitate physical distancing by floor marks and similar means
- Impose face masks and the use of gloves, e.g. when using ticket machines
- Adequate protection for cleaning staff

In sum, the objectives and key measures for epidemic resilience of cities are recapitulated hereafter.

Objective	Measure	Remarks / Synergies
Enhance reaction of immune system	Promote healthy lifestyles	Low cost, with many side benefits
Diminish spread of epidemic	Physical distancing, mouth masks, gloves, hand and object disinfecting	Synergy with healthy lifestyle
Use the first available treatment in epidemics	Examine and, possibly, implement treatment by human convalescent serum (or passive antibody administration) at city level	Low cost and rapid treatment based on solidarity between recovered and infected
Develop production of medical supplies in the city	Foster development of drug and antibiotic companies in the city	Synergy with transit-oriented development TOD
Diminish reproduction number R of transmissible disease	Immediate isolation of suspected cases combined with contact tracing, quarantine and testing	Avoid collateral damage to economy
Discharge intensive care units (ICU) as treatment of last resort	Introduce flexibility to transform hospitals or other infrastructures to special pandemic treatment facilities	
Make infrastructures epidemic-resilient	Examine and, possibly, implement massive deployment of UV-C light disinfection in local stimulus programs	Synergy with economic stimulus programs
Maintain continuity of service of mass transit systems	Priority use of mass transit systems for persons in essential functions and make them safe for all other users	Synergy with transit-oriented development TOD
Improve epidemic resilience of economies	Include key SDGs, targets and indicators into local stimulus packages	Synergy with economy-wide stimulus packages
Prevent spread of fake news about epidemic	Disseminate science-based information	In cooperation with economy

Table 22: Key measures for epidemic resilience at city-level

Source: APSEC

3.2.4. The Steep Path Towards Resilience Against Cyber Threats

The worldwide internet is the most integrated global complex adaptive system. It also develops fastest with the deployment of 5G and IOT. Cyber criminality is the fastest-growing disaster threat for GDP (see section 1.2.2.), hence it is worth discussing cyber resilience for cities. Cities are in most of the cases end-of-pipe users that are increasingly dependent on IT infrastructures and must use all available means to improve cyber resilience as part of urban IT planning.

Section 1.2.2. recites the case of the city of Atlanta that was struck by a cyber-attack in 2018. The lesson to be learnt from the Atlanta case is that information about cyber security deficits – like indeed information about any security deficits or about any security threats – should be taken seriously. Months before the cyber-attack, Atlanta had ignored the findings of an internal audit report mentioning long-standing severe deficits of its IT networks that made them vulnerable to threat. Failure to consider threats to security had also caused the RMS Titanic to sink in the Atlantic in 1912 (see section 2.2.5.). The Titanic crew had ignored unmistakable warnings about icebergs.

As a counterexample, Colorado Department of Transportation was hit on 21 February 2018, also by the same SamSam ransomware which impacted the IT systems of its employees during more than a week. Responding in a novel manner, the local leaders requested Colorado Office of Emergency Management to issue a disaster declaration treating the ransomware attack like a wildfire or flood, opening a host of additional resources such as the Colorado National Guard's cybersecurity unit[421]. The case of the Colorado Department of Transportation took this different development because its leaders had been better prepared to the eventuality of a cyberattack. Preparedness to cyberattacks is one of the characteristics of cyber-resilience.

Cyber-resilience is not yet a commonly used term. A proposal to measure cyber-resilience by means of 46 metrics has been developed in Spain, see figure below. These measures comprise actions along the four lines of anticipation, resistance, recovery, and evolution. Continuity of service management is included under recovery. These measures include the kind of measures that can be implemented by cities.

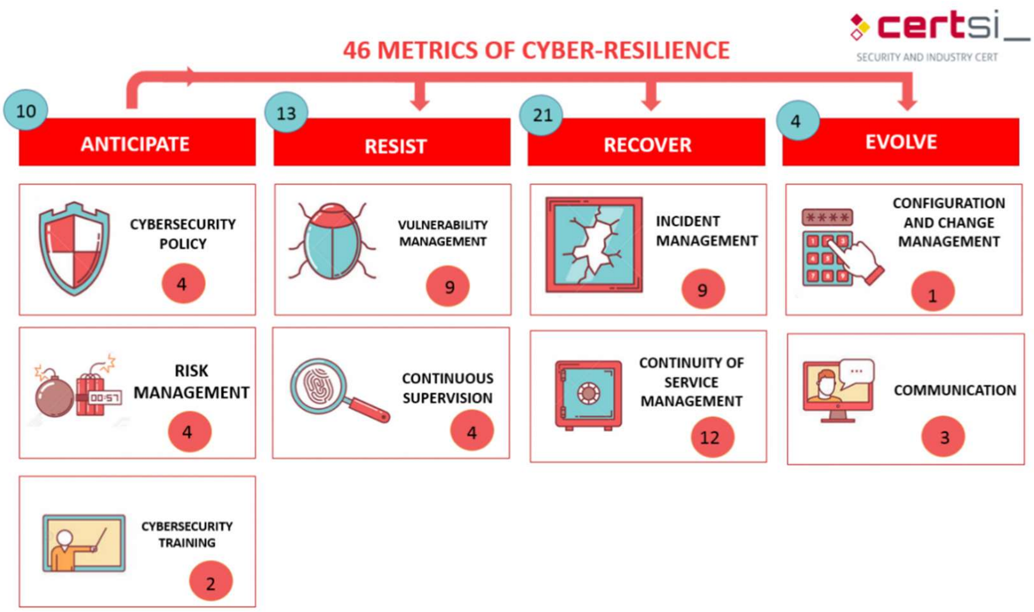


Figure 161: 46 metrics of cyber-resilience

Source: INCIBE-CERT[422]

Any cyber-resilience strategy should adequately address the broad spectrum of cyber-threats and progressively develop cyber immunity. Annex 3 gives a non-exhaustive list of cyber threats. One of them is human nature which figures among the important threats to cyber security. Section 2.2.6. gives the empirical explanation how human psychology tends to neglect security needs and posteriorize them compared to other needs. This effect may also be visible in cyber resilience. As people posteriorize security needs, they threaten their cyber security e.g. by inadequate setting or handling of passwords or other sensitive data. Furthermore, wherever systems of inattentive users are hacked, hackers can receive information about other internet users that may be stored on hacked systems, hence inattentive users also threaten cybersecurity of other users.

Facing a growing number of cyberattacks, the IT industry has started long time ago to develop cyber security. A key element of cyber security is encryption. Currently, the pillar of cyber security resists on Public Key Infrastructure (PKI) and public key encryption. The basic idea of PKI is to use a publicly accessible third party as guarantor to create trust between two communicating private parties[423]. To create trust, PKI uses two keys for encryption, one of which is public and the other one is not. The two keys are related by an algorithm which, depending on the choice of the users, can be easier or more difficult to calculate by an invading third party. Today, most encrypted communications such as e-commerce or e-banking transactions rely on PKI.

The PKI represents, however, a secure system only in a certain level of computing technology as it is used today. Since 23 October 2019, when the first quantum computer was presented, a new era of computing has started. Quantum computing, if it manages to develop, will create computers of an entirely new generation that are much more powerful than today's most powerful supercomputers. The experimental Sycamore quantum processor presented by Google in 2019 needed just 200 seconds to resolve a problem that the best supercomputer of today would require 10'000 years and 350 TWh energy (or about one day of today's world energy consumption) to resolve. Such high computing speed would manage to decrypt any conventional encryption such as the PKI based encryption in useful time.

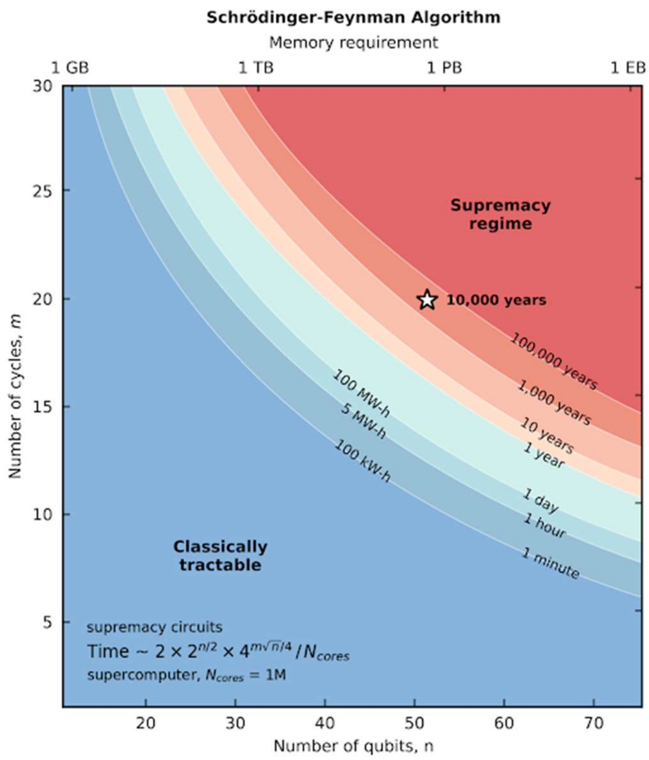


Figure 162: Estimate of the equivalent conventional computation time of the Sycamore processor

Source: Google[424]

From the above it can be concluded that quantum computing is an existential threat to cybersecurity. Quantum computing is so powerful that it will be able to crack the present system of shared security keys. Therefore, an entirely new cyber security paradigm must be invented before the first security-relevant quantum computer comes on the market.

Cities, as well as other private or public entities, hold confidential information that has a long shelf-life time (i.e. the duration during which it should remain confidential). A security threat arises because today's encrypted information can be stored in its encrypted form by potentially unwanted cyber agents today who will be able to decrypt it once the quantum computers are on the market. For this reason, private as well as public entities wishing to maintain today's long shelf-lived confidential information encrypted beyond the moment the first cyber-security relevant quantum computer comes on the market should take essential steps immediately. These steps include at least the physical protection and strict control of servers and data storage devices storing long shelf-lived confidential information. Such long shelf-lived confidential information may include the following:

- Medical histories
- Genetic information
- Juvenile criminal records
- Executive communications
- Drug trial data
- Industrial secrets
- Intellectual property
- Information on cloud data centres
- Classified public information
- Information on public facilities' physical security protocols

The forecast for the timing when quantum computing could be ready to break today's cybersecurity (i.e. be cybersecurity-relevant) is difficult to make. Some experts predict such computers for as early as 2022, some say they will never come. As a weighted average year, the year 2033 emerged from a poll made in April 2020[425]. Equally uncertain is the forecast for the year when quantum security will have emerged. Experts point between 2020 and never, with a weighted average year 2023 emerging.

The above is to explain that cyber-resilience represents a challenge that cities cannot resolve on their own. The development or management of new technologies such as quantum computing is not in the competence of cities. Cities are, however, an important user group of cyber security and should take adequate measures to protect themselves.

Bottom-level resilience against today's cyberthreats includes also firewalls and anti-virus software. In principle each component of the IT architecture can be protected in this way. Firewalling bottom-level IT components mimics a protection mode found in biological organisms which basically protect each cell. Each IT component is like a cell of a multi-cellular organism. Protecting each component separately against cyber-attacks increases the resilience of the network, just as protecting each cell of a biological organism increases resilience of the organism. Broken IT system components can be replaced one by one, just as organisms replace broken cells one by one.

Another difficulty for cities might be the relatively weak international consensus on cybersecurity. At present there exist only a few regional international agreements on cybersecurity[426]. None of them is global. Global internet governance is essentially being formulated by non-governmental actors[427]. Cyber-security does not figure among the SDGs. Continuity of computer systems during disasters figures in criteria 8.11.1 of the Disaster Resilience Scorecard for Cities – Detailed Assessment (see Annex 4).

4. Conclusion: Results-Oriented Monitoring of Local SDGs

The report recommends specifying the strategy outlined in *APSEC (2018)* in more detail so that implementation can start. The cornerstone of the proposed cooperation within the Cooperative Network of Sustainable Cities (CNSC) is an urban SDG tracker or publicly accessible website allowing cities to showcase their results. The SDG tracker should monitor those urban SDG indicators that are relevant to cities, either because they apply directly to them, or because cities own infrastructures which allow attaining the SDG targets. The report proposes and to introduce the tracker in an evolutionary multi-level approach. The relevant disaster resilience criteria are added at each appropriate level.

In commitment level one ("basic showcasing of indicators"), the objective is basic showcasing of indicators on a publicly accessible website or SDG tracker. The city commits to showcase three SDG indicators, namely local energy intensity, annual growth rate of local per capita GDP, and local CO_2-intensity of GDP, and the disaster resilience criteria relating to effective disaster response.

In commitment level two ("local 2050 vision with 2030 targets and action plans") the objective is planning the future along four lines that are known to have the capacity to drive change: the SDG targets on sustainable energy, industrial innovation, IT, and the disaster resilience criteria on corporate urban governance (including financial planning).

In commitment level three ("holistic results-oriented monitoring and implementation") the focus lies on effective realization and implementation of the local 2050 vision with 2030 targets and action plans. It also includes specific questions such as inclusiveness of vulnerable groups. Level three has three subparts: one on implementing the indicators of SDG11 and the disaster resilience essential on pursuing resilient urban development, the second one on implementing the SDG indicators specifically addressing local communities and the disaster resilience criteria on safeguarding natural buffers, strengthening institutional capacity, and strengthening societal capacity, and the third one on implementing those SDG indicators that relate to local infrastructures and the disaster resilience criteria on increasing infrastructure resilience.

Recommendations

The main recommendation of this report is to implement the urban SDG tracker as outlined in the report by inviting APEC cities and local communities to join the Cooperative Network of Sustainable Cities (CNSC).

For improving epidemic resilience of APEC cities, this report recommends examining, and possibly implementing, massive deployment of UV-C light disinfection in all interior spaces as a way for making these free from pathogens causing infectious diseases.

4.1. Overview of Global and APEC Frameworks

4.1.1. The UN Sustainability Frameworks of 2015

APSEC (2018) outlines the essential elements of the 2030 Agenda for Sustainable Development adopted by the UN General Assembly in 2030. For completeness, the 2030 Agenda for Sustainable Development should be described in conjunction with the *Sendai Framework for Disaster Risk Reduction 2015 – 2030* and the *Disaster Resilience Scorecard for Cities* based upon the *Sendai Framework*, as well as the *Paris Climate Agreement* of 2015.

Sustainable development is an interdisciplinary subject combining the complexity of all its component disciplines. It has been an important step for global policy makers, especially the UN General Assembly, to have paved the way by setting a comprehensive "2030 Agenda for Sustainable Development" for the period 2015 – 2030. The agenda contains seventeen SDGs which can be broken down to 169 more specific targets. These goals and targets have the advantage to set priorities in this highly complex area.

Each SDG contains substantive targets (numbered .1, .2, etc., e.g. target 7.1) and instrumental targets (numbered: .a, .b, etc., e.g. target 7.a), except SDG 17 which is itself the overall instrumental goal to attain all the other SDGs and therefore contains only substantive targets. Some of the targets are quantitative, others semi-quantitative allowing specific groups of the global constituency to concretize them to become fully quantitative.

Following the adoption of the SDGs in 2015, the UN General Assembly has further refined and operationalized the targets in 2017 and adopted a fully-fledged SDG indicator framework comprising altogether 244 SDG indicators. Since then, annual updated have increased the total number to 247 targets of which 231 are unique[428]. Each indicator can be referenced either through the three digits indicating goal, target and indicator (e.g. "1.1.1 Proportion of population below the international poverty line"), or through a specific UN Statistics Division (UNSD) indicator code (e.g. C010101).

Looking more precisely at the set of SDG indicators, many of them have only one code, but their definition requires sub-specification by population categories, e.g. 8.5.2 "Unemployment rate, by sex, age and persons with disabilities". This is an example a three-dimensional sub-specification as sex, age and disability are three independent quantities, each of which may even be composed of two or more sub-groups such as, e.g. age groups or disability groups.

One of the strengths of SDGs is their relative conciseness. Conciseness without loss of substance is achieved through referencing altogether 14 other global documents of similar political value adopted by the UN or specialized UN bodies, see *APSEC (2018)* for an analysis. As mentioned above, two of these specialized documents are particularly important for energetic-environmental issues. These are:

- *Paris Agreement* under the UNFCCC[429] to which SDG 13 refers indirectly by "Acknowledging that the UNFCCC is the primary international, intergovernmental forum for negotiating the global response to climate change". The *Paris Agreement* is hitherto the most comprehensive and deep global agreement addressing the aspect of climate mitigation (i.e. reduction of CO_2-emissions) and climate adaptation (i.e. measures adapting to climate change). It is in substance, together with the pledges (or Intended Nationally Determined Contributions INDC), the concretization of SDG 13. Note that also target SDG 9.4, “By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities” includes the CO_2-related indicator 9.4.1 “CO_2 emissions per value added”.

- The *Sendai Framework for Disaster Risk Reduction (DRR) 2015 – 2030*[430], referenced in the *Paris Agreement* as well as in three SDG indicators (1.5.3, 11.b.1, 13.1.2), sets quantitative targets for measuring disaster risk reduction. As hydrometeorological disasters are increasing in frequency and intensity because of climate change, the *Sendai Framework* is also the quantitative framework for measuring reduction to adverse effects of climate change. It is substantively included in SDG 11.5.1 and 11.5.2 on reducing effects of disasters, in SDG 11.b on integrated urban planning and in SDG 13.1 on resilience and adaptive capacity to climate-related hazards. Based upon the *Sendai Framework*, the UN Disaster Risk Reduction Office has elaborated in 2017 the *Disaster Resilience Scorecard for Cities* presented earlier (see Annex 4 for the detailed list of resilience criteria of the detailed assessment of cities). This operationalizes DRR by focusing specifically on disaster resilience and addressing specifically the level of cities.

The relationship between the three basic frameworks adopted in 2015, namely the SDGs, the *Paris Agreement*, and the *Sendai Framework*, all referring to the same period 2015 – 2030, can be illustrated in the following figure. Key goals of the *Sendai Framework* are included in three SDGs, while the *Paris Climate Agreement* is a concretization of SDG 13.

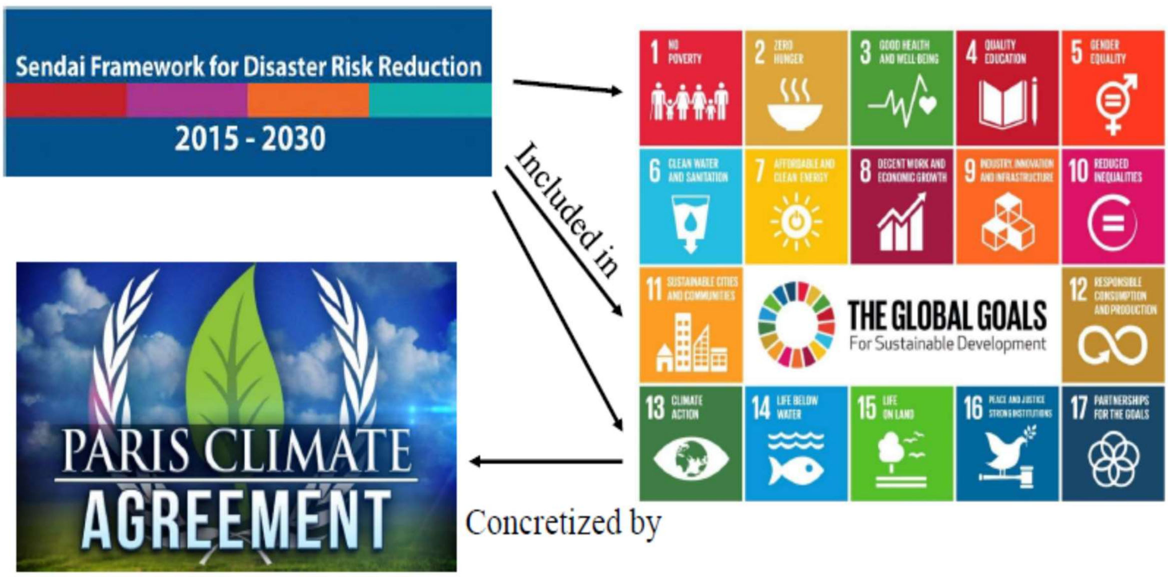


Figure 163: Relationship between the key UN frameworks adopted in 2015

Source: APSEC

4.1.2. APEC Energy and Urbanization Policies and Goals

APEC Economic Leaders have up to now adopted five major energy-related initiatives or goals:

- In 2000, APEC Economic Leaders' Meeting in Indonesia declared: "We welcome the new energy security initiative"[431]. There is no corresponding language on energy security in the SDGs.

- In 2009, APEC Economic Leaders' Meeting in Singapore declared: "We also commit to rationalize and phase out over the medium-term fossil fuel subsidies that encourage wasteful consumption, while recognizing the importance of providing those in need with essential energy services"[432]. This goal mirrors SDG indicator 12.c.1 on inefficient fuel subsidies, which in the SDGs is part of the overarching theme of sustainable consumption and production patterns.

- In 2010, APEC Economic Leaders' Meeting in Yokohama declared "We will create low-carbon communities in the region"[433]. This initiative created the concept of Low Carbon Model Town LCMT and the corresponding indicator system LCT-I as well as an LCMT-Task Force for monitoring progress. Up to now, seven LCMTs have been created. This goal has several indirect mirrors in the SDGs. SDG 11 sets the general goal to make cities and human settlements inclusive, safe, resilient and sustainable. SDG 9 on resilient infrastructure, inclusive and sustainable industrialization and innovation includes as target "CO_2 emissions per unit of value added". SDG 13 formulates the general intention to mitigate carbon emissions, with indicators 13.1.1, 13.1.2 and 13.1.3 addressing disaster risk reduction issues.

- In 2011, APEC Economic Leaders' Meeting in Hawaii declared "We aspire to reduce APEC's aggregate energy intensity by 45 percent by 2035"[434]. This goal mirrors SDG 7.3. on doubling the global rate of improvement in energy efficiency, and SDG indicator 7.3.1 "Energy intensity measured in terms of primary energy and GDP".

- The 2014 APEC Ministerial Meeting in Beijing declared: "We aspire to the goal of doubling the share of renewables in the APEC energy mix, including in power generation, from 2010 levels by 2030"[435]. This goal mirrors SDG 7.2. on the increase of renewables' share.

Besides energy, APEC Economic Leaders also adopted policies on science, technology and innovation (STI), on sustainable urbanization, and on disaster resilience.

- APEC Economic Leaders' Meeting in Vladivostok in 2012 agreed to transform the Industrial Science and Technology Working Group into a Policy Partnership on Science, Technology and Innovation (PPSTI) to bring together the three key groups of innovation stakeholders – business, government and academia – to address common challenges, enhance innovation capacity.

- The 2014 APEC Ministerial Meeting in Beijing declared: "We endorse the APEC Cooperation Initiative for jointly establishing an Asia-Pacific Urbanization Partnership"[436]. It also agreed "to establish a cooperative network of sustainable cities in the APEC economies". The Cooperative Network of Sustainable Cities (CNSC) has rapidly developed to include not only the proper APEC Network of Low-carbon and Energy efficient Cities, but also the APEC Sustainable City Services

Network comprising enterprises or organizations that can provide sustainability services to the cities, and, furthermore, it includes the APEC Sustainable Cities Workshop held annually in conjunction with the APEC Energy Working Group meeting. In the SDGs, the goal of horizontal cooperation is indirectly mirrored by all those SDGs which include language on cooperation and partnerships of all kinds.

- In 2015, few months after the adoption of the *Sendai Framework for Disaster Risk Reduction 2015 – 2030*, APEC Economic Leaders declared: to "endorse the APEC Disaster Risk Reduction Framework"[437]. This is an adaptation of the *Sendai Framework* to the specific situation within APEC, where disasters play a larger role than elsewhere.

APSEC (2018) finds that the needs of improving urban sustainability in APEC is so large that scaling up the process is a first order priority. The objective is to widen the CNSC network, i.e. increase the number of member cities, and deepen the cooperation, i.e. have the possibility for cities to engage in different levels of cooperation, from an initial basic level of commitment consisting of a commitment to improve sustainability and disaster resilience and showcase the results, to a stronger commitment towards a local 2050 vision with 2030 targets and action plans, and beyond that, to a commitment to the highest level of cooperation, consisting of implementing integrated urban policies and planning towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and development and implementation of holistic disaster risk management.

4.2. An Urban SDG Tracker for APEC Cities

4.2.1. Objectives of the Urban SDG Tracker for APEC Cities

APSEC (2018) outlines elements of a cooperative strategy for scaling up APEC sustainable urbanization by targeted focus on energy technologies that synergize resilience with better economic performance, social inclusiveness, and less environmental impact. This report recommends further specifying this strategy with more detail to allow starting implementation.

The objectives of the Urban SDG Tracker are the following:

- Create a platform that can assist cities to improve sustainable development by monitoring key indicators of each city.
- Allow each city to choose the level of commitment towards sustainable development, starting from basic commitment that can be upgraded to rapid progress in key areas and further upgraded to holistic sustainable development.
- Ensure compatibility of the indicator system with the three key UN Frameworks of 2015, namely the *Sendai Framework for Disaster Risk Reduction* and the associated 2017 *Disaster Resilience Scorecard for Cities*, the UN SDGs and the and the *UNFCCC Paris Climate Agreement* as well as the associated 2017 UN SDG indicator system.
- Ensure compatibility with the five APEC energy goals as well as with the relevant APEC frameworks related to other areas, in particular the Policy Partnership on Science, Technology and Innovation (PPSTI) endorsed in 2012, the APEC

Cooperation Initiative for Jointly Establishing an Asia-Pacific Urbanization Partnership endorsed in 2014, and the APEC Disaster Risk Reduction Framework endorsed in 2015.

- Facilitate defining local long-term visions and setting long-term urban development targets.
- Facilitate pilot projects that are in line with the set local development targets.
- Facilitate making large-scale investment into urban infrastructures such as Transit-Oriented Development (TOD) that are in line with the defined local visions and goals.
- Guide the evaluation of large-scale investment.
- Guide the choice of future technologies.

4.2.2. Commitment Level One: Basic Showcasing

The cornerstone of the proposed cooperation is results-oriented monitoring of cities. Monitoring means regularly observing and recording some type of activity of cities. For observing long-term phenomena, annual observations suffice. The observations should, if possible, stretch back at least to the beginning of APEC in 1990. Where urban-scale data is available, the start date 1960 should be chosen.

“Results-oriented” implies linking the monitored activity to some type of result achieved by the cities during the observed period. Since the UN has released the 2015 frameworks mentioned above, the most natural choice is to link the monitored activity to the targets set in these frameworks. As a result of the discussion in section 3.1.1. on the tight equilibrium between sustainability and disaster resilience, the Disaster Resilience Scorecard for Cities is proposed as relevant framework providing instruments to accelerate sustainability. As sustainability, defined by SDGs, is the ultimate goal, it is justified to call the planned data base urban SDG tracker, even though it contains also instrumental data drawn from the Disaster Resilience Scorecard. The explanations hereafter will refer to sustainability and disaster resilience as two dimensions of the data base.

Despite having reduced the complexity of sustainable development, the SDGs still contain a considerable number of altogether 231 unique indicators. The detailed assessment of the Disaster Resilience Scorecard for Cities adds another 117 assessment criteria.

The three-level approach is designed to introduce monitoring these step by step, giving highest priority to the most urgent questions.

The basic commitment level (“basic showcasing of indicators”) is defined as commitment of the city to improve sustainability and to publicly showcase the result. This implies also implementing basic elements of disaster resilience such as effective disaster response as means to support basic achievements of sustainability during disaster times.

Showcasing the result is essential for the SDG indicators, as the whole SDG system is an entirely voluntary endeavour. It is, therefore, widely accepted that progress towards SDGs should be monitored by showcasing the results in public information systems, including public websites.

At the basic commitment level, monitoring sustainability requires compiling SDG-relevant data on four fundamental local input data sets that reflect the basic characteristics of the city, namely local population, local GDP, local energy consumption, and local CO_2 emissions.

Note that local GDP is given in local currency. The CNSC platform operator transforms it to purchase power parity corrected USD with constant base year (e.g. 2017, USD PPP 2017) using the International Comparison Program (ICP) 2017 Data Bank[438]. These four input quantities plus the ICP input conversion factor will allow computing the three output SDG indicators of the sustainability dimension shown below.

SDG indicator	Local equivalent indicator	Primary formula	Composite formula
7.3.1	Local energy intensity measured in terms of local energy consumption and local GDP	Local energy consumption / local GDP	Annual % decrease
8.1.1	Annual growth rate of local real GDP per capita	Local real GDP / capita	Annual % increase
9.4.1	Local CO_2 emission per unit of value added locally, or local CO_2 emissions	Local CO_2 emissions / Local GDP, or local CO_2 emissions	Annual % decrease of local emissions / GDP, or of local emissions

Table 23: Output indicators of the sustainability dimension, commitment level one

Source: APSEC

APSEC (2018) has shown how to handle the problem of attributing emissions that cannot easily be attributed to one place or city because the emitting substance has crossed the city boundary. This is also important to achieve coherence with economy-wide indicators. This problem has been resolved in the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories – Reporting Standard for Cities[439]. It provides basically for three scopes of GHG emissions:

- GHG emissions from sources located from within the city boundary.
- GHG emissions occurring as a consequence of grid-supplied electricity, heat, steam or cooling.
- GHG emissions that occur outside the city boundaries as a result of activity taking place within the city.

Basic commitment level also monitors the most urgent elements of the dimension of disaster resilience. These are found in essential 9, “Ensure effective disaster response”, which includes early warning as most important basic tool to prevent disasters. The 16 criteria of essential 9 are shown in table below, which should be assessed on a scale 0 to 5 as exemplified in the scorecard for detailed disaster risk assessment of cities[440]. The scorecard is more of an assessment than of an exact measurement.

9	Ensure Effective Disaster Response	
9.1	Early warning	Does the city have a plan or standard operating procedure to act on early warnings and forecasts? What proportion of the population is reachable by early warning system?
9.1.1	Existence and effectiveness of early warning systems	Length and reliability of warning – enabling practical action to be taken.
9.1.1.1	Reach of warning	Will 100% of population receive it?

9.2	Event response plans	Is there a disaster management / preparedness / emergency response plan outlining city mitigation, preparedness and response to local emergencies?
9.2.1	Existence of emergency response plans that integrate professional responders and community organizations	Existence of plans formulated to address “most likely” and “most severe” scenarios, shared and signed off by all relevant actors (including citizen organizations
9.3	Staffing / responder needs	Does the responsible disaster management authority have sufficient staffing capacity to support first responder duties in surge event scenario?
9.3.1	‘Surge” capacity of police also to support first responder duties	Sufficient back-up or para-professional capacity to maintain law and order in “most severe” and “most probable” scenarios, in addition to supporting burden of first responder duties.
9.3.2	Definition of other first responder and other staffing needs, and availability	Staffing needs are defined for “most probable” and “most severe” scenarios.
9.4	Equipment and relief supply needs	Are equipment and supply needs, as well as the availability of equipment, clearly defined?
9.4.1	Definition of equipment and supply needs, and availability of equipment	Equipment and supply needs are defined for “most probable” and “most severe” scenarios in Essential 2 (the detail of which will be part of commitment level 2, see below)
9.4.1.1		Estimated shortfall in available equipment per defined needs – potentially from multiple sources. MOUs exist for mutual aid agreements with other cities, and also for private sector sources.
9.5	Food, shelter, staple goods and fuel supply	Would the city be able to continue to feed and shelter its population post-event?
9.5.1	Likely ability to continue to feed population	“Food gap” - # of days that city can feed all segments of its population likely to be affected minus # of days’ disruption estimated under those scenarios
9.5.2	Likely ability to meet needs for shelter/safe places	“Shelter gap” – numbers of displaced persons minus shelter places available within 24 hours.
9.5.2.1		“Shelter gap” – ability of shelters to withstand disaster events and remain safe and usable.
9.5.3	Ability to meet likely needs for staple goods	“Staples gap” - % shortfall in supply within 24 hours relative to demand
9.5.4	Likely availability of fuel	“Fuel gap” - # of days that city can meet fuel requirements, minus # of days’ disruption to regular supply.
9.6	Interoperability and inter-agency working	Is there an emergency operations centre, with participation from all agencies, automating standard operating procedures specifically designed to deal with “most probable” and “most severe” scenarios?
9.6.1	Interoperability with neighbouring cities/states and other levels of government of critical systems and procedures	Ability to cooperate at all levels with neighbouring cities and other levels of government.

9.6.2	Emergency operations centre	Existence of emergency operations centre with participation from all agencies, automating standard operating procedures specifically designed to deal with “most likely” and “most severe” scenarios.
9.6.3	Coordination of post event recovery	Coordination arrangements identified in advance for all post-event activities in the city’s area, with clarity of roles and accountability across all relevant organizations. Does an organizational chart documenting structure and role definitions at each relevant agency exist, to achieve a single overall point of co-ordination?
9.7	Drills	Do practices and drills involve both the public and professionals?
9.7.1	Practices and rehearsals – involving both the public and professionals	Testing of plans annually, by reference to simulated emergency and actual non-emergency events.
9.7.2	Effectiveness of drills and training	Level of effectiveness of drills

Table 24: Essential criteria of disaster resilience, commitment level one

Source: APSEC

An example of results-oriented monitoring at the basic commitment level can be found e.g. in SDG trackers as they appear now more and more frequently on internet, see e.g. the official SDG 7 tracker[441]. None of them has, however, proposed to track evolution at urban level. Still, improving city-level data is being proposed by several organizations, most importantly by the UN Economic and Social Commission for Asia-Pacific UNESCAP which follows a similar idea under the heading localizing SDGs, meaning that SDGs should be translated to local level[442].

For facilitating providing the data, it is advised that each city or community designates a local CNSC expert who will be the contact person with the CNSC network. The receiving data base administrator makes the quality control of the data received from cities, computes the three indicators listed in table 1, and shows each of them in an interactive map and a timeline, respectively. As an example of a figure see the evolution of the global energy intensity below.

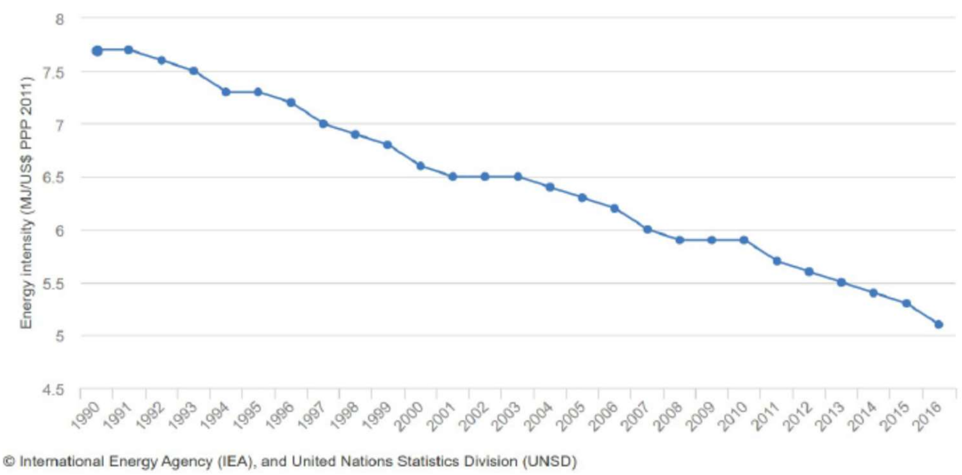


Figure 164: Evolution of global energy intensity since 1990

Source: IEA and UNSD

4.2.3. Commitment Level two: Local Visions, Targets and Action Plans

Some cities might wish to deepen cooperation up to commitment level two.

Commitment level two ("local 2050 vision with 2030 targets and action plans") consists of the commitment to elaborate and implement a local 2050 vision with 2030 targets and action plans along four lines:

- Sustainable energy (SDG 7)
- Industrial innovation (SDG 9)
- IT (SDG 17)
- Corporate urban governance (essentials 1 to 3 and 10, including financial planning).

The rationale for commitment level two is obvious: Many SDGs or targets are either not moving fast enough or moving in the wrong direction. As an example of a variable needing complementary action, take the share of renewable energy in global total final energy consumption. Looking at the past 25 years, rather than steadily moving upward, the global renewables share has been stationary within a narrow corridor between 16% and 17.5%, see figure below. Since the creation of the International Renewable Energy Agency (IRENA) in 2011, the trend has been upward. This is the sign that specific policies are needed to make the evolution disaster resilient. The APEC energy supply and demand outlook 2016 also finds that the goal of doubling the renewables' share by 2030 will not be reached without supplementary measures[443]. In 2014, IRENA published its Renewable Energy Roadmap REMAP 2030[444], showing that doubling the share of renewables from 18% to around 30% to 36% by 2030 was not only possible, but also cheaper than providing energy supply from fossil sources. The Global Renewables Outlook published by IRENA in 2020 shifts the focus on decarbonization by 2050[445].

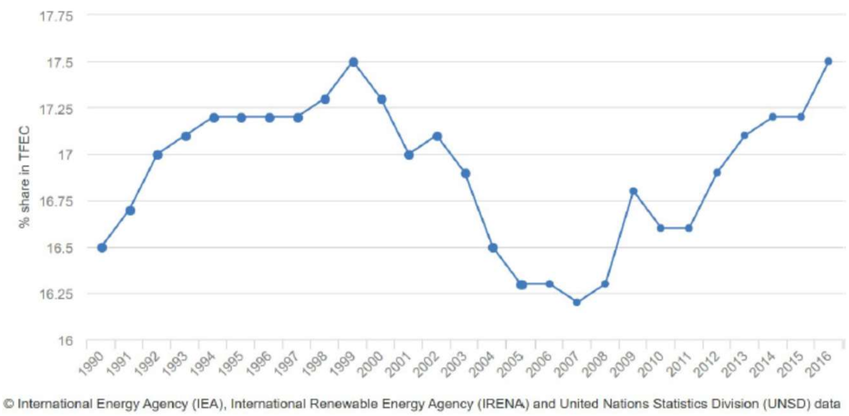


Figure 165: Evolution of the renewables share in total final energy consumption

Source: IEA, IRENA and UNSD

In its report on Electricity Storage and Renewables: Costs and Markets to 2030, IRENA also states: "Total electricity storage capacity appears set to triple in energy terms by 2030, if countries proceed to double the share of renewables in the world's energy system"[446]. Pumped hydro storage, which currently still accounts for 96% of global electricity storage, will increase only marginally; the bulk increase comes likewise from utility-scale batteries and from rooftop-related battery storage. The IRENA report states that stationary battery energy storage increases 17 to 38-fold (i.e. with additional 170 GWh to 410 GWh) between 2015 and 2030 to meet the additional storage demand related to doubling the renewables' share. The big uncertainty stems from the uncertainty over the quantity of EVs in 2030. The higher the quantity of EVs, the less stationary battery storage is needed. Most of this storage will be located near consumer centres, i.e. cities. Battery energy storage also increases local disaster resilience. This illustrates why sustainability and disaster resilience should go together.

Addressing the renewables' share, therefore, clearly requires supplementary action by the cities. Such action should be structured around a coherent 2050 vision. The 2050 date is chosen as this date is more and more often seen as a key milestone for phasing out CO_2 emissions to limit the global temperature rise to 1.5 degrees, see e.g. the European Green Deal[447]. The 2050 vision should embody at least the following interlinked elements:

- What will the energy system of the city look like in 2050?
- What innovative industrial elements are there / should there be in the city to support this energy transformation?
- How does the city's IT infrastructure favour this energy transformation?
- How does urban governance improve urban planning and urban financial resilience?

At commitment level two, a strong focus lies on energy, therefore, the remaining indicators of SDG 7 (clean energy) are included in level two. These require the following local data:

- SDG 7.1.1 Proportion of local population having access to electricity.
- SDG 7.1.2 Proportion of local population with primary reliance on clean fuels and technology.
- SDG 7.3.1 Local renewable energy share in local total final energy consumption.
- SDG 7.b.1 Installed renewable energy-generating capacity in developing economies (in watts per capita), indicator introduced in the 2020 annual update.

A central success factor for implementing sustainable energy is to show that it goes hand in hand with improved economic performance. It would, in fact, be impossible to motivate cities to implement energy policies that diminish economic performance. Annual growth rate of local real GDP per capita is already included in commitment level one. Commitment level two, therefore, focuses on indicators related to industrial innovation as found in SDG 9, "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation". These indicators are to prevent deindustrialization and monitor the growth of innovation by SMEs. For computing output indicator SDG 9.2.2 (local manufacturing employment as a proportion of total local employment), two input data are needed, namely the total employment and the local manufacturing employment.

- SDG 9.2.1 Local manufacturing value added as a proportion of local GDP and per capita.
- SDG 9.2.2 Local manufacturing employment as a proportion of total local employment.
- SDG 9.3.1 Proportion of local small-scale industries in total local industry value added.

- SDG 9.5.2 Local researchers (in full-time equivalent) per million inhabitants. If the city has less than a million inhabitants, the denominator is adjusted to take account of the size of the city.
- SDG 9.b.1 Proportion of medium and high-tech industry value added locally in total local value added.

Given the important role of IT, commitment level two also includes indicators on IT as mentioned in SDG 9 on resilient infrastructure and SDG 17 on strengthening the means of implementation.

- SDG 9.c.1 Proportion of population covered by a mobile network, by technology.
- SDG 17.6.1, Fixed local Internet broadband subscriptions per 100 inhabitants, by speed; is in fact a percentage.
- SDG 17.8.1, Proportion of local individuals using the Internet.

In the dimension of disaster resilience, commitment level 2 adds the assessment on scale 0 to 5 of those essentials focusing on the three areas of corporate urban governance (see below) , and of essential 10, planning for rapid disaster recovery and build back better:

- Organize for Resilience.
- Identify, Understand and Use Current and Future Risk Scenarios.
- Strengthen Financial Capacity for Resilience.
- Expedite Recovery and Build Back Better.

Note that the actual reconstruction or building back process is not part of essential 10. Thus, commitment level 2 adds altogether 29 disaster resilience criteria.

1	Organize for Resilience	
1.1	Plan Making	Does the city master plan (or relevant strategy/plan) include and implement disaster risk reduction approaches in line with the *Sendai Framework*? By 'plan' we typically mean some form of city-wide plan, cross cutting strategy or vision. This could be a spatial plan, an infrastructure plan or an environmental or sustainability plan, providing it complies with the criteria from *Sendai Framework* paragraph 27 (b). For compliance, the plan should have coverage across all of the ten essentials
1.1.1	Risk consideration in Plan Making	To what extent are risk factors considered within the City Vision / Strategic Plan?
1.1.2	Consultation in Plan Making	Is this strategy developed through inclusive, participatory multi-stakeholder consultation?
1.1.3	Review of strategic plans	Is the city strategic plan reviewed on a regular basis?
1.2	Organization, coordination, and participation	Is there a multi-agency/sectoral mechanism with appropriate authority and resources to address disaster risk reduction?
1.2.1	Pre-event planning and preparation	Co-ordination of all relevant pre-event planning and preparation activities exists for the city's area, with clarity of roles and accountability across all relevant organizations.
1.2.2	Co-ordination of event response	Coordination of all relevant event response activities in the city's area, with clarity of roles and accountability across all relevant organizations.
1.2.3	City resources for managing	Ability of the city government to play the critical convening and plan making role for DRR. Do the city and or other lead

	organisation, co-ordination and participation	agencies have the authority and resources to deliver on their DRR commitments? This assessment criteria relating to resources and funding should be considered for pre-event planning (1.2.1), event response (1.2.2) and post event (1.2.6 together).
1.2.4	Identification of physical contributions	Co-option of physical contributions by both public and private sectors. Identification of physical contributions for each major organization.
1.3	Integration	Is resilience properly integrated with other key city functions / portfolios? (e.g., planning, sustainability, investment case approval, finance and compliance, community engagement, emergency management, code compliance, infrastructure management, communications etc.)
1.3.1	Integration of disaster resilience with other initiatives	Extent to which any proposal in government is also evaluated for disaster resilience benefits or impairments. Explicit stage in policy and budget approval process where disaster resilience side benefits, or impairments, of any city government initiative are identified and counted towards the Return on Investment (ROI) for that proposal.
1.4	Data capture, publication and sharing	
1.4.1	Extent to which data on the city's resilience position is shared with other organizations involved with the city's resilience	Availability of a single "version of the truth" – a single integrated set of resilience data for practitioners.
2.	Identify, Understand and Use Current and Future Risk Scenarios	
2.1	Hazard assessment	Does the city have knowledge of the key hazards that the city faces, and their likelihood of occurrence?
2.1.1	Knowledge of hazards (also called perils, or shocks and stresses) that the city faces, and their likelihood	Existence of recent, expert-reviewed estimates of probability of known hazards or perils and their extents.
2.2	Knowledge of exposure and consequence	Are there agreed scenarios setting out city-wide exposure and vulnerability from each hazard, or groups of hazards?
2.2.1	Knowledge of exposure and vulnerability	Existence of scenarios setting out city-wide exposure and vulnerability from each hazard level
2.2.2	Damage and loss estimation	Do risk assessments identify business output and employment at risk, populations at risk of displacement, housing at risk, agricultural land and ecosystems at risk, cultural heritage at risk for key identified scenarios?
2.3	Cascading impacts or interdependencies	Is there a collective understanding of potentially cascading failures between different city and infrastructure systems, under different scenarios?
2.3.1	Understanding of critical assets and the linkages between these	All critical assets are identified (see Essential 8) and relationships between them are identified in the form of potential "failure chains". This is used to frame disaster plans and triage (see Essential 9) and also retrofits and upgrades to improve the capability of the infrastructure to withstand disasters.
2.4	Hazard maps	Do clear hazard maps and data on risk exist? Are these regularly updated?

2.4.1	Hazard maps	Presence of hazard maps (for example, flood or seismic risk maps).
2.5	Updating of scenario, risk, vulnerability and exposure information	
2.5.1	Update process	Process ensuring frequent and complete updates of scenarios. Existence of a process agreed between all relevant agencies to: Update hazard estimates every 3 years or less; update exposure and vulnerability assessments and asset inventory every 18 months or less.
3.	Strengthen Financial Capacity for Resilience	
3.1	Knowledge of approaches for attracting new investment to the city for DRR	The city / lead agencies understand all sources of funding, and the "resilience dividends", are well connected, understand all available routes to attract external funding and are actively pursuing funds for major resilience investments.
3.1.1	Awareness and knowledge of all possible methods of financing and funding, as required. The city is actively pursuing financing and funding, as required Note: If sufficient funds exist these assessment criteria can be omitted	Where a city has outstanding resilience expenditure needs (revenue or capital) – the extent to which it has researched and understands all available routes / options to close any funding shortfalls. The extent to which the city is actively trying to meet funding needs and has a clear responsibility for this. This may include the use of external funding or management consultants. This may include the systematic identification of "resilience dividends" (also known as co-benefits).
3.2	Resilience budgets within the city financial plan including contingency funds	Does the city have in place a specific 'ring fenced' (protected) budget, the necessary resources and contingency fund arrangements for local disaster risk reduction (mitigation, prevention, response and recovery)?
3.2.1	Adequacy of financial planning for all actions necessary for disaster resilience	Presence of financial (capital and operating) plan(s) with a reasoned set of priorities, based on disaster resilience impact achieved, and linked to "most probable" and "most severe" scenarios in Essential 2. Priorities for disaster resilience investment are clear and defensible, based on a view of most beneficial impact. Priorities are assembled into 5-year plan that integrates spending by all key organisations and will meet scenarios in Essential 2.
3.2.2	Capital funding for long run engineering and other works that address scenarios and critical assets identified in Essentials 2 and Essential 8	% funding for capital elements of plan(s) relative to estimated cost. Degree of protection ("ringfencing") from cuts or from being taken away to be used for other purposes.
3.2.3	Operating funding to meet all operating costs of disaster resilience activities	Funding for operating expenses relative to estimated costs: presence of separately delineated budget line item(s). Degree of protection ("ringfencing") from cuts or from being taken away to be used for other purposes.
3.2.4	Contingency fund(s) for post disaster recovery (may be	Existence of fund(s) capable of dealing with estimated impacts from "most severe" scenario (See Essential 2).

	referred to as a “rainy-day fund”)	Degree of protection (“ringfencing”) of contingency fund(s) from being taken away to be used for other purposes.
3.3	Insurance	What level of insurance cover exists in the city, across all sectors - business and community?
3.3.1	Domestic insurance coverage	Extent of coverage of domestic housing. (Personal or life coverage is not assessed).
3.3.2	Non-domestic insurance coverage	Extent of insurance coverage of non-domestic property, infrastructure and assets.
3.4	Incentives and financing for businesses, community organizations and citizens.	What incentives exist for different sectors and segments of business and society to support resilience building?
3.4.1	Incentives to businesses organizations to improve disaster resilience – disaster plans, premises etc	Existence of incentives to help business owners take steps to improve disaster resilience to a standard to deal with the “most severe” scenario (Essential 2).
3.4.2	Incentives to non-profit organizations to improve disaster resilience – disaster plans, premises etc	Existence of incentives to help non-profits take steps to improve disaster resilience to a standard to deal with the “most severe” scenario (Essential 2).
3.4.3	Incentives to homeowners to improve disaster resilience – disaster plans, premises etc	Existence of incentives to help homeowners take steps to improve disaster resilience to a standard to deal with the “most severe” scenario (Essential 2). Ideally means-tested, to ensure that funds go to those most in need
10	Expedite Recovery and Build Back Better	
10.1	Post event recovery planning – pre event	Is there a strategy or process in place for post-event recovery and reconstruction, including economic reboot, societal aspects etc.?
10.1.1	Planning for post event recovery and economic reboot	Existence of comprehensive post event recovery and economic reboot plans.
10.1.2	Extent to which there has been stakeholder consultation around the ‘event recovery and reboot’ plans	Stakeholder involved in build back better plan.
10.1.3	Shadow financial arrangements for processing incoming aid and disbursing funds	Post event arrangements exist for dealing with incoming financial aid and disbursements.
10.2	Lessons learnt / learning loops	Do post-event assessment processes incorporate failure analyses and the ability to capture lessons learned that then feed into design and delivery of rebuilding projects?
10.2.1	Learning loops	Existence of a process and format for “post-mortems” on what went well and less well in the event response and post-event phases.

Table 25: Disaster resilience criteria of commitment level two

Source: APSEC

In commitment level two, cities are also encouraged to implement pilot projects in line with the set targets. Examples of pilot projects are so-called plus-energy districts, see *APSEC*

(2018). These are housing districts that in annual average produce more energy than they consume. Today's best practice typically allows plus-energy districts to produce not only all the energy needed for in-house activities, but also to power the energy needed by the car fleet of the dwellers. The energy surplus of such districts could possibly be further increased in future by integrating small (e.g. foldable or vertical axis) wind turbines, waste-to-energy and/or wastewater-to-energy processes into the design of the district. Plus-energy districts will also contribute to decentralized energy storage.

4.2.4. Commitment Level three: Holistic Monitoring and Implementation

Commitment level three ("holistic results-oriented monitoring and implementation") contains a broad focus on all areas of sustainable development. Level three considers the effective realization or implementation of the 2050 vision and the 2030 targets. It also includes specific questions such as inclusiveness of vulnerable groups.

In the sustainability dimension, commitment level three consists of the commitment to implement local integrated urban policies and planning, incorporating commitment level two as well as all indicators of SDG 11 (cities, level 3a), all other SDG indicators addressing specifically local communities (level 3b), and all indicators relating to local infrastructures (level 3c).

The core of sustainability indicators can be found in SDG 11 (inclusive, safe, resilient, and sustainable cities and communities). Monitoring SDG 11 requires the following local data:

- SDG 11.1.1 Proportion of local urban population living in slums, informal settlements, or inadequate housing.
- SDG 11.2.1 Proportion of local population that has convenient access to public transport, by sex, age, and persons with disabilities.
- SDG 11.3.1 Ratio of local land consumption rate to local population growth rate.
- SDG 11.3.2 Whether the city has a direct participation structure of civil society in urban planning and management that operates regularly and democratically.
- SDG 11.4.1 Total expenditure … per capita … spent on cultural and natural heritage.
- SDG 11.5.1 Number of local deaths, missing persons and directly affected persons attributed to disasters per 100,000 population. This is identical to SDG 1.5.1 and SDG 13.1.1. It is also the combination of the first and second target of the Sendai Disaster Risk Reduction Framework which suggests using the 10-year moving average for this indicator. If the city has less than 100'000 inhabitants, the denominator is adjusted to take account of the size of the city.
- SDG 11.5.2 Direct local economic loss in relation to local GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters. This is very similar to SDG 1.5.2 and the third and fourth target of the Sendai Disaster Risk Reduction Framework. Possibly use a 10-year moving average for this indicator.
- SDG 11.6.1 Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities.
- SDG 11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted).
- SDG 11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age, and persons with disabilities.
- SDG 11.7.2 Proportion of victims of physical or sexual harassment in previous 12 months.

- SDG 11.a.1 Whether the city implements urban development plans integrating population projections and resource needs.
- SDG 11.b.2 Whether the local government adopts and implements local disaster risk reduction strategies in line with national disaster risk reduction strategies. This is identical with SDG 1.5.4 and SDG 13.1.3 and is also the fifth target of the Sendai DRR Framework.

Indicator 11.7.1 requires collecting the data on the built-up area that is open space for public use by sub-categories, as a proportion of the total land consumed, collected in 11.3.1.

Furthermore, commitment level 3 monitors those SDG indicators that are specifically addressing local communities or cities. These are SDG 11.b.2 mentioned just above as well as the identical SDG 1.5.4 and 13.1.3, in sum:

- SDG 2.5.2 Proportion of local breeds classified as being at risk, not at risk or at unknown level of risk of extinction (for rural communities).
- SDG 5.5.1 Proportion of seats held by women in local government.
- SDG 6.b.1 Whether the local administrative unit has established operational policies and procedures for participation of local communities in water and sanitation management.
- SDG 16.7.1 Proportions of positions in local institutions, including (a) the legislatures; (b) the public service; and (c) the judiciary, compared to national distributions, by sex, age, persons with disabilities and population groups.

Besides the above-mentioned, the SDG indicators of level three include those on which local authorities can have an influence as they depend on local infrastructures that are normally in the competence of local authorities:

- SDG 1.4.1 Proportion of local population living in households with access to basic services.
- SDG 1.4.2 Proportion of total adult population with secure tenure rights to land, (a) with legally recognized documentation, and (b) who perceive their rights to land as secure, by sex and type of tenure.
- SDG 3.9.2 Mortality rate attributed to unsafe water, unsafe sanitation, and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services)
- SDG 3.9.3 Mortality rate attributed to unintentional poisoning.
- SDG 4.1.1 Proportion of children and young people (a) in grades 2/3; (b) at the end of primary; and (c) at the end of lower secondary achieving at least a minimum proficiency level in (i) reading and (ii) mathematics, by sex.
- SDG 4.4.1 Proportion of local youth and adults with information and communications technology (ICT) skills, by type of skill
- SDG 6.1.1 Proportion of local population using safely managed drinking water services.
- SDG 6.3.1 Proportion of local wastewater safely treated.
- SDG 6.5.1 Degree of local integrated water resources management implementation.
- SDG 8.5.2 Local unemployment rate, by sex, age, and persons with disabilities.
- SDG 9.1.1 Proportion of the local rural population who live within 2 km of an all-season road (for rural communities).
- SDG 10.4.1 Labour share of local GDP, comprising wages.
- SDG 12.4.2 Local hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment.
- SDG 12.5.1 Local recycling rate, tons of material recycled.

- SDG 14.1.1 Index of local coastal eutrophication and floating plastic debris density (for coastal cities).
- SDG 14.5.1 Coverage of protected areas in relation to marine areas.
- SDG 15.1.1 Local forest area as a proportion of local land area.
- SDG 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type.
- SDG 15.3.1 Proportion of land that is degraded over total land area.
- SDG 16.1.1 Number of local victims of intentional homicide per 100,000 population, by sex and age.

Some of these indicators require collecting more than one input data series. 4.1.1 requires collecting several disaggregate data sets as well as the total number of children and young people of the city. 4.4.1 also requires total number of youth as well as the youth with the mentioned skills. 6.3.1 requires the total amount of wastewater as well as the safely treated wastewater. 12.5.1 requires total local production of municipal solid waste as well as the amount recycled. 15.1.1 requires the total local land area as well as the local forest area.

Thus, the sustainability indicators of level three comprise the three indicators of level one, the twelve indicators of level two, and the 13 indicators of SDG 11, the four supplementary indicators specifically addressing local communities, and 20 indicators linked in one or the other manner to urban infrastructures, in total 52 output SDG indicators of the sustainability dimension. At level three, two SDGs, namely SDGs (energy) and SDG 11 (cities) are included with all their relevant indicators. This list is still a relatively small subset of approximately 20% the 231 SDG indicators. Recall that the SDG indicators have not been drafted for cities or local communities, contrary to the Disaster Resilience Scorecard which applies specifically to cities.

In the disaster resilience dimension, commitment level three consists of the five areas of integrated urban planning covering the five forms of capital that increase disaster resilience. These include Essential 4 (Pursue resilient urban development, level 3a), Essentials 5 to 7 (ecological, institutional, and societal disaster resilience, level 3b), and Essential 8 (increase infrastructure resilience, level 3c), corresponding together to the five areas of urban planning:

- Level 3a (10 criteria): Essential 4, Pursue resilient urban development, including land zoning, new urban development, building codes and standards, application of building codes and standards.
- Level 3b (28 criteria): Essential 5, Safeguard Natural Buffers to Enhance the Protective Functions Offered by Natural Ecosystems, including Existing natural environment and ecosystem health, Integration of green and blue infrastructure into city policy and projects, Transboundary environmental issues.
- Essential 6, Strengthen Institutional Capacity for Resilience, including Skills and experience, Public education and awareness, Data capture, publication and sharing, Training Delivery, Languages, Learning from others.
- Essential 7, Understand and Strengthen Societal Capacity for Resilience, including Community or “grass roots” organizations, Social networks, Private sector / employers, Citizen engagement techniques.
- Level 3c (42 criteria): Essential 8, Increase Infrastructure Resilience, including Protective infrastructure, Water sanitation, Energy – Electricity, Energy – Gas, Transportation, Communications, Healthcare, Education, Prisons, Administrative operations, Computer systems and data.

For a detailed description of these criteria see Annex 4. The three cooperation levels in both dimensions, sustainability and disaster resilience, are shown in the figure below.

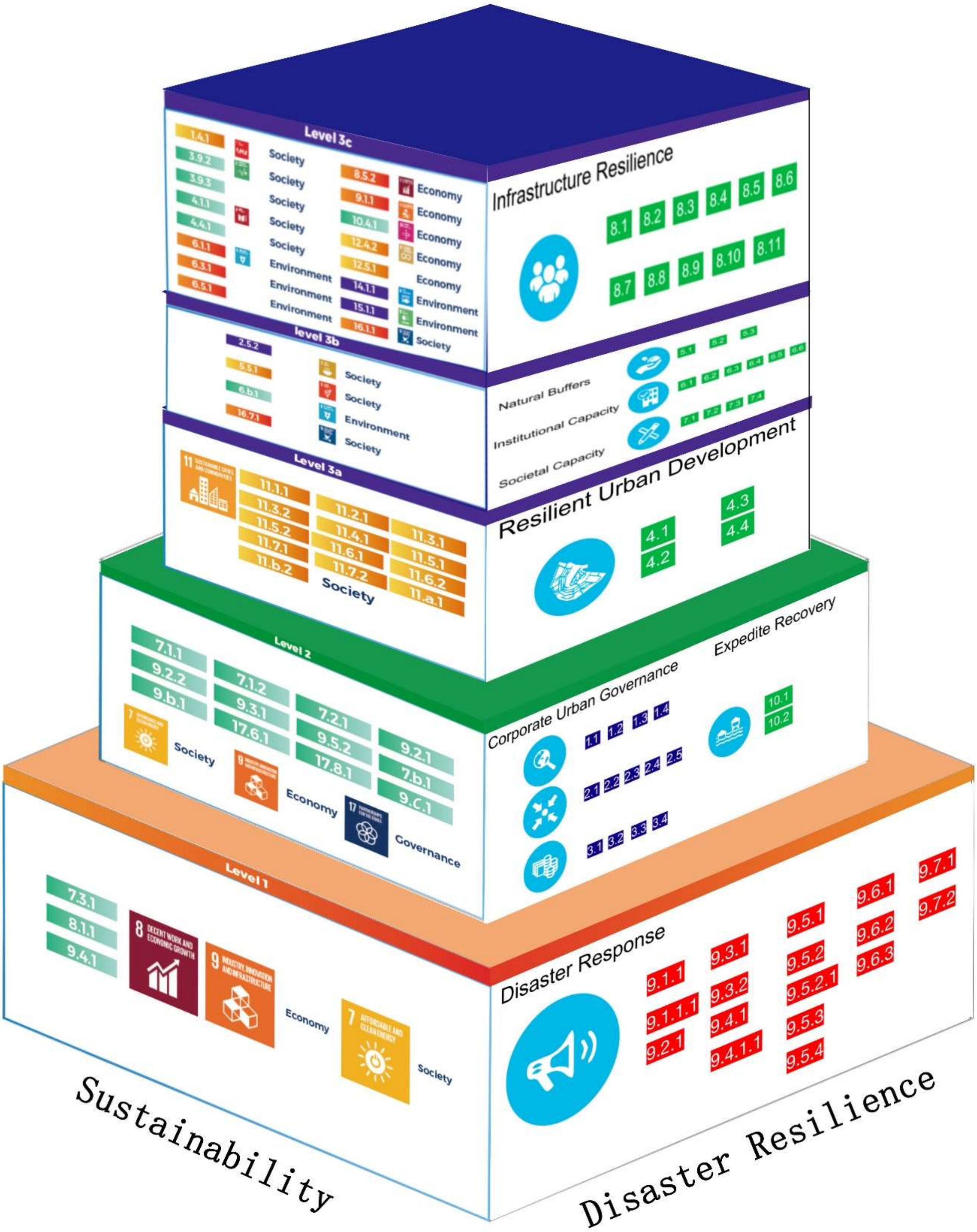


Figure 166: Three cooperation levels in the sustainability and disaster resilience dimensions

Source: APSEC

Annex 1: Basic Reproduction Number and Herd Immunity

Basic reproduction number R_0 is linked to the period of infectiousness. This period has two components: incubation (or latency) period and first stage of symptomatic period. Incubation periods are disease specific and range from 12 to 27 hours in the case of salmonella[448] to more than 10 years in the case of prion-caused diseases[449]. An influenza or common cold has an incubation period of 1 to 3 days[450], but the period of contagiousness also includes the first 5 to 7 days after the sickness has broken out[451]. Coronavirus diseases such as SARS, MERS or COVID-19 have incubation periods between 1 and about 14 days[452][453]. COVID-19 patients whose immune system is responding normally stop being infectious 8 days after the outbreak of the symptoms[454]. COVID-19 patients requiring heavy treatment in intensive care units (ICU) remain infectious much longer time, but they contribute little to the spread of the epidemic due to isolation.

For understanding the speed of transmission of an epidemic disease, the population P(t) at time t should be divided into three segments, S(t) (susceptible, i.e. not yet infected at time t), I(t) (infected et time t) and R(t) (removed from infected at time t, either by recovery or death):

$$P(t) = S(t) + I(t) + R(t)$$

R_0 indicates how many people an infected person (who is already in the population segment I) will move by contagion from the segment of uninfected people (S) to the segment of infected people (I) before the individual stops being infectious by moving into the population segment R of the remainder of people. If $R_0 = 1$, everyone infects exactly one other person. This is the so-called endemic state in which there is always the same number of people in group I(t). If $R_0 < 1$, the epidemic is dying out, if $R_0 > 1$, the epidemic develops exponentially.

In case there is no vaccine, the population segment R is zero at the beginning of the epidemic and will start increasing as soon as the first people recover (come out of segment I). As the epidemic develops, R will increase, but it will stop at a certain level below 100%. This level is the so-called herd immunity (H) and depends on the basic reproduction number R_0 as shown in the figure below by the relation $H = 1 – 1/R_0$. Not everybody will get the transmissible disease. Once a population has achieved herd immunity, the epidemic dies out as the pathogen does not find new hosts any more during the time a patient is infectious.

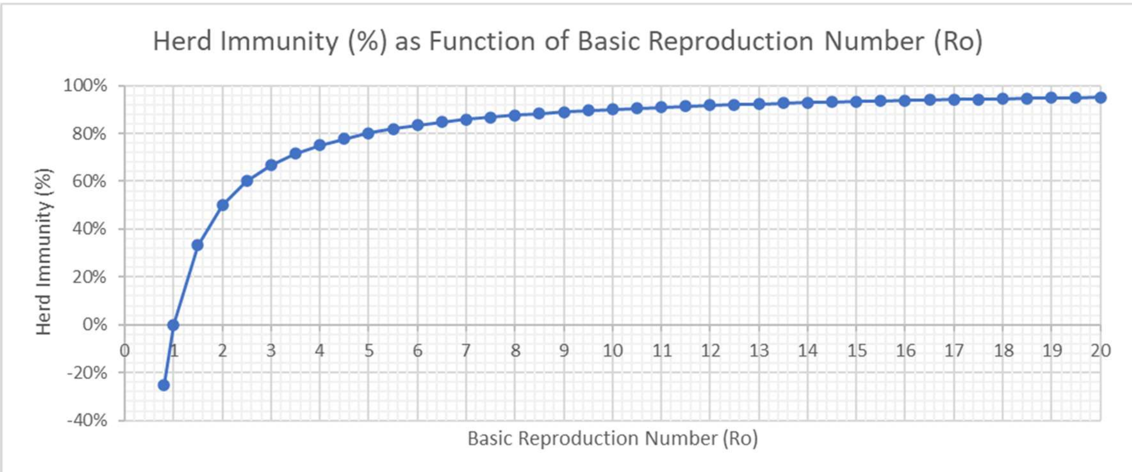


Figure 167: Herd immunity (%) as function of basic reproduction number R_0

Source: APSEC

An easy online presentation of the differential equations underlying the above SIR model can be found in Smith and Moore[455]. With this model the immunization rate of the population can be calculated day by day by using the mortality. For ten US States immunization rate increased day by day as shown for the period 20 to 22 April 2020[456].

State	% Imm 04-20	% Imm 04-21	% Imm 04-22
NY	29.16	30.15	31.00
NJ	15.95	17.20	18.22
MA	8.76	9.46	10.47
PA	3.64	4.34	4.60
CA	1.08	1.15	1.26
MI	8.33	9.08	9.44
IL	3.68	4.00	4.26
FL	1.34	1.41	1.51
LA	9.57	10.09	10.56
TX	0.61	0.64	0.67

For common influenza which spreads mainly by respiratory droplets, the basic reproduction number R_0 is usually said to be around 1.5, which is relatively low for infectious diseases. The spread dampens once 33% of the population is affected. For the Spanish flu, the case fatality rate was much higher than for influenza, but as there was neither vaccination nor treatment, the Spanish flu basically stopped after a third of the world population was attained. On the other side of the spectrum, measles which transmits by airborne transmission has R_0 of around 16, one of the highest; herd immunity is only attained at 94%. One of the most transmissible diseases is the foot-and-mouth disease which is found in cattle. It is caused by the picornavirus which has size of around 30nm, one fourth of the size of COVID-19. The picornavirus is not lethal to humans but survives long time on surfaces and in the air and can easily travel over 10km distance. It was reported to travel over water >250km from Brittany, France, to the Isle of Wight, UK, in 1981[457].

If there is a vaccine, herd immunity can also be attained if the minimum proportion of the population corresponding to the herd immunity threshold is vaccinated. For COVID-19 the magnitude of R_0 is still under debate (2.28 in the model above), but it should be higher than for SARS (shown in figure below) as COVID-19 spread much quicker than SARS[458 459]. All three coronavirus diseases MERS, SARS and COVID-19 have higher case fatality rates than common flu and require considerably higher medical intervention. Their R_0 therefore, may be lowered by measures of isolation[460]. With isolation effectiveness of just below 0.5 as has been observed in Hong Kong and Singapore during SARS, the resulting median R_0 was 1.10.

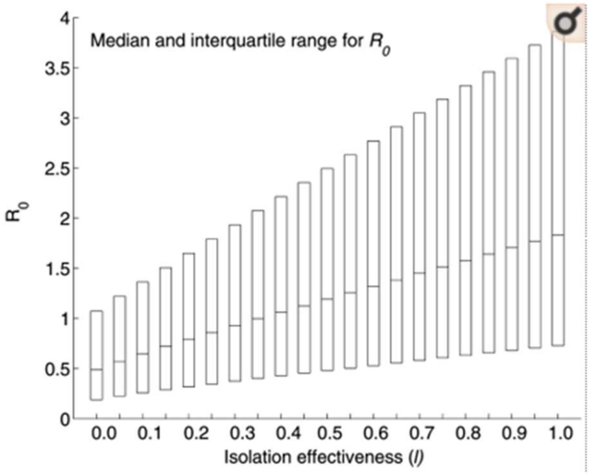


Figure 168: Dependence of R_0 from isolation effectiveness (0=perfect isolation, 1=no isolation) for SARS (2002 – 2003)

Source: Chowell and others[461]

Determining R_0 may depend on the method used. For COVID-19, stochastic methods give R_0 around 2.44, mathematical methods an R_0 averaging 4.2, while statistical methods yield R_0 averaging 2.67[462], the meta-study of which yields median R_0 of 2.79 with an average of 3.28. Also, early estimates of R_0 were comparatively low (between 2 and 3), later estimates where considerably higher (around 4), after which subsequent estimates fell again into the range between 2 and 3. R_0 was found to be specific for each city in Italy with R_0 ranging from 2.43 to 3.09, while it was 3.1 for Italy as a whole[463].

At present the city of Manaus in Brazil is said to be the first city where herd immunity for COVID-19 already exists with an infection rate between 44% and 66% of the population[464].

Annex 2: Köppen-Geiger Climate Types[465]

1st	2nd	3rd	Description	Criterion (see below)
A			Tropical	Not (B) & T_{cold}≥18
	f		- Rainforest	P_{dry}≥60
	m		- Monsoon	Not (Af) & P_{dry}≥100-MAP/25
	w		- Savannah	Not (Af) & P_{dry}<100-MAP/25
B			Arid	MAP<10×$P_{threshold}$
	W		- Desert	MAP<5×$P_{threshold}$
		h	- Hot	MAT≥18
		k	- Cold	MAT<18
	S		- Steppe	MAP≥5×$P_{threshold}$
		h	- Hot	MAT≥18
		k	- Cold	MAT<18
C			Temperate	Not (B) & T_{hot}>10 & 0<T_{cold}<18
	s		- Dry summer	P_{sdry}<40 & P_{sdry}<P_{wwet}/3
		a	- Hot summer	T_{hot}≥22
		b	- Warm summer	Not (a) & T_{mon10}≥4
		c	- Cold summer	Not (a or b) & 1≤T_{mon10}<4
	w		- Dry winter	P_{wdry}<P_{swet}/10
		a	- Hot summer	T_{hot}≥22
		b	- Warm summer	Not (a) & T_{mon10}≥4
		c	- Cold summer	Not (a or b) & 1≤T_{mon10}<4
	f		- Without dry season	Not (Cs) or (Cw)
		a	- Hot summer	T_{hot}≥22
		b	- Warm summer	Not (a) & T_{mon10}≥4
		c	- Cold summer	Not (a or b) & 1≤T_{mon10}<4
D			Cold, Continental	Not (B) & T_{hot}>10 & T_{cold}≤0
	s		- Dry summer	P_{sdry}<40 & P_{sdry}<P_{wwet}/3
		a	- Hot summer	T_{hot}≥22
		b	- Warm summer	Not (a) & T_{mon10}≥4
		c	- Cold summer	Not (a, b, or d)
		d	- Very cold winter	Not (a or b) & T_{cold}<-38
	w		- Dry winter	P_{wdry}<P_{swet}/10
		a	- Hot summer	T_{hot}≥22
		b	- Warm summer	Not (a) & T_{mon10}≥4
		c	- Cold summer	Not (a, b, or d)
		d	- Very cold winter	Not (a or b) & T_{cold}<-38
	f		- Without dry season	Not (Ds) or (Dw)
		a	- Hot summer	T_{hot}≥22
		b	- Warm summer	Not (a) & T_{mon10}≥4
		c	- Cold summer	Not (a, b, or d)
		d	- Very cold winter	Not (a or b) & T_{cold}<-38
E			Polar, Alpine	Not (B) & T_{hot}≤10
	T		- Tundra	T_{hot}>0
	F		- Frost	T_{hot}≤0

Variable definitions: MAT = mean annual air temperature (°C); T_{cold} = the air temperature of the coldest month (°C); T_{hot} = the air temperature of the warmest month (°C); T_{mon10} = the number of months with air temperature >10 °C (unitless); MAP = mean annual precipitation (mm y^{-1}); P_{dry} = precipitation in the driest month (mm month−1); P_{sdry} = precipitation in the driest month in summer (mm $month^{-1}$); P_{wdry} = precipitation in the driest month in winter (mm $month^{-1}$); P_{swet} = precipitation in the wettest month in summer (mm $month^{-1}$); P_{wwet} = precipitation in the wettest month in winter (mm $month^{-1}$); $P_{threshold}$=2×MAT if >70% of precipitation falls in winter, $P_{threshold}$=2×MAT+28 if >70% of precipitation falls in summer, otherwise $P_{threshold}$=2×MAT+14. Summer (winter) is the six-month period that is warmer (colder) between April-September and October-March.

Annex 3: Non-Exhaustive List of Cyber Threats[466]

Adware (Advertising Supported Software)

Adware is software that automatically displays or downloads advertising material when a user is online, without the user's permission. It is considered 'unwanted'. It is used to throw advertisements up on a user's screen, most often within a web browser. A user can see this as a 'pop-up' on their screen. It draws more adware to your PC, which can become a bother, but also bring malware into the open port it creates.

Botnets

The word Botnet is formed from the words 'robot' and 'network'. Cybercriminals use special Trojan viruses to breach the security of several users' computers, take control of each computer and organize all the infected machines into a network of 'bots' that can be remotely managed.

Cryptominers/Cryptojacking

Cryptominers are malicious code designed to highjack idle processing power of a victim's device and use it to mine cryptocurrency. Victims are not asked to consent to this activity and may even be unaware that it is happening in the background. Cryptojacking is in-browser mining using simple code that enables malicious activity to be executed directly in a browser. Both are associated with extremely high processor activity on devices.

Denial of Service (DoS)

Denial of Service attacks typically flood servers, networks and systems with traffic to overwhelm resources and bandwidth. The attack is so overwhelming that users are completely unable to access infected servers, networks and systems. This often targets businesses with the intent to compromise and interrupt for lengthy periods of time.

Formjacking

Formjacking is a newer form of digital information theft. A hacker attacks commercial websites involved in banking, e-commerce and other activities that collect customer's personal information. A site infected with formjacking code captures user data as it is entered into a form. Once the user submits it to an online order form, the code collects the payment information and transmits it to the data thieves. Like a card skimmer, a formjacked website does its work without disrupting a legitimate transaction. The sale will go through as expected, even as the user's data is transferred to the hackers. Criminals use viruses to insert formjacking code into commercial websites.

Human Nature

People are the biggest threats to cyber security. This vulnerability not only comes from employees, but vendors, customers or anyone else who has access to a network, or IT-related systems. Sometimes it can come from using an easy-to-guess password, falling for a phishing email or even a targeted social engineering attack.

Internet of Things Insecurities

There is new malware starting to bring smart devices down. The malware ruins smart devices by gaining access to and destroying a device's storage, eliminating its firewall and removing its network configuration. While IoT devices have wireless connectivity, some don't have the type of classic user interface or computing power of PCs, for example. They often lack proper cyber security controls. Users tend to install them with default passwords and forget about them. Many IoT malware look to leverage devices for cryptocurrency mining, creating a botnet capable of generating a profit of untraceable, digital currency.

Malware

Malware is a general term used to cover multiple software-based threats, i.e., viruses, worms, trojans, ransomware, adware and spyware. These malicious threats are used to steal, encrypt, delete, alter and hijack user information and compromise core computing functions.

Trojan Horse

A Trojan horse or "Trojan" is a type of malware that is often disguised as legitimate software. Trojans can be employed by cyber-thieves and hackers trying to gain access to users' systems. Users are typically tricked by some form of social engineering into loading and executing Trojans on their systems. Once activated, Trojans can enable cyber-criminals to spy on a user, steal sensitive data, and gain backdoor access to a user's systems. These actions can include deleting, blocking, modifying and copying data and or disrupting the performance of computers or computer networks. Types of Trojan Horse attacks:

- Remote Access Trojans
- Data Sending Trojans
- Destructive Trojans
- Proxy Trojans
- FTP Trojans
- Security Software Disabler Trojans
- Denial of Services (DoS) Trojans

Malvertising

Malvertising is the use of online advertising to spread malware. It is criminally controlled advertisements within internet connected programs. It typically involves injecting malicious or malware-laden advertisements into legitimate online advertising networks and webpages. It will distribute malware and other threats with little to no user interaction required. When a user clicks on them, they release the malware which is downloaded to the user's system. Typically, it installs a small piece of code which sends the user's computer to criminal command and control servers.   The server scans the computer for its location and the software installed on it, then chooses which malware it determines is most effective to send to it.

Man in the Middle (MITM)

MITM is also knows as 'eavesdropping' attacks. These attacks happen when a hacker inserts themselves in the middle of a two-party transaction. Some MITM attacks alter the communication between the parties, by taking over conversation between them. These commonly happen on unsecured wi-fi networks or on malware breached devices. They disrupt the web traffic and pull data from it for their own use. Types of MITM attacks:

- IP Spoofing
- DNS Spoofing
- HTTPS Spoofing

- Email Hijacking
- Wi-Fi Eavesdropping
- SSL Hijacking
- Stealing Browser Cookies

Phishing
Phishing is an email used to distribute malicious links and attachments. Cyber criminals want to gain access to user login credentials and other confidential information. Some forms of phishing:

- General Phishing
- Spear Phishing
- CEO Fraud
- Smishing
- Vishing
- Clone Phishing
- Domain Spoofing
- URL Phishing
- Watering Hole Phishing
- Evil Twin Phishing

Spear Phishing
Spear phishing is an email or electronic communications scam targeted towards a specific individual, organization or business. Often, it is intended to steal data for malicious purposes. However, cybercriminals may also intend to install malware on a targeted user's computer. An email arrives, apparently from a trustworthy source but, instead, it leads the recipient to a false website full of malware.

Spam
Email spam is unsolicited bulk email. Unsolicited means that the recipient has not granted verifiable permission for the message to be sent. Bulk means that the message is sent as part of a larger collection of messages with identical content. It is spam if it is both unsolicited and bulk.

Spyware
Software that is designed to gather data from a computer or other device and forward it to a third party without the consent or knowledge of the user. This often includes collecting confidential data such as passwords, PINs, credit card numbers, monitoring keyword strokes, tracking browsing habits and harvesting email addresses. In addition, it tends to affect network performance by slowing down systems. Following are categories of Spyware:

- Trojans
- Adware
- Tracking Cookies
- System Monitors

Ransomware
Ransomware is a type of malware that threatens to publish the victim's data or perpetually

block access to it unless a ransom is paid. Ransomware attacks cause downtime, data loss, possible intellectual property theft, and in certain industries an attack is considered a data breach. Crypto ransomware encrypts certain file types on infected systems and forces users to pay the ransom through certain online payment methods to get a decrypt key.

Social Engineering
Social engineering, in the context of information security, is the psychological manipulation of people into performing actions or divulging confidential information.

- Phishing
- Spear Phishing
- CEO Fraud
- Typosquatting
- Pretexting
- Water-Holing
- Diversion Theft
- Baiting
- Quid Pro Quo
- Tailgating
- Honeytrap
- Rogue

Risks that can enable Cyber Threats to breach systems:

- Human Nature
- Inadequate Patch Management
- Outdated Hardware and Software
- Poor Digital Certificate Management
- Removable Media

Annex 4: Disaster Resilience Scorecard for Cities (UNDRR)[467]

Criteria for detailed resilience assessment of cities, measured on a 0-5 scale (quoted)

Ref	Subject / Issue	Question / Assessment Area
1	Organize for Resilience	
1.1	Plan Making	
1.1.1	Risk consideration in Plan Making	To what extent are risk factors considered within the City Vision / Strategic Plan?
1.1.2	Consultation in Plan Making	Is this strategy developed through inclusive, participatory multi-stakeholder consultation?
1.1.3	Review of strategic plans	Is the city strategic plan reviewed on a regular basis?
1.2	Organization, coordination, and participation	
1.2.1	Pre-event planning and preparation	Co-ordination of all relevant pre-event planning and preparation activities exists for the city's area, with clarity of roles and accountability across all relevant organizations.
1.2.2	Co-ordination of event response	Coordination of all relevant event response activities in the city's area, with clarity of roles and accountability across all relevant organizations.
1.2.3	City resources for managing organisation, co-ordination and participation	Ability of the city government to play the critical convening and plan making role for DRR. Do the city and or other lead agencies have the authority and resources to deliver on their DRR commitments? This assessment criteria relating to resources and funding should be considered for pre-event planning (1.2.1), event response (1.2.2) and post event (1.2.6 together).
1.2.4	Identification of physical contributions	Co-option of physical contributions by both public and private sectors. Identification of physical contributions for each major organization.
1.3	Integration	
1.3.1	Integration of disaster resilience with other initiatives	Extent to which any proposal in government is also evaluated for disaster resilience benefits or impairments. Explicit stage in policy and budget approval process where disaster resilience side benefits, or impairments, of any city government initiative are identified and counted towards the Return on Investment (ROI) for that proposal.
1.4	Data capture, publication and sharing	
1.4.1	Extent to which data on the city's resilience position is shared with other organizations involved with the city's resilience	Availability of a single "version of the truth" – a single integrated set of resilience data for practitioners.
2.	Identify, Understand and Use Current and Future Risk Scenarios	
2.1	Hazard assessment	
2.1.1	Knowledge of hazards (also called perils, or shocks and stresses) that the city faces, and their likelihood	Existence of recent, expert-reviewed estimates of probability of known hazards or perils and their extents.

2.2	Knowledge of exposure and consequence	
2.2.1	Knowledge of exposure and vulnerability	Existence of scenarios setting out city-wide exposure and vulnerability from each hazard level (see above)
2.2.2	Damage and loss estimation	Do risk assessments identify business output and employment at risk, populations at risk of displacement, housing at risk, agricultural land and ecosystems at risk, cultural heritage at risk for key identified scenarios?
2.3	Cascading impacts or interdependencies	
2.3.1	Understanding of critical assets and the linkages between these	All critical assets are identified (see Essential 8) and relationships between them are identified in the form of potential "failure chains". This is used to frame disaster plans and triage (see Essential 9) and also retrofits and upgrades to improve the capability of the infrastructure to withstand disasters.
2.4	Hazard maps	
2.4.1	Hazard maps	Presence of hazard maps (for example, flood or seismic risk maps).
2.5	Updating of scenario, risk, vulnerability and exposure information	
2.5.1	Update process	Process ensuring frequent and complete updates of scenarios. Existence of a process agreed between all relevant agencies to: Update hazard estimates every 3 years or less; Update exposure and vulnerability assessments and asset inventory every 18 months or less.
3.	Strengthen Financial Capacity for Resilience	
3.1	Knowledge of approaches for attracting new investment to the city for DRR	
3.1.1	Awareness and knowledge of all possible methods of financing and funding, as required. The city is actively pursuing financing and funding, as required Note: If sufficient funds exist these assessment criteria can be omitted	Where a city has outstanding resilience expenditure needs (revenue or capital) – the extent to which it has researched and understands all available routes / options to close any funding shortfalls. The extent to which the city is actively trying to meet funding needs and has a clear responsibility for this. This may include the use of external funding or management consultants. This may include the systematic identification of "resilience dividends" (see right – also known as co-benefits).
3.2	Resilience budgets within the city financial plan including contingency funds	
3.2.1	Adequacy of financial planning for all actions necessary for disaster resilience	Presence of financial (capital and operating) plan(s) with a reasoned set of priorities, based on disaster resilience impact achieved, and linked to "most probable" and "most severe" scenarios in Essential 2. Priorities for disaster resilience investment are clear and defensible, based on a view of most beneficial impact. Priorities are assembled into 5-year plan that integrates spending by all key organisations and will meet scenarios in Essential 2.
3.2.2	Capital funding for long run engineering and other works that address scenarios	% funding for capital elements of plan(s) relative to estimated cost. Degree of protection ("ringfencing") from cuts or from being taken away to be used for other purposes.

	and critical assets identified in Essentials 2 and Essential 8	
3.2.3	Operating funding to meet all operating costs of disaster resilience activities	Funding for operating expenses relative to estimated costs: presence of separately delineated budget line item(s). Degree of protection (“ringfencing”) from cuts or from being taken away to be used for other purposes.
3.2.4	Contingency fund(s) for post disaster recovery (may be referred to as a “rainy-day fund”)	Existence of fund(s) capable of dealing with estimated impacts from “most severe” scenario (See Essential 2). Degree of protection (“ringfencing”) of contingency fund(s) from being taken away to be used for other purposes.
3.3	Insurance	
3.3.1	Domestic insurance coverage	Extent of coverage of domestic housing. (Personal or life coverage is not assessed).
3.3.2	Non-domestic insurance coverage	Extent of insurance coverage of non-domestic property, infrastructure and assets.
3.4	Incentives and financing for businesses, community organizations and citizens.	
3.4.1	Incentives to businesses organizations to improve disaster resilience – disaster plans, premises etc	Existence of incentives to help business owners take steps to improve disaster resilience to a standard to deal with the “most severe” scenario (Essential 2).
3.4.2	Incentives to non-profit organizations to improve disaster resilience – disaster plans, premises etc	Existence of incentives to help non-profits take steps to improve disaster resilience to a standard to deal with the “most severe” scenario (Essential 2).
3.4.3	Incentives to homeowners to improve disaster resilience – disaster plans, premises etc	Existence of incentives to help homeowners take steps to improve disaster resilience to a standard to deal with the “most severe” scenario (Essential 2). Ideally means-tested, to ensure that funds go to those most in need
4.	Pursue Resilient Urban Development	
4.1	Land use zoning	
4.1.1	Potential population displacement	% of population at risk of displacement.
4.1.2	Economic activity at risk	% of employment at risk.
4.1.2.1		% of business output at risk.
4.1.3	Agricultural land at risk	% of agricultural land at risk.
4.2.	New urban development	
4.2.1	Urban design solutions that increase resilience	Use of urban design solutions to improve resilience; often by maximizing the extent and benefit of ecosystem services within the city (see also Essential 5).
4.3	Building codes and standards	Existence of applicable codes to all physical assets.

4.3.1	Existence of building codes designed to address risks identified in Essential 2	Existence of applicable codes to all physical assets.
4.3.2	Updates to building codes	Codes are updated every 5 years
4.3.3	Sustainable building design standards	Use of sustainable building design standards such as REDi, LEED, GreenStar and BREEAM to improve resilience.
4.4	Application of zoning building codes and standards	
4.4.1	Application of land use zoning	Extent to which land use zoning is enforced
4.4.2	Application of building codes	Implementation of building codes on relevant structures.
5	Safeguard Natural Buffers to Enhance the Protective Functions Offered by Natural Ecosystems	
5.1	Existing natural environment and ecosystem health	
5.1.1	Awareness of the role that ecosystem services may play in the city's disaster resilience	Ecosystem services are specifically identified and managed as critical assets.
5.1.2	Ecosystem health	Change in health, extent or benefit of each ecosystem service in last 5 years.
5.2	Integration of green and blue infrastructure into city policy and projects	
5.2.1	Impact of land use and other policies on ecosystem services	Absence of policies or land uses liable to weaken ecosystem services
5.2.2	Green and blue infrastructure is routinely embedded into city projects	Green and blue infrastructure is routinely embedded into projects across the city – in new urban development, regeneration and infrastructure projects.
5.3	Transboundary environmental issues	
5.3.1	Identification of critical environmental assets	How many critical ecosystem assets have been identified outside of the city boundaries that act towards enhancing city resilience?
5.3.2	Transboundary agreements	Are there trans-boundary agreements and collaborations in place to enable policy and planning for the implementation of ecosystem-based approaches? For those ecosystems that are outside city jurisdictional boundary.
6	Strengthen Institutional Capacity for Resilience	
6.1	Skills and experience	
6.1.1	Availability of skills and experience in disaster resilience – risk identification, mitigation, planning, response and post event response	Known (i.e. inventoried in last 1 year) availability of key skills, experience and knowledge.
6.1.2	Private sector links	To what extent does the city utilise and engage the private sector?

6.1.3	Engagement of the insurance sector	Is the city engaging with the insurance sector to assess, mitigate and manage risk and stimulate a market for insurance products?
6.1.4	Civil society links	To what extent does the city utilise and engage civil society organisations?
6.2	Public education and awareness	
6.2.1	Exposure of public to education and awareness materials/ messaging	Coordinated public relations and education campaign exists, with structured messaging, channels, and delivery.
6.2.1.1		Exposures per member of the public, per month to messaging
6.3	Data capture, publication and sharing	Availability of a single "version of the truth" – a single integrated set of resilience data for practitioners; see also points below.
6.3.2	Extent to which data on the city's resilience position is shared with the community organizations and public	Availability of a single "version of the truth" – a single integrated set of resilience data for citizens and community organizations containing at least the items shown below. • A summary of readiness – perhaps a summary of the outcomes of this Scorecard; • An explanation of the hazards that the city is thought to face, and probabilities; • A hazard-map based summary (see Essential 2) of at risk areas; • A description of what building codes will protect against, and where these have been applied; • A description of what citizens should expect by way of disaster impacts, the city's likely response and the implications for daily life; • A description of citizens need to do for themselves and their families; • Key roles and accountabilities in the city; • Planned investments that will affect the city's – or a neighbourhood's - resilience; • Further resources and contact details.
6.4	Training Delivery	
6.4.1	Availability, take-up of training focussed on Risk and Resilience (Professional Training	Training offered and available to resilience professionals (from city government, voluntary or other sources)
6.4.1.1		% of population trained in last year.
6.4.2	System / process for updating relevant training	Frequency of repeat training
6.5	Languages	
6.5.1	Accessibility of education and training to all linguistic groups in the city	Availability of all education and training in all languages spoken in the city.
6.6	Learning from others	

6.6.1	Effort taken to learn from what other cities, states and countries (and companies) do to increase resilience	Learning activities executed with other cities and other practitioners.
7	Understand and Strengthen Societal Capacity for Resilience	
7.1	Community or “grass roots” organizations	
7.1.1	Coverage of community or “grass roots” organization(s) throughout the city	Presence of at least one nongovernment body for pre- and post-event response for each neighbourhood in the city.
7.1.2	Effectiveness of community network	Community organization meeting frequency and attendance.
7.1.2.1		Clear identification and coordination of pre- and post-event roles for community bodies, supported by training. Roles agreed and signed off, preferably via MOU or similar.
7.2	Social networks	
7.2.1	Social connectedness and neighbourhood cohesion	Likelihood that residents will be contacted immediately after an event, and regularly thereafter to confirm safety, issues, needs etc.
7.2.2	Engagement of vulnerable groups of the population	Evidence of disaster resilience planning with or for the relevant groups covering the span of the vulnerable population. Confirmation from those groups of effective engagement.
7.3	Private sector / employers	
7.3.1	Extent to which employers act as a channel with employees	Proportion of employers that pass resilience communications to employees and allow limited time off for resilience volunteer activities.
7.3.2	Business continuity planning	Proportion of business with a solid business continuity plan
7.4	Citizen engagement techniques	
7.4.1	Frequency of engagement	Use of regular overlapping modes of engagement to create repeated and reinforcing message deliver
7.4.2	Use of mobile and e-mail “systems of engagement” to enable citizens to receive and give updates before and after a disaster	Use of mobile and social computing-enabled systems of engagement (supported by e-mail).
7.4.3	Validation of effectiveness of education	Knowledge of “most probable” risk scenario and knowledge of key response and preparation steps is widespread throughout city. Tested by sample survey.
8	Increase Infrastructure Resilience	
8.1	Protective infrastructure	
8.1.1	Adequacy of protective infrastructure	Protective infrastructure exists or is in the process of construction – capabilities known to match hazards envisioned in “most probable” and “most severe” scenarios in Essential 2.

	(Ecosystems can offer a natural buffer – see Essential 5)	
8.1.2	Effectiveness of maintenance	Processes exist to maintain protective infrastructure and ensure integrity and operability of critical assets.
8.2	Water sanitation	
8.2.1	Customer service days at risk of loss	"Water/sanitation loss factor". If: a = estimated # of days to restore regular service areawide and b = % of user accounts affected… then water/sanitation loss factor = a x b (Example – 1.5 day's loss of service for 10% of user accounts in city = loss factor of 15%; 3 days' loss of service for 50% of user accounts in city = loss factor of 150%)
8.2.2	Designated critical asset service days (for example, service to hospitals or other critical assets) at risk of loss from water or sanitation failure	"Water/sanitation critical asset (WCA) loss factor". If: a = estimated # of days to restore regular service area-wide and b = % of critical assets affected… then WCA loss factor = a x b (Example – 1.5 day's loss of service for 10% of critical assets in city = loss factor of 15%; 3 days' loss of service for 50% of critical assets in city = loss factor of 150%)
8.2.3	Cost of restoration of service	Likely cost of lost service and restoration as % of annual billed revenue
8.3	Energy - Electricity	
8.3.1	Customer service days at risk of loss	"Electrical energy loss factor". If: a = estimated # of days to restore regular service areawide and b = % of user accounts affected…then electrical energy loss factor = a x b (Example – 1.5 day's loss of service for 10% of user accounts in city = loss factor of 15%; 3 days' loss of service for 50% of user accounts in city = loss factor of 150%)
8.3.2	Designated critical asset service days at risk of loss from energy failure	"Electricity critical asset (ECA) loss factor". If: a = estimated # of days to restore regular service area-wide and b = % of critical assets affected… then ECA loss factor = a x b (Example – 1.5 day's loss of service for 10% of critical assets in city = loss factor of 15%; 3 days' loss of service for 50% of critical assets in city = loss factor of 150%)
8.3.3	Cost of restoration	Likely cost of lost service and restoration as % of annual billed revenue.
8.4	Energy - Gas	
8.4.1	Safety and integrity of gas system (if applicable)	Use of fracture resistant gas pipes in seismic or flood zones, and installation of automated shut-off capabilities.
8.4.2	Customer service days at risk of loss	"Gas loss factor". If: a = estimated # of days to restore regular service area-wide and b = % of user accounts affected… then gas loss factor = a x b. (Example – 1.5 day's loss of service for 10% of user accounts in city = loss factor of 15%; 3 days' loss of service for 50% of user accounts in city = loss factor of 150%).
8.4.3	Designated critical asset service days at risk of loss from gas supply failure	"Gas critical asset (GCA) loss factor". If: a = estimated # of days to restore regular service area-wide and b = % of critical assets affected… then GCA loss factor = a x b. (Example – 1.5 day's loss of service for 10% of critical assets in city = loss factor of 15%; 3 days' loss of service for 50% of critical assets in city = loss factor of 150%).

8.4.4	Cost of restoration of service	Likely cost of lost service and restoration as % of annual billed revenue.
8.5	Transportation	
8.5.1	Road – service from road system at risk of loss	Road loss factor – If: a = miles of major road network for city and surrounding area at risk of becoming impassable to any type of vehicle after event, and b = likely number of days estimated before reopening, and c = total of major roads in the city and surrounding area lost for one day…then road loss factor = (a/c) x b as a %. (Example - 10 miles of major road likely to be lost for two days, out of total of 100 miles of major road = road loss factor of 20% ((10/100) x 2).
8.5.2	Road – survival of critical access and evacuation routes	Road critical asset (RCA) loss factor. If: a = carrying capacity (vehicles per hour) of evacuation/emergency supply routes to and from the city at risk of becoming impassable after event and b = # of days estimated before reopening and c = carrying capacity (vehicles per hour) of all designated critical evacuation/emergency supply routes… then RCA loss factor = (a/c) x b as a %. (Example –route with carrying capacity of 1,000 vehicles per hour likely to be closed for 3 days, out of a total carrying capacity on all evacuation/ supply routes of 2,000 vehicles per hour = RCA loss factor of 150% ((1000/2000 x 3).
8.5.3	Rail/metro (if applicable) – service from rail system at risk of loss	Rail loss factor (for rail, use tons; for metro, use passengers). If: a = carrying capacity (tons or passengers per day) of affected rail lines to the city and b = # of days estimated before reopening and c = carrying capacity (tons per day per hour) of all rail links to the city…then RCA loss factor = (a/c) x b as a %. Example – rail line with carrying capacity of 10,000 tons or passengers per day likely to be closed for 2 days, out of a total carrying capacity on all rail lines of 15,000 tons or passengers per day = RCA loss factor of 133% ((10000/15000 x 2).
8.5.4	Air (if applicable)	Airport loss factor. If: a = estimated # of flights in and out per day possible after the disaster and b = max # of flights per day in normal operations and c = # of days estimated before restoration of full capacity…then airport loss factor = (a/b) x c as a %. Example if 80 flights in and out per day are possible after a disaster, compared with a normal maximum of 100, and it takes 2 days to restore full capacity, then the airport loss factor is 160% ((80/100) x 2).
8.5.5	River/Sea (if applicable)	River/seaport loss factor. If: a = estimated # of dockings per day possible after the disaster and b = max # of dockings per day in normal operations and c = # of days estimated before restoration of full capacity… then River/seaport loss factor = (a/b) x c as a %. (Example if 5 dockings per day are possible after a disaster, compared with a normal maximum of 8, and it takes 2 days to restore full capacity, then the airport loss factor is 125% ((5/8) x 2).
8.5.6	Other public transport (if applicable)	(Buses and taxis effectively captured in road measures above).

8.5.7	Cost of restoration of service (all transport routes)	Likely cost of lost service and restoration.
8.6	Communications	
8.6.1	Service days at risk of loss	"Communications loss factor". If, a = estimated # of days to restore regular service area-wide and b = % of user accounts affected… then communications loss factor = a x b (Example – 1.5 day's loss of service for 10% of user accounts in city = loss factor of 15%; 3 days' loss of service for 50% of user accounts in city = loss factor of 150%).
8.6.2	Designated critical asset service days at risk of loss from communications failure	"Communications critical asset (CCA) loss factor". If a = estimated # of days to restore regular service areawide and b = % of critical assets affected… then CCA loss factor = a x b. (Example – 1.5 day's loss of service for 10% of critical assets in city = loss factor of 15%; 3 days' loss of service for 50% of critical assets in city = loss factor of 150%).
8.6.3	Cost of restoration	Likely cost of loss of service and restoration of communications system(s) as % of annual billed revenue.
8.7	Healthcare	
8.7.1	Structural safety and disaster resilience of health care and emergency facilities (Staffing/ first responders – see Essential 9)	"Bed days lost" – estimated # of beds at risk x number of days' loss under "most probable" and "most severe" scenarios.
8.7.1.1		"Critical bed days lost: estimated # of bed days for designated critical services (e.g. ER, dialysis, intensive care – TBD) at risk under "most probable" and "most severe" scenarios.
8.7.2	Health records and data	% of patient and health system data and associated apps stored and accessible at location unlikely to be affected by the event.
8.7.3	Availability of emergency healthcare including facilities and urgent medical supplies for acute needs	Sufficient acute healthcare capabilities exist to deal with expected major injuries.
8.8	Education	
8.8.1	Structural safety of education facilities	% of education structures at risk of damage from "most probable" and "most severe" scenarios
8.8.2	Loss of teaching time	Number of teaching days lost as % of total in academic year.
8.8.3	Education data	% of critical education data and associated applications imaged at remote site.
8.9	Prisons (Note that law and order, and other first responder assets, are covered in Essential 9)	
8.9.1	Disaster resilience of prison system	Ability of prison system to survive "most probable" and "most severe", scenarios, without releasing or harming inmates.
8.10	Administrative operations	
8.10.1	Assurance of continuity of all	Estimated # of days' disruption to critical administration services under "most probable" and "most severe"

	critical administration functions	scenarios, given availability of redundant facilities, support staff etc.
8.11	Computer systems and data	
8.11.1	Assurance of continuity of computer systems and data critical to government continuity	% of critical applications and associated data (to include social services and other personal records) imaged at, and accessible from, remote site
8.11.2	Assurance of continuity of computer systems and data critical to any of the above infrastructure	% of critical applications and associated imaged at, and accessible from, remote site.
9	Ensure Effective Disaster Response	
9.1	Early warning	
9.1.1	Existence and effectiveness of early warning systems	Length and reliability of warning – enabling practical action to be taken.
9.1.1.1	Reach of warning	Will 100% of population receive it?
9.2	Event response plans	
9.2.1	Existence of emergency response plans that integrate professional responders and community organizations (For post-event response - see Essential 10)	Existence of plans formulated to address "most likely" and "most severe" scenarios, shared and signed off by all relevant actors (including citizen organizations
9.3	Staffing / responder needs	
9.3.1	'Surge" capacity of police also to support first responder duties	Sufficient back-up or para-professional capacity to maintain law and order in "most severe" and "most probable" scenarios, in addition to supporting burden of first responder duties.
9.3.2	Definition of other first responder and other staffing needs, and availability	Staffing needs are defined for "most probable" and "most severe" scenarios.
9.4	Equipment and relief supply needs	
9.4.1	Definition of equipment and supply needs, and availability of equipment	Equipment and supply needs are defined for "most probable" and "most severe" scenarios in Essential 2

9.4.1.1		Estimated shortfall in available equipment per defined needs – potentially from multiple sources. MOUs exist for mutual aid agreements with other cities, and also for private sector sources.
9.5	Food, shelter, staple goods and fuel supply	
9.5.1	Likely ability to continue to feed population	"Food gap" - # of days that city can feed all segments of its population likely to be affected minus # of days' disruption estimated under those scenarios
9.5.2	Likely ability to meet needs for shelter/safe places	"Shelter gap" – numbers of displaced persons minus shelter places available within 24 hours.
9.5.2.1		"Shelter gap" – ability of shelters to withstand disaster events and remain safe and usable.
9.5.3	Ability to meet likely needs for staple goods	"Staples gap" - % shortfall in supply within 24 hours relative to demand
9.5.4	Likely availability of fuel	"Fuel gap" - # of days that city can meet fuel requirements, minus # of days' disruption to regular supply.
9.6	Interoperability and inter-agency working	
9.6.1	Interoperability with neighbouring cities/states and other levels of government of critical systems and procedures	Ability to cooperate at all levels with neighbouring cities and other levels of government.
9.6.2	Emergency operations centre	Existence of emergency operations centre with participation from all agencies, automating standard operating procedures specifically designed to deal with "most likely" and "most severe" scenarios.
9.6.3	Coordination of post event recovery	Coordination arrangements identified in advance for all post-event activities in the city's area, with clarity of roles and accountability across all relevant organizations. Does an organizational chart documenting structure and role definitions at each relevant agency exist, to achieve a single overall point of co-ordination?
9.7	Drills	
9.7.1	Practices and rehearsals – involving both the public and professionals	Testing of plans annually, by reference to simulated emergency and actual non-emergency events.
9.7.2	Effectiveness of drills and training	Level of effectiveness of drills
10	Expedite Recovery and Build Back Better	
10.1	Post event recovery planning – pre-event	
10.1.1	Planning for post event recovery and economic reboot	Existence of comprehensive post event recovery and economic reboot plans.
10.1.2	Extent to which there has been stakeholder	Stakeholder involved in build back better plan.

	consultation around the 'event recovery and reboot' plans	
10.1.3	Shadow financial arrangements for processing incoming aid and disbursing funds	Post event arrangements exist for dealing with incoming financial aid and disbursements.
10.2	Lessons learnt / learning loops	
10.2.1	Learning loops	Existence of a process and format for "post-mortems" on what went well and less well in the event response and post-event phases.

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APEC Integrated Urban Planning Report

Combining Disaster Resilience with Sustainability

The APEC Region has a disproportionately high exposure to disaster risk, with many of its cities and local communities experiencing growing impact of tropical storms, wildfires, and extreme heat waves. The uphill struggle to recover from ever-returning devastations might threaten efforts to eliminate the causes of disasters and distract communities from a sustainable development path.

This report which follows the APEC Sustainable Urban Development Report – From Models to Results, gives a comprehensive overview of disasters hitting APEC cities and shows how integrated urban planning, employing governance of complex adaptive systems, can contribute towards effective synergy between disaster resilience and sustainability.

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Fax: (65) 68 919 690
Email: info@apec.org
Website: www.apec.org

APEC#221-RE-01.1   ISBN：978-981-18-0275-1

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