



UNDERSTANDING INFRASTRUCTURE INTERDEPENDENCIES IN CITIES



Foreword

Today, over half the global population lives in cities; by 2050, two thirds are expected to do so. Cities are key global centres of economic growth and opportunity. This ever-growing concentration of population and economic value is exposed to increasing climate risk both in terms of climate phenomena, exposure and vulnerability, and requires our close attention.

At AXA, we believe there needs to be a high level of awareness and preparedness in both the private and public sector in order to best manage climate risk. This is why city-based adaptation measures are so important, bringing together private actors, municipalities and local communities to better understand and mitigate such risks.

The present report, **Understanding Infrastructure Interdependencies in Cities**, could not be more timely. Helping cities better understand infrastructure interdependencies and systemic risks in the face of climate change is essential if they are to properly future proof against the impacts of climate change.

AXA is proud to have partnered with C40 to work together on this important subject. We know that understanding risk, which is at the heart of our vocation as an insurer, is key to managing it. As this report demonstrates, multi-stakeholder coordination and improved data collection and analysis will benefit all actors and yield results for cities and their inhabitants.

At AXA, we understand the importance of adaptation and mitigation for meaningful climate action. AXA's strategy is not only to adapt, but also to take advantage of our expertise to provide solutions. As an insurer, we contribute to climate adaptation by protecting cities and their residents against natural events through the insurance of property loss and casualties for

individuals, companies and municipalities. As an investor, AXA is proud to have been a pioneer in the financial sector in the fight against climate change. We were the first mainstream investor to divest from coal, and we continue to use all financial levers – investing and divesting – to contribute to climate mitigation efforts.

Through this partnership with C40, we are pleased to share AXA's risk prevention expertise to contribute to our collective understanding of climate adaptation measures for cities. We hope that the fruits of our partnership will help build our collective resilience to climate change.



Alban de Mailly Nesle

Chief Risk and Investment
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Understanding Infrastructure

Interdependencies in Cities is a vital piece of research demonstrating the crucial role cities can play in reducing vulnerability to the impacts of climate change. To succeed we need to overcome some major challenges and to form partnerships to drive collaboration of resources and knowledge.

The impacts of climate change are already being felt all around the globe. This means that adapting to climate change is a task for today, not the distant future. From the severe droughts in Chennai and Cape Town, heatwaves in Tokyo and European cities, wildfires in California, and Melbourne, floods in Durban and Rio de Janeiro, and storm surges in Hong Kong and Houston, climate change has become more and more evident. The good news is that many cities are already confronting these impacts head-on and working hard to keep their citizens safe. They understand that these extreme events are not isolated, but an indication of the climate change to come.

Modern urban infrastructure systems are highly **interdependent**. Extreme weather events cause damaging ripple effects in these systems, which will get worse as the magnitude and frequency of these events increases. Again, many cities are rising to the challenge that these interdependencies present. Mainstreaming adaptation in different city systems is helping cities to address the cascading impacts of climate change by making these systems climate resilient. This report highlights the barriers cities face in integrating these interdependencies in their long-term planning, how cities are overcoming these barriers and recommendations for other cities to do the same.

The impacts of climate change and their consequences on cities' systems have also raised

alarms in the business and financial communities which increasingly recognise that extreme events impact how cities function, and therefore their attractiveness for investment. The leaders in both these sectors are now considering the vulnerability of cities as a major criterion for investment.

C40 is grateful for the support from **AXA** on this report, who truly is a champion in the space with a strong commitment to helping cities become more adaptable and also provide solutions to do so.



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Contents

Executive Summary	6
1 Introduction: interdependencies and climate risk in cities	8
2 Cities' progress in addressing their infrastructural interdependencies	11
3 Key Barriers to Addressing Interdependent Risk	14
3.1. Governance	
3.2. Data	
3.3. Resources	
4 Best Practices from Cities	18
Dhaka, Bangladesh; Quezon City, Philippines; New York City, United States; London, United Kingdom; Paris, France; Philadelphia, United States; Rio de Janeiro, Brazil; Durban (eThekweni), South Africa; Montréal, Canada; Sydney, Australia; Jakarta, Indonesia	
5 Recommendations from cities	40
6 Climate Interdependencies and Insurance	46
7 Conclusion	51
References	52
Appendix I: Methodology	54
Appendix II: Example of interdependencies planning to safeguard assets	55

Executive Summary

Modern urban infrastructure and their systems of operation are highly interdependent. They are formed of multiple connections, feedback and feedforward paths, and intricate branching where services or information are transferred across city sectors. This means that if one system fails, it can have cascading impacts on other systems. Climate change can compound these impacts significantly.

Some systems may be directly affected by climate change events – such as roads during flooding. Other systems may be affected indirectly, such as the health sector and the financial sector if there are power outages. The interdependencies of city systems combined with climate impacts can lead to a ripple effect of disruptions. Understanding infrastructure interdependencies and critical failure points is therefore vital to achieving long-term climate resilience across a whole city.

City Progress

Extreme events – such as floods in Jakarta and Quezon City and ice storms in Montréal – that have resulted in wide-scale disruption have driven some cities to look into the interdependencies of their infrastructure and services. However, analysis shows that, overall, cities are at varying levels of progress when it comes to assessing their interdependencies and incorporating this analysis into climate actions. Some cities have not begun an interdependencies assessment; others have a well-established process of identifying critical infrastructure and their cascading risks and have even quantified potential economic losses and damages. An estimated 61% of C40 cities have identified actions to address interdependencies in their adaptation plans, but few have detailed how they will put this into practice and, ultimately, action has been limited.

Challenges in Addressing Infrastructure Interdependencies

Cities identified several barriers to understanding and addressing their infrastructural interdependencies. Broadly, these barriers fell into three categories: those related to governance, data and resources.

Governance

Interdependencies assessments require effective participation across a wide range of city stakeholders, from different city departments, agencies, state and national government, and privately owned or managed utilities. The involvement of such a vast and varied array of stakeholders creates significant management and governance issues, and interdependencies assessments often lack ownership.

Data

All cities mentioned the importance of reliable and accurate data to provide an evidence base for both policymaking and investment in interdependencies assessment and planning. Data availability and access is a major challenge. Data sensitivity given the number of stakeholders involved in the process was also highlighted by cities as a major issue.

Resources

A key challenge to addressing infrastructural interdependencies is a lack of capacity and resources. Coordination across sectors is often constrained by time and resources, as well as competing priorities and overreliance on the knowledge of particular individuals to integrate considerations of cascading climate impacts during infrastructure planning phases. Some cities also mentioned the lack of open source tools available to assist them in conducting an interdependencies assessment.

Best Practice and Possible Solutions

There are, however, examples of best practice that tackle these governance, data and resource issues. Some solutions focus on existing tools, mechanisms and information – from leveraging national mandates, legislation and forums to overcome coordination and cooperation challenges, to using open-source data, systems and software to solve data and resource limitations. Other solutions relate to partnership and collaboration, particularly with the private sector but also with NGOs and research institutions, which has been an important contributing factor in several cities' progress on interdependencies. These best practices provide a menu of options or ideas for cities to consider, based on their context and the particular challenges they face in understanding its infrastructure interdependencies to strengthen climate resilience.

Recommendations

- Focus stakeholder engagement around critical failures related to specific climate hazards and impacts. Use the same method and the same questions so that findings can be aligned. Leverage existing national legislation to enable coordination and incentivise city departments, national departments and external local stakeholders to work together and contribute sensitive data handling and accurate and reliable information.
- Use established mechanisms to facilitate stakeholder cooperation. If groups don't exist, establish a forum in which relevant stakeholders and sectors can discuss system connections and dependencies.
- Leverage existing national legislation to enable coordination and incentivise city departments, national departments and external local stakeholders to work together and contribute sensitive data handling and accurate and reliable information.
- Establish partnerships with the private sector to encourage their collaboration in an interdependencies assessment, and in activities to address interdependencies and strengthen climate resilience.
- Set up pilot projects or research and development programmes to help make the potential benefits of understanding interdependencies – such as future cost savings or loss avoidance – clear to utility providers.
- Use NDAs with private utilities, which can encourage data sharing and develop the trust needed to maintain longstanding relationships.
- Use file-sharing software, to centralise and align datasets.
- Invest in the technical resources to enable scientists and experts to provide real-time meteorological data for forecasting climate risks.
- Encourage proactive measures to protect infrastructure and use early warning systems to establish long-term response plans.
- Develop partnerships with research institutes, the private sector and NGOs that have additional resources and knowledge capabilities and use existing software and tools.
- Ensure that scientific evidence is informing the implementation and that climate risk and interdependencies are integrated into a long-term strategy for the city.
- Explore further ways in which insurers and cities can work together to assess and quantify climate risks to assets and infrastructure, particularly from a Global South city perspective.





1. INTRODUCTION

INTERDEPENDENCIES AND CLIMATE RISK IN CITIES

Modern urban infrastructure systems are highly interdependent, formed of multiple connections, feedback and feedforward paths, and intricate branching. This means that if one system fails, it can have cascading impacts (when disruptions to a system cause second-order impacts via

connections that are not physical, cyber, or geographic in nature) on other systems (C40 Cities, 2017). Climate change can compound these impacts significantly, as shown in Figure 1. Climate change-related events have devastating impacts on the city's infrastructure systems.

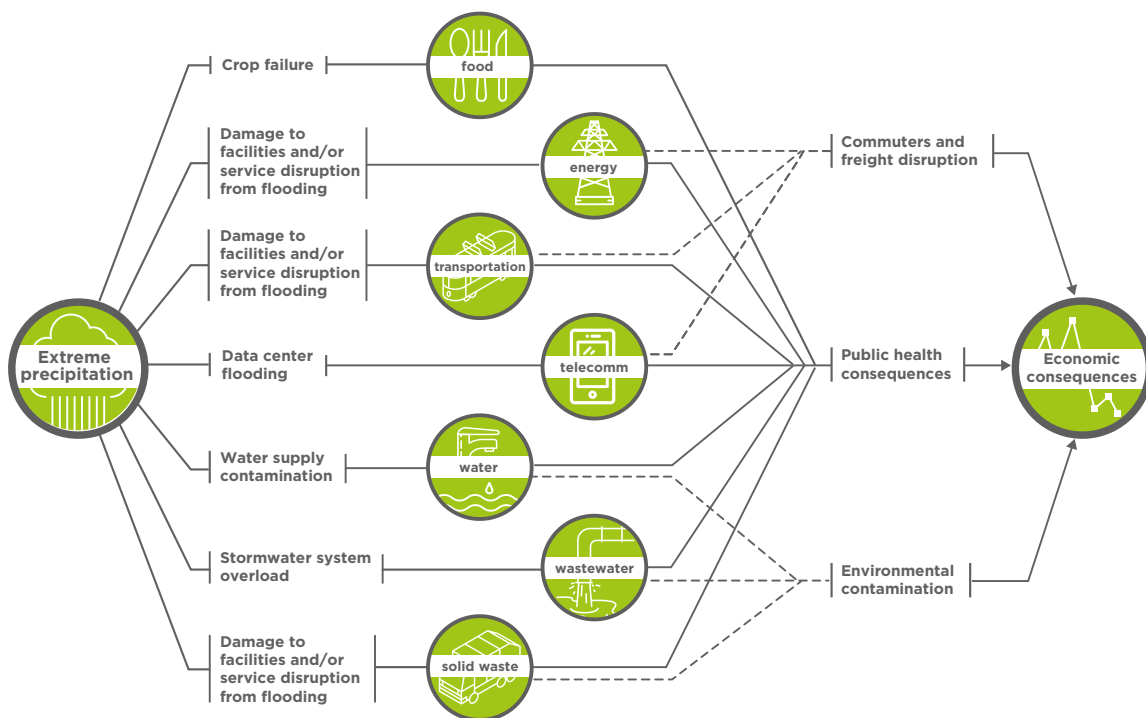


FIGURE 1

Example of sectors impacted by extreme precipitation

About this report

In 2017, C40 conducted a study on infrastructural interdependencies – 'C40 Infrastructure Interdependencies and Climate Risks'. The study explained the concept of interdependencies among and within infrastructure sectors and looked at city approaches to understanding climate change impacts on interdependent systems. However, while some approaches existed, cities faced several barriers to identifying their interdependencies and challenges in addressing them.

This report is a collaboration between AXA and C40 Cities. It seeks to: understand the progress that cities are making in including infrastructural interdependencies in their adaptation plans; identify the barriers they are facing; and, provide best practices and practical recommendations for how cities can overcome these challenges to improve the resiliency of their networks.



C40 Interdependencies and Climate Risks Report

2017

Extreme weather events, such as coastal and inland flooding, heatwaves, droughts and wildfires, are increasing in frequency and magnitude, and gradual changes in sea levels and temperatures are projected to have (and are already having) adverse effects on city systems. Some systems may be directly impacted by climate change events, e.g. roads being flooded, whilst other systems may be impacted indirectly because of the nature of their operations and their interdependencies. Transportation services cannot operate without energy, and energy generation facilities cannot operate without the reliable delivery of fuels. The interdependencies of city systems combined with climate impacts can, therefore, lead to a ripple effect of disruptions.

Understanding a city's interdependent infrastructure and critical failure points is therefore vital to achieving long-term climate resilience across a whole city. As cities continue to expand and their systems become more complex, the breakdown of a single part of an infrastructure system – even in cities with a large response capacity such as New York City – can rapidly deplete their ability to stage an effective response, as was seen in the case of Hurricane Sandy. Cities are already experiencing climate impacts and city agencies need to take action to manage the climate risks facing their urban infrastructure and services, and the communities they serve. To do so, they must also understand infrastructure interdependencies. This will enable them to secure the resources and investment needed to increase the resilience of their city's critical infrastructure.

Methodology

The findings in this report are a result of an extensive desk-based review and interviews with city officials from 11 cities, C40 networks and sector experts' interviews. Alongside a broader desk-based review, we reviewed C40 member cities' adaptation plans (49) to understand how cities are including an analysis of interdependencies in their city planning. This

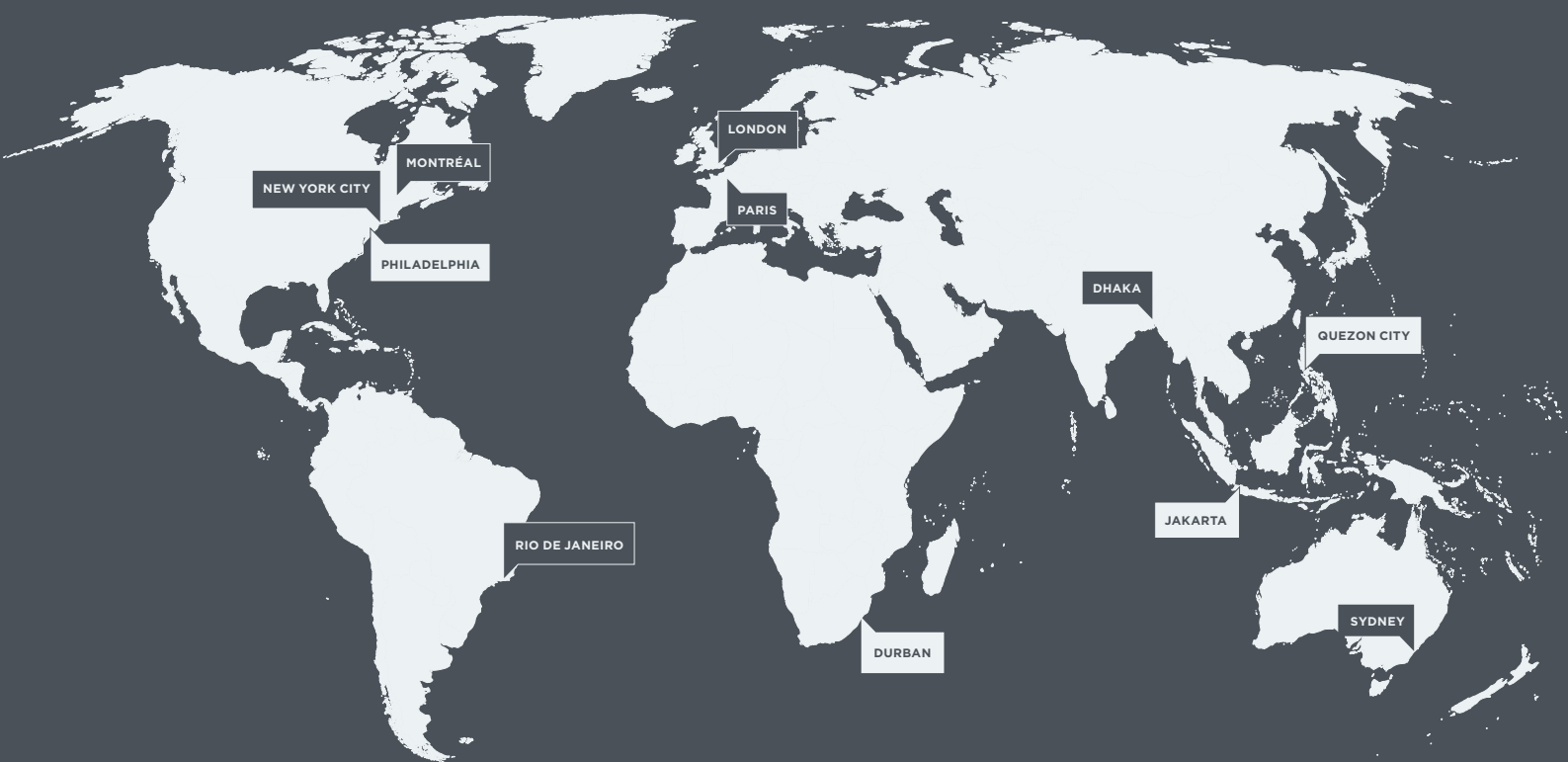
was followed by a city survey¹ that had a deeper contextual focus on the cities' progress on the topic of interdependencies. Based on the survey responses, 11 cities were identified from across the globe and at varying stages in addressing their infrastructural interdependencies. Interviews were then conducted, which inform the case studies presented in chapter 4. A detailed methodology of the research that underpins the report is provided in Appendix I.

1. The city survey was sent to 51 C40 cities, of which 19 replied. The desktop analysis featured 23 interviews from 11 cities, 9 C40 network managers and 3 risk analysis experts.

PILOT CITIES

INVOLVED IN THE STUDY

These 11 cities were identified from across the globe and at varying stages in addressing their infrastructural interdependencies (case studies presented in chapter 4).





2. CITIES' PROGRESS IN ADDRESSING INFRASTRUCTURAL INTERDEPENDENCIES

This chapter sets out the current landscape in terms of how C40 cities have progressed in understanding and implementing actions with regards to infrastructure interdependencies. It is based on a review of C40 Cities' adaptation plans, responses from city surveys and interviews with C40 city representatives and sector experts about their experiences.

Our analysis shows that cities are at varying levels of progress. Some cities have not begun an interdependencies assessment while others have a well-established process of identifying critical infrastructure and their cascading risks and have even quantified potential economic losses and damages as a result of any disruption. Furthermore, 61% of cities have identified actions to address interdependencies in their adaptation plans. However, not many of these give details of an implementation plan.

Understanding Interdependencies

Across cities, there is no common definition of 'interdependencies' and, in many, the term is rarely used – particularly not in the context

of climate risk. Although 34 of the 49 cities' adaptation plans that we reviewed referred generally to infrastructural interdependencies, and 30 identified critical infrastructure or sectors that would lead to cascading impacts, they did not use the term 'interdependencies'. Moreover, mentions were related to the direct impacts of climate events on critical infrastructure as opposed to the ripple effect of interdependencies specifically.

Quantifying the impacts of interdependent infrastructure can allow cities to understand how much impact or economic damage climate hazards will cost and therefore how high the risk is. This understanding is essential as it allows cities to make the case for investment into strong action on adaptation and demonstrates to senior leadership the imperative to act. However, only four cities – Copenhagen, Philadelphia, Quezon City and Rotterdam – have quantified damage and losses as a result of analysing their infrastructure interdependencies.



Identifying Critical Infrastructure

Due to their links to other sectors, some infrastructure systems will be particularly critical if an extreme weather event happens. Through our analysis of 49 C40 Cities' adaptation plans, we have identified the critical infrastructure in these cities that have cascading impacts from climate risks onto other sectoral infrastructure. Though cities do not define these infrastructures in a common way we were able to categorise them as follows in Figure 2.

Transportation and energy were most commonly identified as critical infrastructure with the maximum interdependent links that affect other sectors. This is primarily because both the sectors are immediately affected by extreme events and have a direct supply link to other sectors – hence, their failure leads to citywide disruption. The Sydney case study in chapter 4 highlights how in the event of a disruption, transport infrastructure like rail stations, can have cascading impacts on road networks, airports, and sub-stations as well as wider socio-economic implications when people are displaced and unable to travel to work.

Addressing infrastructural interdependencies

Action on the interdependent risk between infrastructure systems is emergent – in its early stages but developing. Some cities that have conducted interdependencies assessments have gone on to identify actions, such as updating infrastructure design standards or partnering with key infrastructure stakeholders to find opportunities to improve resilience to service failures. Other cities identified the need to make such changes or simply to 'conduct a thorough risk assessment of critical infrastructure' in their adaptation plans. However, while many

FIGURE 2

List of Critical Infrastructure identified by cities

- ✓ Energy
- ✓ Transport
- ✓ Water supply
- ✓ Drainage (wastewater, stormwater, sewage)
- ✓ Telecom
- ✓ Buildings
- ✓ Coastal infrastructure
- ✓ Industry
- ✓ Waste
- ✓ Public works
- ✓ Gas supply
- ✓ Emergency management
- ✓ Health
- ✓ Economy (trade, tourism, financial services)
- ✓ Parks and recreation
- ✓ Fleet management

city adaptation plans committed to addressing infrastructural interdependencies, in most cities, action to do so was limited.

As part of our desk-based review, we also collected inputs from C40 sector-based networks about how cities are working on infrastructural interdependencies in specific sectors. These actions are summarised, by sector, in Figure 3.

FIGURE 3

How city sectors have worked on interdependencies

City sector	Action
Buildings	Cities have been looking more at direct impacts from climate risks, with cities such as New York (City of New York, 2014) incorporating flood risk into building designs. The city has also published guidance on building codes for extreme events and also focused on internal appliances within residential homes.
Energy	Consideration of interdependencies has been variable. Many cities understand how energy infrastructure is linked with other activities across the city as without power many sectors cannot function properly, however, interdependencies due to climate risk are not necessarily assessed. Rather the focus on infrastructure resilience has stemmed from other issues that are exacerbated from climate change – such as ageing infrastructure, increased demand oversupply (which can lead to power outages), failing equipment and natural disasters. An example of this can be seen from Yokohama , where the city has run an exercise to model a virtual power plant to provide energy during hazard events, which began as a policy broadly focused on natural disasters, with the climate risk being integrated later on.
Waste	C40 cities within the waste networks have demonstrated several considerations of interdependencies. Much of these interdependent interactions depend on the structure of waste services: some cities directly own and manage waste, such as Mexico City, which has a Public Works Ministry that owns the solid waste department; others contract or franchise it to private companies.
Food systems	Urban food systems are hugely interdependent and have been a key focus in understanding cascading impacts across urban sectors. New York's ' Five Boroughs ' report assessed the extent to which the food supply is disaggregated, monitored the accessibility and routes of supply trucks entering the city through bridges into Manhattan to assess if the sector could self-regulate in the event of one of the bridges being inactive during disruption (City of New York, 2016). This study has motivated other cities such as Austin, Los Angeles, Paris and Toronto to undertake similar studies. Furthermore, as food is a widely cross-cutting sector, relying heavily on the supply chain, and many cities usually have interdepartmental platforms called 'food boards'. Food boards in African cities such as Nairobi have included the transport sector and stakeholders from markets, as well as the water sector due to issues of food wastage in transit from the outskirts of the city.
Mass transit	Despite transportation being the most notable sector within cities' adaptation plans, we have not seen evidence of how active cities are on the issue of interdependencies with regards to mass transportation systems within the C40 network. Some cities – such as Singapore, Auckland and Barcelona – have started developing measures to increase the resiliency of their city's mobility by protecting mass transportation systems. Transportation systems can provide significant data on interdependencies such as alternate modes of transport available in flood-prone areas. However, accessing and using this data requires capacity and resources that are generally lacking. Also, transportation systems are crucial connective systems within cities' territories. These infrastructures could potentially form a network of climate shelters that people could rely on in the occurrence of extreme climate events; however, this is yet to be a resource that is explored by cities.
Urban planning	Although urban planning within cities incorporates several city sectors, we found that urban planners across C40 Cities have not yet been extensively involved in assessments on interdependencies from a climate risk perspective. Rather, urban planners are more familiar with certain infrastructures than others, especially transportation, and often acts as a convener of other departments including the buildings department for approvals, environmental department, fire and safety department, public works and parks and recreation. The breadth of cross-departmental collaboration depends on the individual city.



3. KEY BARRIERS TO **ADDRESSING INTERDEPENDENT RISK**

Cities face significant barriers to addressing the interdependencies in their systems. Having established where cities are at in the process, we looked to understand the reasons behind progress – or lack thereof. This chapter summarises the key barriers that cities identified in survey responses and interviews.



Governance

Lack of ownership on the interdependencies issue

A primary issue related to addressing interdependent risk is that of ownership. The data, information and impacts on interdependencies extend to several city departments, agencies, regional and national governments and private utilities. But the involvement of so many players means overall ownership of the issue is lacking; there is no single department or agency to lead the work to drive action and implement changes. Cities such as London and Rio de Janeiro have highlighted the issue of ownership and the need for a leading agency to structure and drive cross-city, national and regional cooperation on interdependencies. Without this, the risk is that somewhere in the process momentum and accountability for action will be lost.

Competing priorities and different levels of government jurisdictions

The jurisdictional limitations on local governments can make it difficult to align priorities and coordinate with regional and national governments. Different city sectors operate within different jurisdictional boundaries, such as city, metro, state and national level. This makes it difficult for a city to align the priorities of a city-level infrastructure interdependencies assessment with the priorities of national-level departments. City networks are also connected to, or a part of regional, national and international networks. For every infrastructure network, critical links of failure where systems are vulnerable must be determined. Often the solution lies within the city itself. Sometimes, however, it is more effective to adapt and implement resiliency measures across the overall regional or national network. This necessitates joint action and cross-governmental coordination at different scales, extending beyond the city boundaries.



Coordinating between siloed departments

An interdependencies assessment requires cross-departmental and cross-governmental coordination. It is important to understand which departments, agencies, utilities and other private partners should be involved to ensure robust coverage of all critical infrastructure, their systems and the cascading impacts they may have. However, city governments operate in deeply entrenched siloes, perpetuated by fiscal and administrative systems linked to higher levels of government and also by officials' professional backgrounds (Cities that Work, 2018). Several cities, including Paris, identified the segregation of these departments as a key barrier to a robust interdependencies analysis.

Working with the private sector and utilities

Often, city departments have limited power to influence infrastructure that is owned or managed by private utility companies. These infrastructure systems, such as natural gas, electricity, water and so on, are crucial for an interdependencies assessment as they are generally one of the most critical infrastructure systems. Privately owned or managed utilities will want to ensure the continued functioning of their infrastructure and the ability to re-establish themselves quickly in the case of extreme weather events. However, there is little incentive for them to collaborate with the city or multiple stakeholders or to allocate the resources required for a public, city-driven interdependencies assessment. Lack of awareness about the long-term impact of climate events on their infrastructure often leads to reduced interest in interdependencies assessment. Privately owned and managed utilities are often concerned about sharing sensitive data that highlights vulnerable critical infrastructure as this can affect insurance premiums. It can, therefore, be difficult within city governments to maintain these collaborative private-sector relationships, due to unclear payoffs for cooperation for the private asset owners.

KEY BARRIERS TO

Addressing Interdependent Risk



GOVERNANCE

Lack of ownership on the interdependencies issue.

Competing priorities and different levels of government jurisdictions.

Coordinating between siloed departments

Working with the private sector and utilities.



DATA

Identifying what data exists and what cities should collect.

Data availability and accessibility.

Unsystematic data collection and data coordination.

Processing and using data to inform meaningful actions.



RESOURCES

Lack of capacity and resources.



Data

Identifying what data exists and what cities should collect

All cities mentioned the importance of reliable and accurate data, and data literacy for its effective use, in providing an evidence base for policymaking. Both effective responses in the short term and resilience building in long term depend on real-time and high-quality data about people and systems (Cities that Work, 2018). This data need also has to be understood by the private sector and utilities. To conduct an interdependencies assessment, cities must collect and analyse a substantial amount of data (see chapter 5 box 1 for examples of datasets that cities need to gather). However, several cities – particularly those in the initial stages of such assessments – noted that a key challenge is knowing exactly what data is needed across relevant sectors and utilities and how to manage and align these datasets.

Data availability and accessibility

Cities commonly noted that a key barrier to conducting an interdependencies assessment is the inaccessibility of important datasets and the sensitivity issues around data on privately owned and managed utility assets and their vulnerabilities. As already mentioned, many critical urban infrastructure and services are privatised, meaning they fall beyond local governments' jurisdiction. While city authorities may understand the locational risks of critical private assets that may affect other sectors, they may not be able to share this with other sectors or with the wider public, which leads to information asymmetry.



Unsystematic data collection

Paris identified the difficulty of ensuring that data is collected systematically and in a consistent format. Different city sectors collect data in different ways, which makes it difficult to store and share across city departments.

Unsystematic data collection and data coordination

Another data issue identified by cities such as Jakarta, Paris and Quezon City is the difficulty of ensuring that data is collected systematically and in a consistent format. Different city sectors collect data in different ways; some data may be captured electronically while some may be paper-based. This makes it difficult to store and share across city departments. Additionally, data coordination is a common issue cited by cities. Data sits in different departments and different formats and therefore needs to be brought together in a centrally stored space so that it can be easily accessed and assessed.

Processing and using data to inform meaningful actions

Ensuring that collected data is used and translated into actionable measures is essential for increasing urban resilience. Several cities noted that, following extensive data collection and sector collaboration, there is often a lag in developing holistic policies and actions that address the cascading risks between systems from climate impacts. Although much of this lag can be attributed to lack of ownership, there is also a data literacy challenge, whereby city departments may not have the skills to analyse, interrogate and work with various datasets from other departments to inform policymaking and actions.



Resources

Lack of capacity and resources

A key challenge to addressing infrastructural interdependencies is lack of capacity and resources. Some cities also mentioned the lack of open source tools – that is, tools which are freely available for use and modification – to help them to initiate and conduct an interdependencies assessment.

Cities beginning an interdependencies assessment should where possible, use existing tools and frameworks. There are several external tools and frameworks that cities have used to structure their work on interdependencies (though some of these do require partnerships or funding). We provide some examples of such tools in Chapter 5, Box 2.

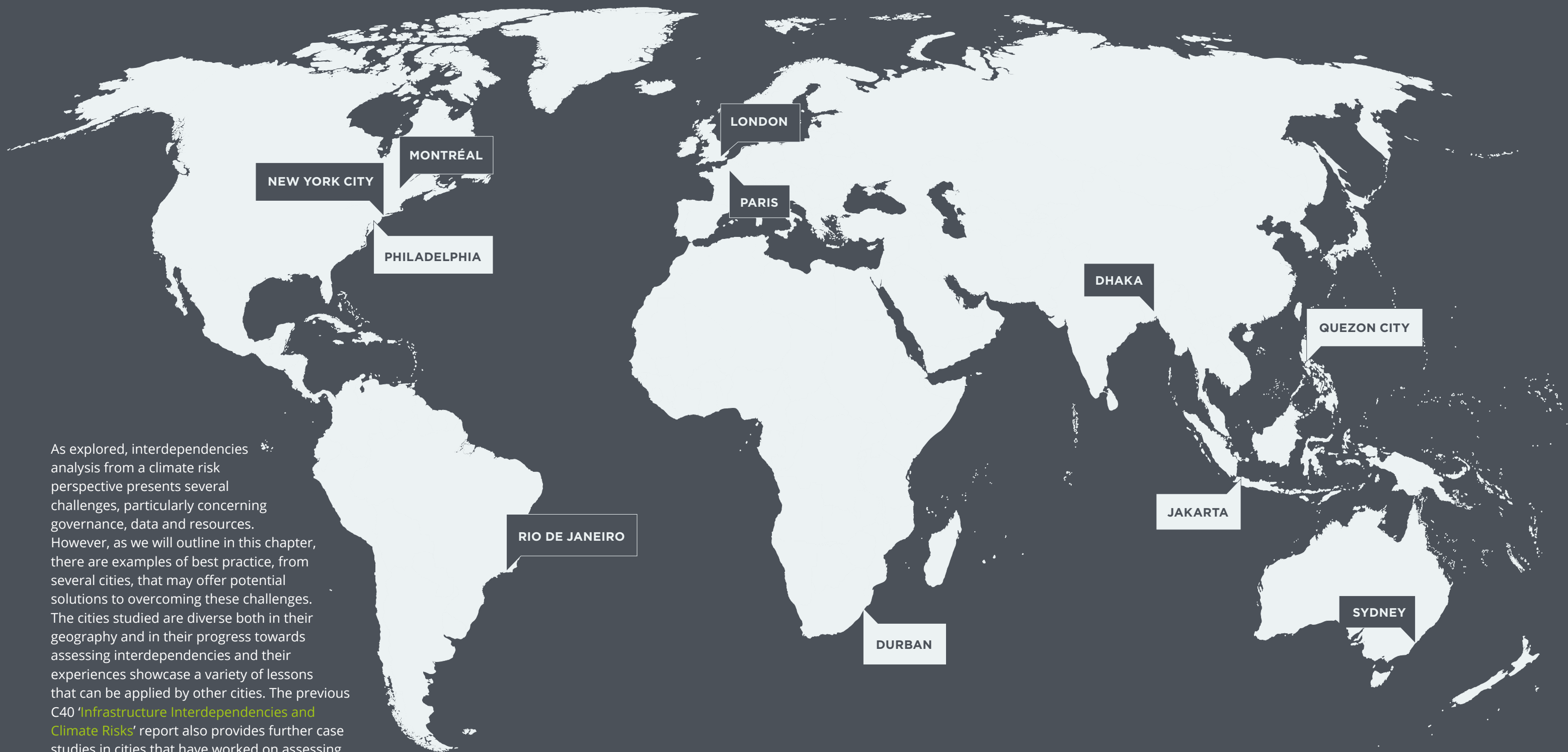
Ensuring that collected data is translated into actionable measures is essential for increasing urban resilience. Several cities noted that there is often a lag in developing holistic policies and actions that address the cascading risks between systems from climate impacts.



4. BEST PRACTICES

FROM CITIES

As explored, interdependencies analysis from a climate risk perspective presents several challenges, particularly concerning governance, data and resources. However, as we will outline in this chapter, there are examples of best practice, from several cities, that may offer potential solutions to overcoming these challenges. The cities studied are diverse both in their geography and in their progress towards assessing interdependencies and their experiences showcase a variety of lessons that can be applied by other cities. The previous C40 'Infrastructure Interdependencies and Climate Risks' report also provides further case studies in cities that have worked on assessing interdependencies.



Dhaka, Bangladesh

Dhaka South City Corporation (DSCC) is currently master planning a strategy for transportation and mobility and believes that understanding interdependencies will help to reveal how transport is affected by climate impacts. DSCC convenes various state-mandated and independently managed operational agencies in a bi-monthly coordination committee chaired by the city mayor. Committee discussions aim to share information on upcoming infrastructure developments in the city so that cross-cutting issues can be identified, and activities coordinated between agencies.

Committee participants include Dhaka's Capital Development Agency (Rajdhani Unnayan Kartripakkha, RAJUK), a public agency that is responsible for coordinating urban development in Dhaka and oversees the master planning of the city, approvals and controls; Dhaka's Transport Coordination Authority (DTCA); Dhaka Water Supply & Sewerage Authority (DWASA); Dhaka Electric Supply Company Limited; and Dhaka Power Distribution Company Limited. Many of these entities focus their operations in the city but come under the jurisdiction of the national government.

While each infrastructure development in Dhaka requires an environmental impact assessment and feasibility report concerning climate risks, the identification of third-party cross-sectoral impacts is yet to be formalised. Cities are often faced with resource and budgetary constraints in setting up a new coordination system. The example of DSCC is therefore important in demonstrating the value of identifying existing structures and resources within cities that could be harnessed for future work on interdependencies.



BARRIER

Interdepartmental coordination between siloed departments.



SOLUTION

Leveraging high-level coordination committees.

Applying this to your city

- ▶ **Identify the stakeholders and sectors** that will be relevant to understanding interdependencies and climate risks in the city.
- ▶ Where possible, **use established mechanisms** to facilitate interdepartmental cooperation.
- ▶ **Create interdepartmental groups and stakeholder groups** to generate ownership of, and accountability for, interdependencies work.

Quezon City, Philippines

A key enabler for encouraging various departments within Quezon City to collaborate on the topic of interdependencies has been robust multilevel governance. In the Philippines, the “Disaster Risk Reduction and Management Act of 2010” has mandated the creation of a comprehensive, multi-sectoral and inter-agency council at the national level and across local government units, leading to the Quezon City Disaster Risk Reduction and Management Council (QCDRRMC). Comprising of a wide range of city departments and external local stakeholders, the QCDRRMC promotes coordination and policy-making towards the “integration of disaster risk reduction and climate change adaptation into local development plans, programs and budgets as a strategy in sustainable development and poverty reduction”. Furthermore, the National Disaster Risk Reduction and Management Council (NDRRMC) have developed criteria to evaluate local government work on disaster risk reduction. Recognitions awarded by these national government agencies – such as the Regional and National KALASAG Awards – have incentivised Quezon City’s departments to work together and has facilitated the coordination that is needed for an infrastructure interdependencies assessment.

Quezon City has demonstrated a history of data sharing and collaborative practices, both with external partners and city departments. This is necessary for an interdependencies assessment, and Quezon City Disaster Risk Reduction and Management Office (DRRMO) has also worked across Quezon City’s departments, inviting different offices to participate in collaboration exercises. Within Quezon City, there is a formal process for requesting shared data across departments, involving letters, technical working groups, workshops and in-person meetings.



BARRIER

Interdepartmental coordination between siloed departments.



SOLUTION

Enabling coordination through national mandates and recognition.

Applying this to your city

- ▶ **Leverage existing national legislation** to enable coordination and incentivise city departments, national departments and external local stakeholders to work together and contribute data and information.
- ▶ **Use or create formalised institutional processes** to collaborate and request information from other departments.



Formalised institutional processes

Quezon City's formal process for requesting shared data across departments ensures that requests are clearly articulated, that cooperation is clearly documented and includes a quality check, which assures the accuracy and reliability of the data.

This formal process ensures that requests are clearly articulated, that cooperation is clearly documented and includes a quality check, which assures the accuracy and reliability of the data. The process itself has also become a means for interdepartmental coordination in and of itself. In submitting and responding to data sharing requests, departments are in constant contact, making it easier to collaborate and share ideas. As an outcome of this collaborative and consultative process, Quezon City has developed the following assessment reports and plans: (i) Disaster Risk Reduction and Management Plan 2014-2020, (ii) Hazards, Vulnerability and Risk Assessment Report, and (iii) Quezon City Risk Atlas.

Through a combination of incentives and legislation, Quezon City has been able to facilitate interdepartmental coordination. The formalised

processes have enabled different departments to work together more efficiently and has helped establish a collaborative culture of work, which has seen them win the KALASAG award three years in a row.

As a result of the increased coordination, Quezon City has quantified losses from interdependent infrastructure, which are included in the Hazard and Vulnerability Risk Assessment and within the analysis of their contingencies plan. Finally, the consideration of interdependencies has been integrated within their implementations plans and policies such as the 'Green Building Ordinance policy', 'Zoning Ordinance policy', the mainstreamed Disaster Risk Reduction and Management and Climate Change Adaptation (DRRM-CCA), Local Climate Change Action Plan (LCCAP) and the Quezon City Environment Code.

New York City, United States

A key issue for New York City (NYC) and many other cities has been coordinating different levels of government, city agencies and private infrastructure service providers to understand risks and dependencies in the face of climate change. In NYC, a valuable forum for coordination on infrastructure service is provided via the governance framework of its New York City Climate Change Adaptation Task Force.

Through **City Council legislation** (The New York City Council Committee on Environmental Protection, 2012), the Task Force convenes city agencies and major private infrastructure service providers in the energy, transportation, water and wastewater, and telecommunications sectors. This same legislation also enables the Task Force to outline its objectives for working together, which include: identifying critical infrastructure in NYC that could be at risk from the effects of climate change, facilitating knowledge sharing, developing coordinated adaptation strategies to secure these assets and producing reports on their actions with recommendations.

Task Force stakeholders collaborate in working groups to assess cross-sector risks (Figure 4). The Task Force's work is supported by forward-looking, science-based climate projections from the New York City Panel on Climate Change (NPCC), a group of scientists, academics and private-sector practitioners that was convened in 2008 to advise the city. The NPCC is required to meet twice a year to present to the Mayor research updates and the latest climate change projections and potential impacts on the city.

Downscaled and locally specific climate projections inform decision making across the city. The NPCC downscales global climate models to a 100-mile radius around NYC.



BARRIERS

Working with the private sector and utilities.

Interdepartmental coordination between siloed departments.

Data availability and accessibility.

Lack of ownership on the issue.



SOLUTION

Coordinate a task force with private utilities, scientists and other agencies through legislation.

Applying this to your city

- ▶ **Formalise stakeholder groups** to give them a mandate for concrete action on interdependencies and to ensure the group's longevity.
- ▶ **Work closely with scientists** to get access to downscaled climate projections specific to a city or region
- ▶ Ensure that **scientific evidence is informing the policy** and implementation of climate actions and that climate risk and interdependencies are integrated into a long-term strategy for the city.

Among other end uses, this data informs the city's [Climate Resiliency Design Guidelines](#) (NYC Mayor's Office of Resiliency, 2019), which apply NPCC projections to design interventions for buildings and infrastructure. For example, if the Task Force's members are constructing critical infrastructure, they can use sea-level rise projections from the Guidelines to adjust the design according to the asset's expected useful life. Any stakeholder can apply NYC's Guidelines to ensure that building and infrastructure design is based on forward-looking climate projections.

The Task Force is unique because it brings together a wide variety of stakeholders mandated to work on interdependencies (among other things) and identify the critical infrastructure. The relationship between the NPCC and the NYC Climate Change Adaptation Task Force is established in law, under legislation that sets out, for example, how often they must meet and what information the NPCC must provide the Task Force.

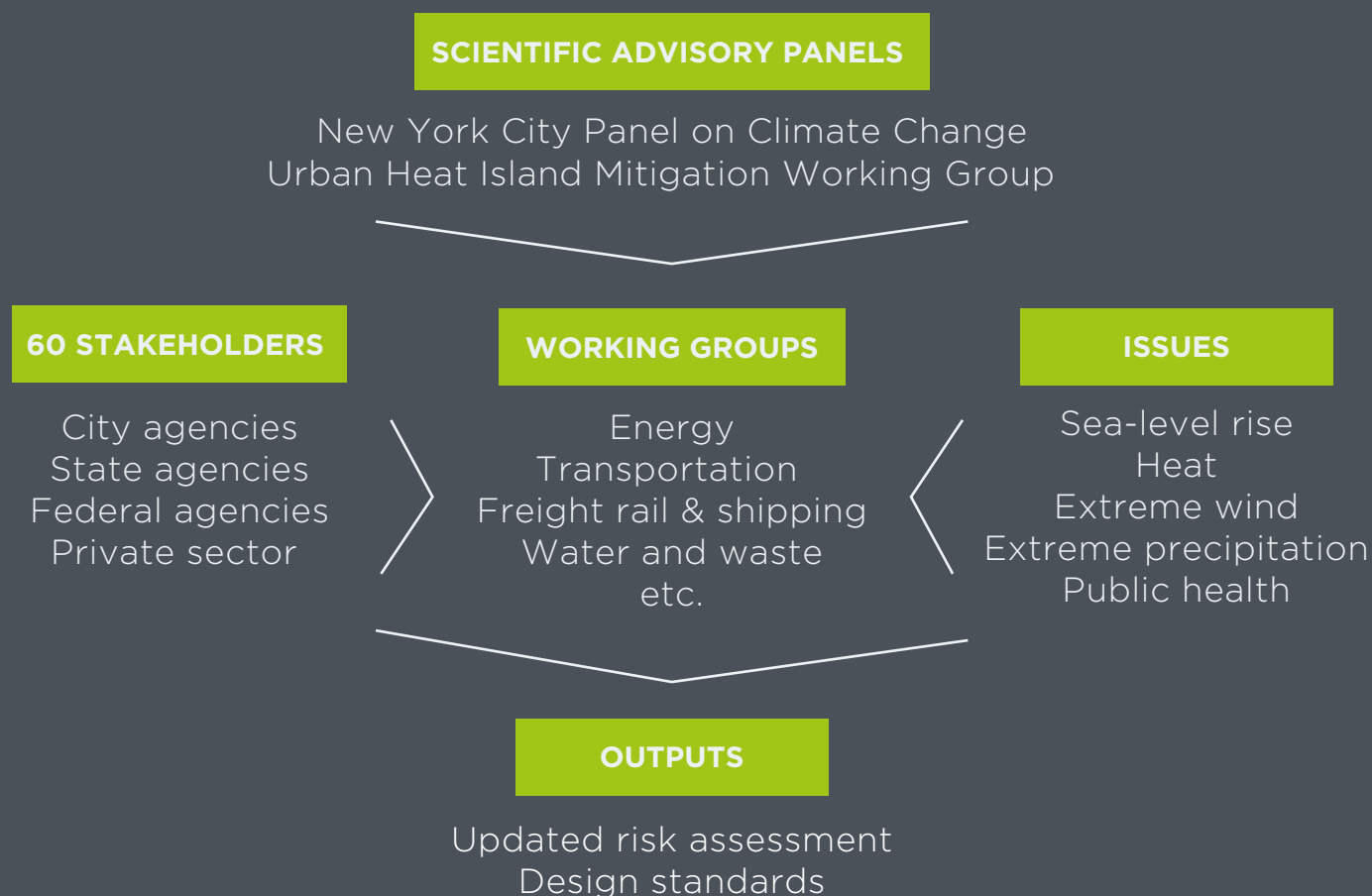


FIGURE 4

The organisational structure of NYC's Climate Change Adaptation Task Force

Adapted from *NYC Mayor's Office of Recovery and Resiliency (2016)*.

London, United Kingdom

The London Resilience Partnership is responsible for ensuring London is prepared to respond to and recover from emergencies. Driven by the arrangements of the [Civil Contingencies Act 2004](#), the Partnership is made up of around 200 member organisations (including private utilities – gas, electricity and water) that have a collective responsibility to plan, prepare and communicate in a multiagency environment. The Partnership works closely with the Mayor, Greater London Authority, local authorities and emergency responders to coordinate plans to respond to the disruption in the city. In collaboration with sector experts and practitioners, the Partnership developed a methodology to identify linkages between different infrastructure systems and how risks can have a cascading impact on services – for example – power outage, loss of water supply or interruptions to any other entities that trigger losses.

As part of the city's long-term thinking about maintaining resilience to shocks and stressors – including climate impacts – London has developed a series of pilot projects on growth and infrastructure in collaboration with the private sector. These projects have facilitated a strong relationship between the city's public departments and private utility owners. [Transport for London's \(TfL\) lane-rental scheme](#) (TfL, n.d.), focused on reducing disruption caused by street works, is paid into by private utilities, including gas, electricity and water. Through this scheme the Mayor's team is working to encourage collaboration between private utilities and to improve coordination on infrastructure planning in rapidly developing parts of the city to ensure that infrastructure changes consider future climate impacts. As well as improving resilience and reducing disruption, these efforts offer private utilities the opportunity to make future cost savings.



BARRIERS

Working with the private sector and utilities.

Data availability and accessibility.

Lack of capacity and resources.



SOLUTION

Partnerships with the private utilities

Applying this to your city

- ▶ Establish strong **partnerships with the private sector** through a variety of projects.
- ▶ **Use data sharing agreements** to ensure buy-in from different stakeholders including private utilities.
- ▶ **Demonstrate to private utilities the economic benefits** of considering the cascading impacts of asset risks and use this to secure their funding and participation.



Building a culture of collaboration

Through pilots and projects, the Greater London Authority is talking to the city's utilities contacts daily and have created a strong culture of collaboration.

Emphasising this financial incentive has been essential for securing private-sector buy-in, funding and cooperation.

London is also working on several innovative infrastructure mapping projects. London's Underground Asset Register is a government-funded pilot which is in development, that seeks to compile data from infrastructure providers to map the location of physical infrastructure that is housed underground. The **Infrastructure Mapping Application**, meanwhile, aggregates infrastructure providers' forward investment plans and live planning application data, among other information. The tool aims to reveal where investments may overlap both in space and in time, to identify opportunities for collaboration as a result of this mapping, and to help infrastructure providers plan more proactively for new development. Infrastructure mapping

has various resiliency benefits as it allows the city to know better where critical infrastructure is and can help it to streamline the delivery of new infrastructure that will improve resilience.

Through pilots and projects, the Greater London Authority is talking to the city's utilities contacts daily and have created a strong culture of collaboration. Although these collaborations have not focused solely on climate risk, the team is working to establish what the gaps or priorities are in London's long-term resilience planning and to identify the areas in which the Mayor of London can intervene to build resilience city-wide. A key facilitative mechanism was establishing non-disclosure agreements between the organisations involved, which allowed utilities to share sensitive data on their assets and operations.

Paris, France

Undertaking an infrastructure interdependencies requires input from different stakeholders. A first step to coordinating these inputs is identifying and bringing together representatives from city and national departments and utility providers, both public and private, that operate in the city.

In 2012, Paris commissioned a study to understand the city's strengths and weaknesses in facing climate change issues. The discussion was driven by a focus on the climate risks. Various public administrations, research centres, public infrastructure, hospitals, utilities companies operating the water and the energy grid answered a survey, and provided all the data necessary for the scientific relevance of the study. The city brought together more than 100 people from various departments and collated data and responses across 18 months. This successful sharing of data and information from different actors and stakeholders was challenging, however its success made it possible to develop strategies and public instruments necessary for tackling climate change issues in the city. This study was the scientific basis of the Paris Adaptation plan, voted in 2015, which highlights 4 main challenges for both public authorities and other actors involved:

- ▶ Protecting Parisians against extreme climate events such as heatwaves, floods, heavy rains, extreme cold, storms and fires but also against health risks connected to climate changes
- ▶ Ensuring water, food and energy supply
- ▶ Having a more sustainable urban planning to live with climate change
- ▶ Fostering new lifestyle and boosting solidarity

The hazards addressed in the adaptation plan



BARRIER

Identifying what data exists and what cities should collect.

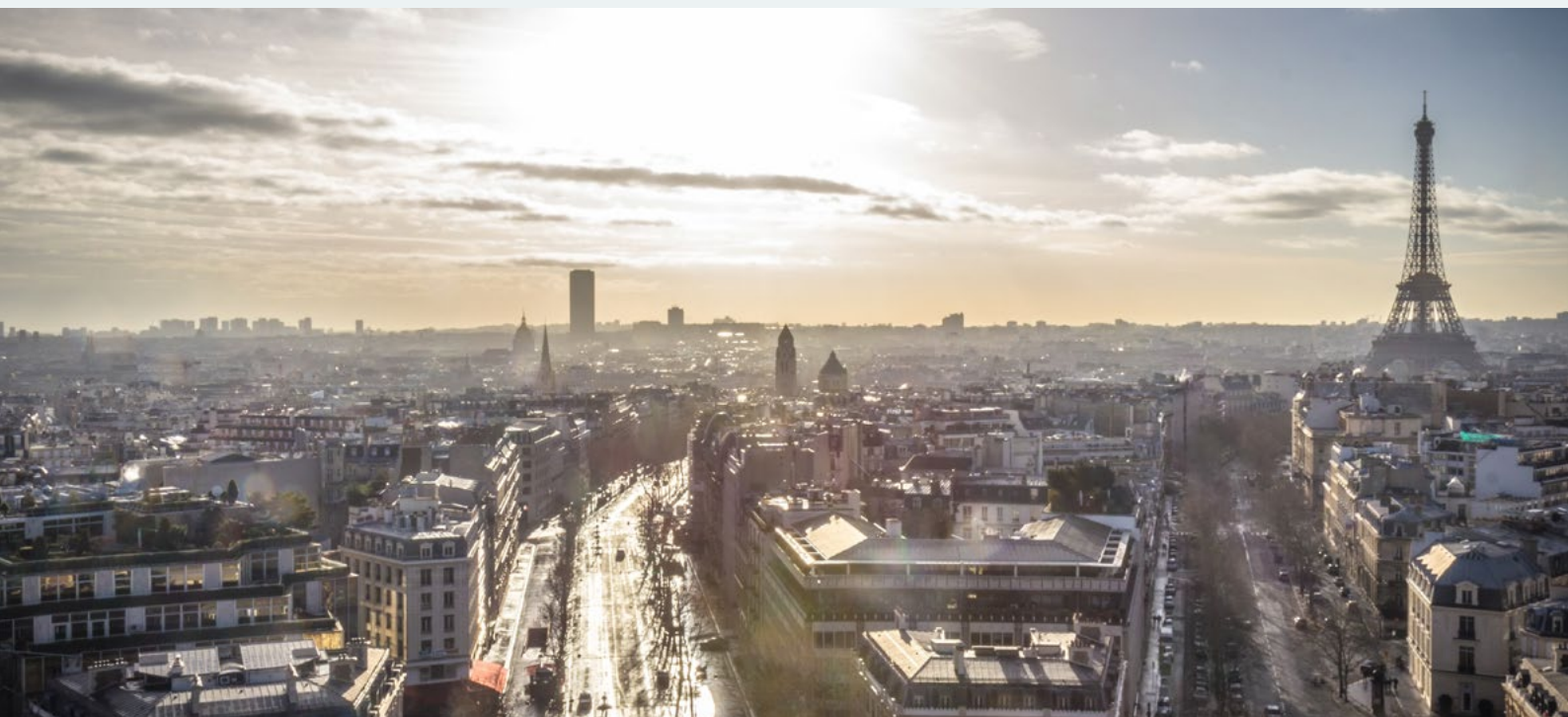


SOLUTION

Using a structured approach to gather sectoral and infrastructure information through surveys.

Applying this to your city

- ▶ **Undertake an initial stocktake** of the city's infrastructure to help build an inventory and develop among stakeholders a common and shared understanding of city assets.
- ▶ **Employ a coordinated approach** when reaching out to all stakeholders, using the same method and similar questions.
- ▶ **Identify a motivating factor** for the city to carry out the interdependencies assessment and frame the conversation around this to help bring different stakeholders on board.



A coordinated approach

Having a coordinated approach and being clear at the outset about how and why data will be used helps to ensure it is useful for an assessment on interdependencies.

identified a number of key stakeholders who also need to consider the cascading impacts on services and infrastructure climate change could have on their assets.

The success of this study shows that having a coordinated approach and being clear at the outset about how and why data will be used helps to ensure it is useful for an assessment on interdependencies. The city works continuously on data and information sharing because it enables different actors to develop a set of consistent and specific questions about critical failures related to particular climate hazards and impacts. It has also been a requirement for different exercises, such as the publication of the Paris Climate Action Plans published in 2012 and 2018. The city is also working on open-data services in order to accelerate public and private appropriation of climate information.



To get people to work together on interdependencies, you have to focus on a specific initiative and understand the strength of the city in facing climate change issues and the resource risks.

Yann Francoise
City of Paris

Philadelphia, United States

Accurate and reliable data is essential in understanding risk and communicating across sectors. In Philadelphia, data collection across departments is motivated by collaboration and the need to provide data-informed policy and regulatory decisions. The approach is the culmination of several years of effort to build relationships with departments, agencies and offices, and it has required the use of non-disclosure agreements so that various stakeholders are comfortable sharing publicly sensitive information.

Internal data management: Internally, the Flood Risk Management Task Force (FRMTF) of Philadelphia has created a shared web-based Geographic Information Systems (GIS) map to collect all relevant flood-related data across city departments. Through its [Growing Stronger: Toward a Climate Ready Philadelphia](#) report, the city has identified what critical infrastructure is vulnerable to flooding, and therefore created datasets of various vulnerable assets. Philadelphia uses platforms such as Microsoft SharePoint and its internal GIS databases to compile and share relevant data and information. National datasets, such as the Federal Emergency Management Agency's (FEMA) repetitive loss data, are also incorporated in the dashboard and highlight the cross-governmental coordination that is required in interdependencies analysis. The Department of Public Property has embedded flood risk data in the City's Integrated Workplace Asset Management System (IWAMS) to manage flood risk related to the City's asset portfolio.

External data management: Externally, through its partnership with regional planning organizations, Philadelphia has developed a public-facing GIS story-map, illustrating the effects of climate change flooding. This map



BARRIERS

Lack of ownership of the issue.

Unsystematic data collection and data coordination.



SOLUTION

Data sharing platforms.

Applying this to your city

- ▶ **Use data-sharing platforms**, through which departments can contribute information, to centralise and align datasets and make sure that information is provided in a clear and consistent format. Always considering long-term maintenance of data sets.
- ▶ Use the tools such as non-disclosure agreements to **encourage data sharing between stakeholders**.
- ▶ **Harness existing data sets** and data that could easily be collected through incremental policy changes
- ▶ **Leverage regional- and national-level agencies** to collect and process data and evaluate impacts on critical infrastructure.
- ▶ **Quantify the impacts of interdependencies on different sectors** – that is, what assets will be impacted and by how much – to help to secure buy-in from senior leadership and to bring other stakeholders on board.

uses publicly available data on property values, critical infrastructure and roads to effectively communicate the impacts of flooding on the tax base and city infrastructure, to drive policy and regulation changes. The city is currently working with several departments to develop a historic flood risk map, to educate the public on past flood events as a risk communication tool. External partners such as state agencies like the Pennsylvania Emergency Management Agency (PEMA), the State Historic Preservation Office, and United State Army Corps of Engineers (USACE) have also brought technical expertise, data sharing and most importantly funding. The city attributes a significant part of the success of their work on interdependencies to these partnerships.

The data collected from the FRMTF informed the city's first Flood Risk Management Strategic Plan and provides senior leadership with data-informed planning to implement a holistic Flood Management Program city-wide. Philadelphia has

considered the yearly costs of climate change to the city, which range from the increasing costs of continuing to provide services to maintenance costs for upkeep. Some examples of additional costs due to flooding are (*Growing Stronger*, 2015):

- ▶ Increased Disaster Costs: one severe hurricane could cause more than \$2 billion in damages citywide
- ▶ Extreme storms with higher winds and more flooding could cause between \$20 million and \$900 million in damages citywide
- ▶ An additional \$2 to \$4 million in roadway maintenance costs from rutting (permanent pavement indentations from traffic) caused by precipitation, rutting caused by freeze-thaw cycles, and cracking during periods of high temperatures.
- ▶ The regional transit system operational costs could raise \$2 million per year.



I can't stress enough the importance of partnerships: some of the most successful initiatives for addressing interdependencies are due to the partnerships forged.

Josh Lippert
Philadelphia

Figure 5a and b show how the city has identified the critical assets that are vulnerable to six scenarios of sea-level rise and the quantified potential costs of flooding and hurricane damages respectively.

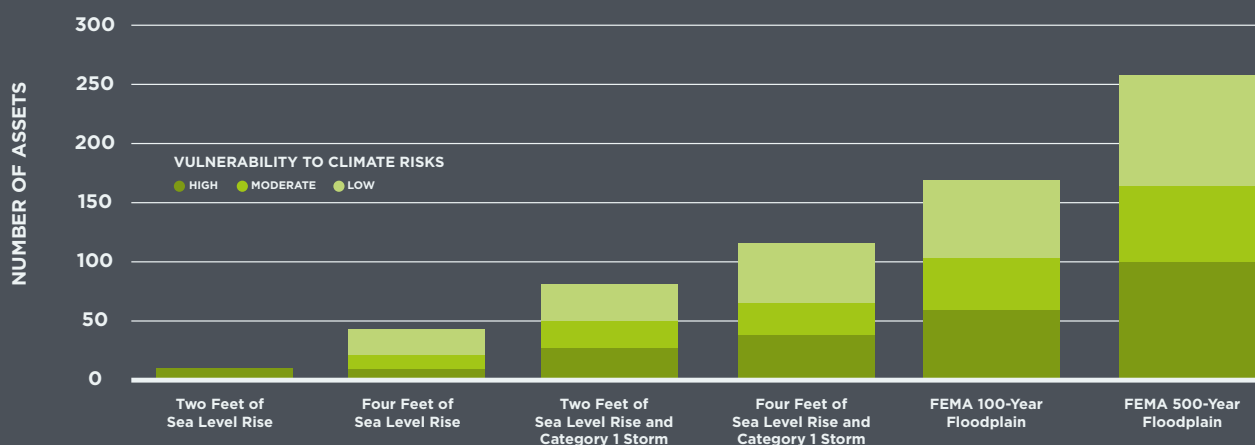
As a result of its extensive work on interdependencies, the City of Philadelphia has implemented several action changes to increase the resilience of the city. Among these actions are training related to city departments and other assets in the city, such as the zoning, building permits, flood management, hazard mitigation and emergency planning. The example of Philadelphia's interdependencies work has seen federal and state partners looking to the city as a model to replicate in cities across the US with FEMA now creating a resilience playbook based on the city's interdependencies work.

POTENTIAL COSTS OF FLOODING AND HURRICANE DAMAGES IN PHILADELPHIA

IMPACT CATEGORY	POTENTIAL COSTS
Cost of an additional 100-year flood	\$600,000,000
Direct economic loss	
Gusts of 73-78 mph (1% chance of occurrence each year)	\$20,000,000
Gusts of 81-86 mph (0.5% chance of occurrence each year)	\$90,000,000
Gusts of 92-96 mph (0.2% chance of occurrence each year)	\$300,000,000

FIGURE 5B

Potential costs of flooding and hurricane damages in Philadelphia



The high, moderate and low portions of the bars indicate the number of assets that would have high, moderate, and low vulnerability under each scenario. Source: Master facilities Database.

FIGURE 5A

Number of vulnerable city-owned assets under six scenarios, by vulnerability level

Rio de Janeiro, Brazil

Much of Rio de Janeiro's work to identify and understand the interdependent infrastructure has been from a data point of view. The city's Rio de Janeiro Center of Operations (COR) collects and uses data from around 30 entities (municipal and state departments and essential services) to monitor the city and help it run smoothly, especially during large-scale climate events.

As well as monitoring conditions in the city 24/7, the COR helps to resolve problems efficiently and minimise the impact of incidents by notifying the affected entities of risk situations. This enables services to respond quickly to emergencies such as heavy rains, flooding and landslides. The key advantage of a centralised department is that using real-time weather data, extreme events related to climate change can be monitored and information shared across the city's various departments, as well as with citizens through the press and social media.

The city's meteorological office that monitors local weather forecasts sits within the operational centre. Whenever there are forecasts of extreme precipitation that may lead to flooding, storm surge or landslide risks, the office can communicate with departments such as fire, police, transport and even citizens via social media to distribute early warnings. For example, Rio has used the COR in times of flooding to re-plan the transportation routes of local buses and mass transit systems to avoid potential disruption.

Rio de Janeiro also uses municipal data collection systems, which have data points for every city entity (City Hall of Rio de Janeiro, n.d.). Data is available online and used as the city's public-facing sharing platform for transparency (City Hall of Rio de Janeiro, 2017). Other forms of data collection include mapping the city's climate-related risks and vulnerable assets and infrastructure. This has been made possible by the city's routine use of Esri GIS software and remote-sensing data to map rainfall and flood areas. Collecting data on rainfall and flood projections allows the city to consider this in future development plans through its Planning Office, which integrates all sectoral plans into a city-wide, long-term strategy; the Sustainable Development Plan which includes the first Climate Action Plan, under construction by the Municipality and supported by C40.



BARRIER

Processing and using data to inform meaningful actions.



SOLUTION

Integrating real-time data in city operations.

Applying this to your city

- Where possible, **establish a centralised centre for communication and operations** that will enable city departments to take real-time measures that address interdependencies to protect critical infrastructure.

Durban (eThekweni), South Africa

The understanding of interdependencies has facilitated the implementation of eThekweni's early warning forecast system with integrated hydraulic modelling. This work has identified critical areas such as informal settlements and, in the event of a potential flood, infrastructures along the river such as pump stations, substations, wastewater works and road crossings are notified. Three-day weather forecasts are taken from the South African Weather Service and input into an automatic hydraulic model that runs and triggers different warning levels for the critical points of each asset. The city's engineering department is engaging with disaster management, waste, electricity and water sectors to set up a process whereby they are also notified of the potential hazard. A system of instruments, including rainfall radar, stream gauges and real-time rainfall gauges, is used to calibrate models and verify actual conditions in the field. This will allow these sectors to develop a response plan in the event of heightened climate risk.

eThekweni is also undertaking infrastructure design actions as a result of understanding infrastructure interdependencies due to risk of flooding from the city's river. The city is now designing their stormwater and drainage infrastructures as an integrated system and has worked with the University of KwaZulu-Natal, which has provided downscaled global climate model data to the regional level and the city's catchment level. The university has estimated a 15% increase in rainfall by 2065, a time frame that is gradually becoming a design standard for infrastructure. Whenever the city receives complaints of flooding or waterlogging in the city, it checks for maintenance and time capacity; wherever it finds shortfalls (generally in older parts of the city), it is upgrading the systems and designing for the rainfall increase. New infrastructure along the river will factor



BARRIER

Processing and using data to inform meaningful actions.



SOLUTION

Communicating risks to infrastructure owners,

Upgrading infrastructure based on climate projections to avoid impacts.

Applying this to your city

- ▶ Invest in the technical resources to enable engineers to **acquire good baseline and ground data**, which is needed to develop representative hydraulic river models.
- ▶ Invest in the technical resources to enable scientists and experts to **provide real-time meteorological data** for forecasting climate risks to guide design parameters and infrastructural upgrades.
- ▶ **Pilot in smaller areas design guidelines** that are based on scientific projections of hazard impact. Once results have been demonstrated, apply the guidelines citywide.
- ▶ **Calculate the wider benefits of interdependencies projects** to make the case for wider implementation.



Working with the community

The city has worked with local people and helped them to establish cooperatives to clear out the rivers, removing blockages such as alien vegetation and waste.

in a 1-in-10-year storm event and use the latest rainfall projection figures.

Based on these projections, the city is revising its flood lines. In the past, the flood lines were developed based on what flood lines would be in the catchment after being fully developed based on present zoning, even if the sites weren't developed. Now the city is amending all the flood lines according to the 15% increase in rainfall intensity so that future developments will be designed with this risk as a consideration. This is being done in 3 out of 17 catchment areas to develop a protocol for all 17. Once complete, the risk parameter will be translated to all the infrastructure adjacent to streams and rivers. The main driver for the city for the vulnerability work on streams, river and urban drainage system is the need to make sure the system is altered to the anticipated risk. The idea is to provide information about the anticipated risk, against which each asset must be assessed; the response will then be determined by asset owners, who will decide whether to make design changes or to relocate the asset.

For the past eight years, the city has also been running a stream management programme in townships. The city has worked with local people and helped them to establish cooperatives to clear out the rivers, removing blockages such as alien vegetation and waste. Left unattended, these blockages cause significant cascading impacts to adjacent infrastructure during periods of increased rainfall and flooding. Furthermore, the city is now looking to quantify the impacts of risk reduction of these interdependencies through a project with C40's City Finance Facility. This project will undertake a cost-benefit analysis that considers wider benefits such as increased biodiversity, increase in water availability. Previous estimates showed that a single road crossing blockage caused by overflow from the river due to alien vegetation and solid waste blockages had costs well above the average of annual blockage removals if the stream had been under the original programme. In addition to reducing costs, the stream management programme avoids disruption to businesses and the need to replace roads, as well as generating other benefits.

Montréal, Canada

In 1998 a historic ice storm left parts of Montréal without power, telecom services and water. After this event, the city and some of its key service providers – telecom, electricity, natural gas, water and transport – came together to conduct research and gather information on how their systems would be affected in the event of a major disaster. They set up a unique collaboration between critical infrastructure managers, the Civil Protection Centre of Montréal and the Centre risque & performance of Polytechnique Montréal to develop a tool called DOMINO (see box 2).

A key part of the work in Montréal involved conducting exercises to assess the impact of a critical infrastructure failure, without considering the causes that led to it. The exercises examined the 72 hours that follow a predicted incident to highlight its cascading effects and to calculate the emergency resources that will be required for the given scenario – e.g. to fuel generators in a blackout or provide access to potable water. In 2012 the Civil Protection Centre and the research centre conducted a water exercise to understand the cascading effects of water system malfunction on other critical infrastructure and identify all the dependencies related to water. Coincidentally, the following year, water supply in the city was disrupted, and half of Montréal was under a preventative boiled water advisory for approximately three days. This showed the city the significance of both the tool and running disruption exercises.

One of the city's key achievements has been the mobilisation of the private network operators that co-funded the creation of the DOMINO tool and the partnerships forged between public and governmental organisations. These private network operators recognised their vulnerabilities to climate impacts because of their experience with past extreme climate-



BARRIER

Processing and using data to inform meaningful actions.



SOLUTIONS

Leveraging research to assess the impact of cascading failure.

Leveraging research to collaborate with utilities and other departments.

Applying this to your city

- ▶ **Collaborate with private and public utilities** to provide data to secure funding for interdependencies planning and confidential data.
- ▶ **Accept the potential limits of public data** and do not bypass the spatial data private utility networks can provide through partnerships and to build relationships.
- ▶ **Share interdependencies planning tools** so that cities can collaboratively develop tools and benefit from them.
- ▶ **Leverage research** to demonstrate to utility providers and generate funds the benefits of interdependencies assessments.

related events and were prepared to invest in research and development (R&D) to avoid similar losses in the future. The partnership also established NDAs to motivate the sharing of confidential information. In particular, Montreal has highlighted that the spatial data provided by private networks should not be bypassed to develop GIS-based tools on interdependencies through public data. This can be counterproductive to the trust-building work needed between the public and private sector.

City agencies must learn to accept the potential limits set by public and private infrastructures managers and find a collaborative way to go beyond this challenge. Whilst understanding interdependencies and pinpointing critical infrastructure can be challenging, cities will benefit from investing the work and time needed in creating these necessary public-private partnerships. Planning how projects can be sustained and financed long term is also a crucial factor for cities to consider early on.



Cities need to have a win-win situation with critical infrastructure networks. The fact that Domino resulted from a research project and a bottom-up collaborative effort made its advancement easier. The tool has come far and allowed the sharing of confidential information between public and private entities in an emergency planning context.”

Irene Cloutier
Ville Montréal



Sydney, Australia

The city of Sydney was first motivated to understand its infrastructure interdependencies as a result of initial work on its climate strategy. The New South Wales Critical Infrastructure Resilience Strategy and Resilient Sydney initiative subsequently found that 'Infrastructure Interconnectedness/Interdependencies' was an area of study that required more knowledge and evidence and noted the need to develop a critical infrastructure resilience strategy. The city is now writing plans to increase the overall resilience of the city and identify critical points.

Sydney has identified interdependencies on the city's rail corridor, which runs from the Central Business District, throughout the city, from the north to the south. If one station in the rail corridor was affected by flooding, it could stop 70% of trains from running. This also demonstrated cascading impacts on the motorway, airport, substations, rail network and road network, as well as significant disruption in the Green Square area itself – including the displacement of people.

A crucial element of Sydney's progress in the area of interdependencies and climate risk has been its use of tools and resources to fill its capacity and resource gaps. As well as the state-owned Emergency Information Coordination Unit (EICU) database, the city has used tools and resources that have been made available through external partnerships with 100 Resilient Cities' Risk and Assets Tool and data company Climate Risk, which provides software to bring together asset-level datasets.

Recognising the need to understand interdependencies, the New South Wales State Government and the city of Sydney partnered with Climate Risk to launch the Cross-Dependency Initiative (XDI) Sydney Pilot Project, a large-scale, multi-utility analysis programme



BARRIER

Processing and using data to inform meaningful actions.



SOLUTION

Use of tools to identify the critical links in the city systems.

Applying this to your city

- ▶ **Invest in tools to assess and quantify** the interdependencies for the city and fill knowledge and capacity gaps.
- ▶ **Identify and map the critical links** to the infrastructure in case of extreme events, to develop the response plan and avoid damages.



The Cross-Dependency Initiative (XDI) Sydney Pilot Project

This a large-scale, multi-utility analysis project covered approximately 4 million individual assets across six infrastructure types within the city, including critical public and private infrastructure in power, water, roads, rail and telecommunications sectors.

(XDI, 2017). Other project partners included the state's transport agency, major water utility and emergency management department. The XDI-Sydney collaboration enabled the asset managers from all these agencies to identify the interdependencies within their critical infrastructure networks and identify their at-risk assets.

The project covered approximately 4 million individual assets across six infrastructure types within the city, including critical public and

private infrastructure in power, water, roads, rail and telecommunications sectors. It has provided state-level analysis of the infrastructure that cuts across the city and is often privatised, and also enables the city to update data, add and remove assets, and incorporate climate change projections. This provides insight into interdependencies, and one that is not static but evolves as the city itself and climate change projections change.

Jakarta, Indonesia

The city of Jakarta is keen to undertake an interdependencies assessment and to integrate this into its wider resiliency strategy. To prepare climate and risk studies and to provide the City Governor with recommendations on climate resiliency planning, the city has developed several external partnerships. These partnerships have included collaborating with researchers and academic institutions such as the University of Indonesia and the Bandung Institute of Technology, devising flood risk maps with assistance from the Netherlands government and working with councils of research professors and professionals who provide recommendations to infrastructure agencies. The city is currently developing a resilience strategy in partnership with 100 Resilient Cities, which aims to map vulnerable locations including the city's central business district and mass rapid transit infrastructure.

NGOs and research institutes have the resources and knowledge capabilities to help cities like Jakarta to identify data on infrastructure and undertake interdependencies assessments. Cities with limited data resources can partner with local and regional organisations and universities to increase their access to climate data. International assistance and funding can facilitate knowledge exchanges, particularly for Global South cities that may have resource and priority constraints.

However, this proliferation of partnerships and collaborations has created a key challenge in Jakarta. An extensive number of planning documents – spatial plans, sectoral plans and strategies have been completed by several different agencies and across different time periods. The city now needs guidance on how to align these multiple documents to create a holistic climate resilience strategy that not only understands spatial risks and vulnerabilities but includes clear identifications of assets and infrastructures that can lead to cascading failures, both now and in the future.



BARRIER

Lack of capacity and resources



SOLUTION

Partner with local research institutions and NGOs.

Applying this to your city

- **Partner with local and regional organisations** and universities to increase their access to localised climate and infrastructure data.



Urban risk assessment and infrastructure interdependencies study are important to better understand what infrastructures are at risk and adversely affected by climate hazards. Policymakers can make use of the study in project prioritising and budget planning. However, incorporating the study in the annual planning process is a challenge on its own.

Feirully Irzal
City of Jakarta



5. RECOMMENDATIONS

FROM CITIES

From the examples of best practices outlined in chapter 4 and during the interviews conducted for this study, several recurrent themes emerged concerning how cities are overcoming key barriers to understanding and managing interdependencies in the context of climate risk. We summarise these solutions in this chapter. It is important to note that every city is different and not every solution presented will be feasible for every city – especially concerning governance issues.

Overcoming governance challenges

Cities have found several ways to improve coordination and collaboration between the city sectors, stakeholders and across jurisdictions. Many cities, such as Dhaka, already have some form of **interdepartmental group or agency** through which sectors communicate, collaborate and share. For cities that are yet to begin an assessment on interdependencies, steering groups and councils are an existing mechanism by which initial work on the topic can begin and offer a way to include all potentially affected sectors.

Coordination groups in London have used the [Anytown Framework](#) (Box 3; Hogan, 2013) to establish cross-sectoral and cross-jurisdictional workshops and exercises to develop the city's

understanding of interdependencies. Paris and Quezon City have developed more formalised methods to gather information and start the discussion about interdependencies, with the latter drawing upon the incentives of national mandates.

London and Montréal have both established **private-public partnerships** to work beyond traditional domains of influence, and other cities highlighted many ways to facilitate private-sector collaboration. One is to demonstrate an understanding of, and to stress, the financial impacts to private servers if interdependencies remain unaddressed. Cities should make the case that investing time and resources in such interdependencies assessments can generate value for the entire system.

NDAs between stakeholders can encourage cooperation and external parties, particularly the private sector, by generating trust and reassuring those involved that data will be handled sensitively. It should be noted, however, that while public reporting is contentious (and specific datasets may not be disclosed), overall community and city resiliency can be increased if findings are made publicly available to citizens. If water shortages or energy supply disruptions are expected due to climate change-related events, communities – particularly vulnerable communities – should be informed and be made aware of what actions they can take so they can prepare an emergency response.

Governance recommendations

Lack of ownership on the interdependencies issue

- ✓ Create interdepartmental groups and stakeholder groups to generate ownership of, and accountability for, interdependencies work.

Competing priorities and different levels of government jurisdictions

- ✓ Identify a motivating factor for the city to carry out the interdependencies assessment and frame the conversation around this to help bring different stakeholders on board.
- ✓ Leverage existing national legislation to enable coordination and incentivise city departments, national departments and external local stakeholders to work together and contribute data and information.

Coordinating between siloed departments

- ✓ Identify the stakeholders and sectors that will be relevant to understanding interdependencies and climate risk in the city.
- ✓ Formalise the stakeholder groups to give them a mandate for concrete action on interdependencies and to ensure the group's longevity.
- ✓ Create incentives for departments to coordinate and work together to share data to address interdependencies.

Working with the private sector and utilities

- ✓ Establish strong partnerships with the private sector through a variety of projects.
- ✓ Use data-sharing agreements and non-disclosure agreements to ensure buy-in from different stakeholders including private utilities.

Improving data collection and use

Some cities reported uncertainty around what data to collect. Based on our interviews with C40 network managers, Box 1 sets out suggestions for data that cities may find it useful to collect. The list is not exhaustive but is designed to give a sense of data that can exist within the city

departments and private providers and how these can be used.

But knowing what to collect is one thing; being able to collect it is another – particularly when data is owned by private utilities. To make this possible, cities often need to establish long-standing **public-private partnerships** and establish NDAs with privatised utility owners.



BOX 1

What data do cities need for interdependencies assessments for the mitigation of climate risk?

Cities will need up-to-date and localised **climate projections for the city**, both for current and future scenarios for longer-term planning. Spatial data on climate hazards will be crucial to understand where in the city the greatest impacts will be. This includes flood mapping in the case of heavy precipitation and, for coastal cities, storm surge, as well as future heat projections. eThekweni has integrated the latest 1:100-year flood lines as a result of national legislation for zoning, and New York and Philadelphia both use updated data on flood mapping from the Federal Emergency Management Agency (FEMA).

Infrastructure and systems data forms the core of the information needed for a city to understand its interdependent risks and potential challenges. To ensure they have a robust understanding of critical assets across the city, municipal agencies should ask the following questions:

- A stocktake of the city's assets
- What are the critical infrastructures and services in the city?
- Who owns the critical infrastructures and services; public (city, state or national)/private/quasi-private?
- What particular assets are exposed or vulnerable to climate risks, and how?
- At what points can one sector's infrastructure affect another's?

Finally, **socio-economic data** is crucial to understanding who in the city is most vulnerable from climate impacts on infrastructure and systems failures. Having fully mapped neighbourhoods will allow city planning departments to understand which communities may be vulnerable to cut-offs in the event of an extreme event so that they can devise policies and allocate resources to ensure these areas do not remain underserved.

To make sure that the data collected is useful, cities should look to set up **data-sharing platforms**, as in the case of Philadelphia, and establish data-sharing processes. These can help to ensure the reliability and accuracy of the data, but also help make coordination between stakeholders more efficient.

In interviews, London highlighted the need for **ownership and delegated responsibility** across a governance structure to help maintain momentum for collaboration beyond the data collection phase. Ownership also ensures that work to address interdependencies is actionable, with defined tangible commitments that are integrated into wider city planning

and adaptation strategies. Interviewees from London and Montréal acknowledged that the interdependencies work can be difficult to manage if there is no organisation with the mandate to manage the relationships between stakeholders. Strategic public authorities can attempt to fill this gap; however, convening stakeholders to continue phases of work is still challenging without the legal or regulatory mandate or powers.

Data recommendations

Identifying what data exists and what cities should collect

- ✓ Undertake an initial stocktake of the city's infrastructure to help build an inventory and develop among stakeholders a common and shared understanding of city assets.

Data availability and accessibility

- ✓ Employ a coordinated approach when reaching out to all stakeholders, using the same method and similar questions.
- ✓ Work closely with scientists to get access to downscaled climate projections specific to a city or region.
- ✓ Partner with local and regional organisations and universities to increase their access to localised climate and infrastructure data.
- ✓ Use the tools such as non-disclosure agreements to encourage data sharing between stakeholders.
- ✓ Leverage regional- and national-level agencies to collect and process data and evaluate impacts on critical infrastructure.
- ✓ Harness existing data sets and data that could easily be collected through incremental policy changes.
- ✓ Accept the potential limits of public data and do not bypass the spatial data private utility networks can provide through partnerships and to build relationships.

Unsystematic data collection and data coordination

- ✓ Use or create formalised institutional processes to collaborate and request information from other departments.
- ✓ Use data-sharing platforms, through which departments can contribute information, to centralise and align datasets and make sure that information is provided in a clear and consistent format. Always considering long-term maintenance of data sets.

Processing and using data to inform meaningful actions

- ✓ Ensure that scientific evidence is informing the policy and implementation of climate actions and that climate risk and interdependencies are integrated into a long-term strategy for the city.
- ✓ Quantify the impacts of interdependencies on different sectors – that is, what assets will be impacted and by how much – to help to secure buy-in from senior leadership and to bring other stakeholders on board.
- ✓ Calculate the wider benefits of interdependencies projects to make the case for wider implementation.
- ✓ Identify and map the critical links to the infrastructure in case of extreme events, to develop the response plan and avoid damages.
- ✓ Invest in the technical resources to enable engineers to acquire good baseline and ground data, which is needed to develop representative hydraulic river models.
- ✓ Invest in the technical resources to enable scientists and experts to provide real-time meteorological data for forecasting climate risks to guide design parameters and infrastructural upgrades.
- ✓ Invest in tools to assess and quantify the interdependencies for the city and fill knowledge and capacity gaps.
- ✓ Where possible, establish a centralised centre for communication and operations that will enable city departments to take real-time measures that address interdependencies to protect critical infrastructure.
- ✓ Pilot in smaller areas design guidelines that are based on scientific projections of hazard impact. Once results have been demonstrated, apply the guidelines citywide.

BOX 2

Climate-related Financial Disclosure

Where private network operators have their interests to act on adapting their assets to face climate risks, cities serve the broader population and businesses within their boundaries. The role of the Task force on Climate-related Financial Disclosure (TCFD) can, therefore, be pivotal in mobilising city agencies as well as private network operators. The TCFD provides voluntary recommendations to help asset owners and managers measure and disclose information about how climate change could affect their facilities, supply chains, labour force, delivery of products and services and other essential operations (Bloomberg, 2019). These disclosure recommendations help private stakeholders, as well as public companies, make sound financial investment decisions. TCFD currently is applied only to the private sector. However, Chartered Professional Accountants of Canada (CPA Canada), has conducted a study for public sector companies to report their climate-related financial risks. Cities wanting to understand and report on their climate risks will not only need to understand how their own infrastructure systems could fail or be weakened but also how other systems could be affected from cascading impacts, with TCFD guidelines presenting a mechanism for public assets to do so. As the climate change impact on supply chains grow and affect the cities' growth, TCFD can help in reporting cities' vulnerability, and the impact on their supply chains.

Expanding Capacity and Mobilising Resources

A key recommendation from cities is to **develop external partnerships** with researchers and private utilities that need to be involved in conducting an interdependencies assessment as these parties can provide resources that city governments often cannot fund themselves. As one interviewee said, 'Public capacities and resources alone are inadequate for responding to the resilience challenge, thus the private-sector's ingenuity, financial resources and technical skills could support cities.' Montréal has shown that private-sector utilities and service providers can also bring in funding if they are made aware of the financial gain from understanding an overall system's resiliency.

It is also important to **make use of the resources and tools that already exist**. During this study, cities and insurers highlighted several tools that they have used, and which may be useful to other cities that are looking to identify critical infrastructure and quantify the value of their assets in the event of losses. We provide an overview of these in box 3.

Resources recommendations

- ✓ Where possible, use established mechanisms to facilitate interdepartmental cooperation.
- ✓ Collaborate with private and public utilities to provide data to secure funding for interdependencies planning and confidential data.
- ✓ Demonstrate to private utilities the economic the benefits of considering the cascading impacts of asset risks and use this to secure their funding and participation.
- ✓ Share interdependencies planning tools so that cities can collaboratively develop tools and benefit from them.
- ✓ Leverage research to demonstrate to utility providers and generate funds the benefits of interdependencies assessments.

BOX 3

Examples of external tools and frameworks to help cities structure their work on interdependencies

Easy XDI (XDI, n.d.)

Using public asset data against proprietary hazard data, Easy XDI provides on-demand reporting for any location around the world. City practitioners can assess the climate vulnerability of specific infrastructure types until the end of the assets' design life in an address or drop a pin on a map for free with projections incorporated up until 2100. See also chapter 4, which describes the experience of Sydney in partnering with XDI.

100 Resilient Cities Assets and Risks Tool (100 Resilient Cities, 2019)

100 Resilient Cities Assets and Risks Tool prioritises shocks and stresses in the context of their interaction under future scenarios and identifies vulnerable physical assets. The tool was designed to provide insight to inform the Preliminary Resilience Assessment and is designed to be used in the 100 Resilient Cities Resilience Strategy Process, which many cities including Sydney have taken part in and used.

Oasis Loss Modelling Framework (Oasis, n.d.)

Insurance companies commonly use the Oasis Loss Modelling Framework for open source catastrophe modelling when valuing assets for insurance payouts in the event of a climate hazard. Catastrophe models can often answer important questions for cities by providing the methodology and standards needed, which will, in turn, allow local, regional and national academics to build or apply the necessary catastrophe models. Cities can use Oasis Loss Modelling Framework to predict economic losses and to clarify the uncertainties with regards to risk decisions.

Anytown Framework (Hogan, 2013)

The Anytown Framework, as used by the London Resilience Group, can provide cities with a useful resource to initiate discussions and develop workshops on the topic of interdependencies. Anytown workshops were held bringing together various sector experts and practitioners that operate in London and beyond to discuss the potential implications of disruption to infrastructure. London Resilience Group has created a model to help facilitate and map these discussions that can also be used by other cities to identify stakeholders needed for an interdependencies analysis as well as providing a useful resource on structuring the discussion. The webpage provides the final report and visual diagrams produced from workshop discussions. It is free to access and has been used since by other cities such as Toronto.

DOMINO (Polytechnique Montréal, n.d.)

DOMINO is a decision support tool that aims to anticipate and model the spatial and temporal spread between infrastructure systems with cascading impacts within the first 72 hours that follow a predicted incident. It covers sectors such as electricity, gas, water, telecommunications and transportation but can also include dependent infrastructure such as banks and hospitals. DOMINO was created as a planning tool, rather than intervention or emergency management tool. However, it has been used to analyse both the impacts of maintenance works on especially critical networks across the city and the effects of the water department's retrofitting work on other networks. DOMINO is not open access but its success has drawn attention from the Canadian federal government, which is looking to roll this out further in other Canadian cities. The tool was the product of a unique partnership between Montréal's critical infrastructure managers, the Civil Protection Centre of Montréal and the Centre risqué & performance of Polytechnique Montréal, and this collaboration, as discussed in chapter 4, is a key learning point for other cities.





6. CLIMATE

INTERDEPENDENCIES AND INSURANCE

Cities are centres of economic growth and comprise high-value assets and these interdependent assets and infrastructure must be safeguarded against climate risks to reduce post-disaster economic losses and enhance recovery. Insurance is, therefore, a critical financial instrument within disaster risk financing as it allows for residual risks to be managed after risk reduction, adaptation and risk retention approaches are implemented.

Throughout our study and in working with AXA, a common theme that emerged was the role of the insurers in risk pricing critical infrastructure in cities. In this chapter, we discuss the needs of both insurers and cities and how they can work together in understanding and quantifying losses from climate risks on interdependent infrastructure.

Working Together on Assessing Interdependent Infrastructure

The relationship between cities and insurance companies can be reciprocal. Beyond the obvious interaction between cities and insurance companies, whereby cities' infrastructure is insured against climate hazards and insurance

companies gain clients taking up their products, there may be opportunities for other exchanges. This might include collaboration or cooperation in the areas of risk modelling, data analytics, risk quantification, adaptation and resilience option design and data collection practices.

Making the case for planning

Interdependencies are likely to compound risks that increase the likelihood and scales of economic losses. The risk modelling capabilities of the insurance sector can, therefore, be critical in helping cities to avoid catastrophic climate impacts. From a funding perspective, the quantification of interdependencies in terms of their financial consequences can equip adaptation departments within cities with the knowledge to better engage budget committees and city treasuries. This could allow for an increase in adaptation finance and finance to address interdependencies to be stimulated from the public budget.

In terms of longer-term planning, cities can construct new infrastructure in ways that reduce interdependent risks, thereby decreasing the exposure of a city to climate hazards. This may also, reduce larger economic losses accruing from high-severity, low-frequency events, thus

maintaining the profitability of disaster risk insurance products. The reduction of larger economic losses could also result in less risk transfer by primary insurance to reinsurance markets which may also enhance profitability. This reduces the cost to cities and keeps cover viable in the long term.

Understanding adaptation costs and benefits

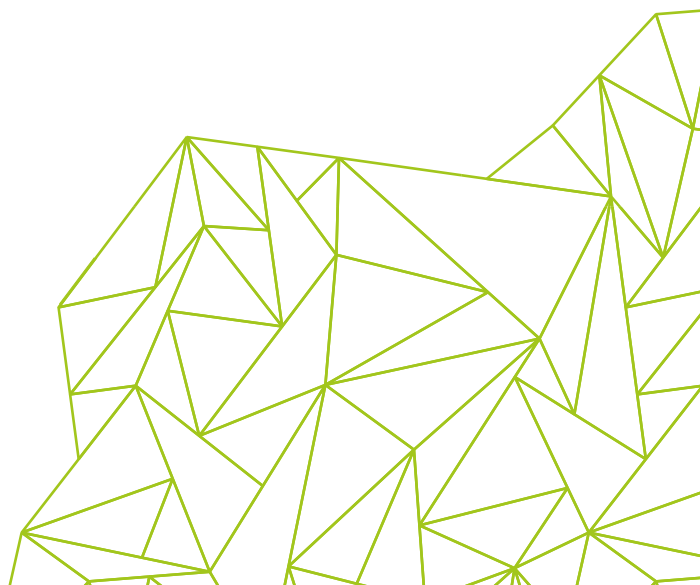
One difficulty for assessing interdependencies, and for adaptation generally, is the risk reduction analysis accruing from the implementation of an adaptation action. Measuring the risk associated with a given action is critical to understanding whether the reduction of vulnerability and exposure of a city are 'real' – and whether cities are fulfilling their public goods mandate. From a city perspective, insurance companies can guide cities in terms of risk information and quantification methodologies useful for the design of adaptation and resilience programmes. The implementation of adaptation and resilience options will also allow insurance companies to reduce the risk exposure of cities and their infrastructure systems with coverage against climate hazards, thereby increasing the time horizon that certain risks may be insurable under future climate scenarios.

The implementation of adaptation options may not yield 'real' return on investment; rather the risk reduction is captured in avoided economic losses. Reduced insurance premium costs may be another way in which cities receive a financial benefit from adaptation implementation. Accounting for adaptation and resilience in terms of reductions in premiums remains a challenge for insurance companies because of the lack of data and research focused on quantifying the risk reduction benefits. Insurers and cities can work together to co-develop monitoring, evaluation and reporting (MER) methodologies to evidence the risk reduction benefits that adaptation and resilience measures deliver. This will ensure that cities and their sectors reap the financial rewards from adaptation and resilience implementation and insurance companies can better design their products while reducing their economic loss exposure.

Data sharing between cities and insurance companies

While intellectual property law and competitive advantage concerns between private utilities within city sectors make data sharing between cities and insurance companies difficult, there are clear benefits for both the insurance sector and cities. The economic loss data held by insurance companies can provide cities with useful insights to help in the planning of adaptation and resilience measures and to ensure that implementation is targeted in terms of location and sector focuses. Similarly, insurers look at infrastructure and their compounded risks from an asset point of view. The underlying asset needs to be identified to price its risk, but insurers may not know exactly which asset should be priced. This is where the collaboration

Insurers and cities can work together to co-develop monitoring, evaluation and reporting (MER) methodologies to evidence the risk reduction benefits that adaptation and resilience measures deliver.



with the asset owner – public sector or private – is important: they can provide insurers with a picture of exactly what they want to protect and what assets are at risk.

Furthermore, insurance companies may already possess insight into known risk reduction measures and behaviours that allow for premium cost reductions, particularly for more traditional climate hazards such as floods and droughts. The communication of these measures to cities can help decision-makers within city sectors to better design policies supporting risk reduction of infrastructure that has cascading impacts. For example, building infrastructure in future floodplains under climate scenarios maybe disincentivised by insurance companies while the implementation of zoning laws may reinforce this sentiment by prohibiting the construction of infrastructure in these areas.

What methods of insurance can cities use for climate risk protection?

Parametric insurance is based on the use of a parameter that is correlated to the client's damages or financial losses to create the most relevant cover. It has existed since the 1920s, when agricultural payouts were made to Indian farmers following periods of low rainfall and subsequent drought. Historically, rainfall (the climatological parameter) would be measured, and deficits in the required rainfall of that period would trigger payments to farmers, protecting them from uncontrollable environmental losses. Since then the quantity and quality of data has increased significantly allowing insurers to structure coverage which reflects the actual loss.

Parametric insurance differs from traditional indemnity-based insurance where an asset is insured and, after an incident, a loss adjuster will quantify the actual loss and provide a payout. With parametric insurance, a pay-out is pre-agreed, so the insured party is aware beforehand of the amount they will receive in the case of a triggering event occurring. Parametric insurance solves the dilemma of asymmetric information and the underlying challenges of traditional insurance which can lead to moral hazard, fraud and anti-selection.

Challenges in collaboration between cities and insurers

The development of parametric insurance products has increased the transparency of insurance, although issues remain around payout triggers. In certain instances, damages caused by different environmental parameters may result in confusion among policyholders. In the case of Haiti in 2008, economic losses from Hurricane Ike were caused by flooding (water) and not wind, therefore payouts were not triggered (World Bank, 2010). Payouts may also not occur if the threshold is not exceeded. For example, in the case of Hurricane Dean in 2007, Jamaica did not receive a payout from the Caribbean Catastrophe Risk Insurance Facility because the wind speed was insufficient to result to trigger one (World



BOX 4

Insurance loss data sharing with local authorities in Oslo

The holistic risk landscape in Norway involves multiple stakeholders including government, local authorities, public agencies and the private sector. The engagement between insurance companies and municipalities began with a series of small workshops including all stakeholders.

The City of Oslo faces several adaptation challenges, which include excess surface water and storm surges. Furthermore, the lack of vulnerability assessments and socio-economic and cost-benefit analyses hinders the ability to implement sound climate adaptation measures. To overcome this

insurance loss data was used to strengthen the climate adaptation and prevention efforts of municipalities.

Using the damage data from insurance companies the city improved its understanding of why, how and when damages occur, and helped it to prioritise adaptation measures. The use of insurance data allowed for greater precision and accuracy in mapping and identifying risk zones – compare, for example, figure 6(A) with 6(B) in which only data from the City of Oslo was used.

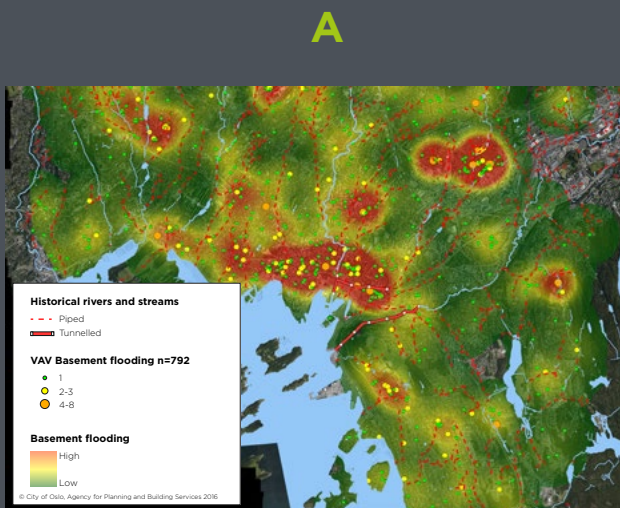


Figure 6 (A)

City-data economic losses.

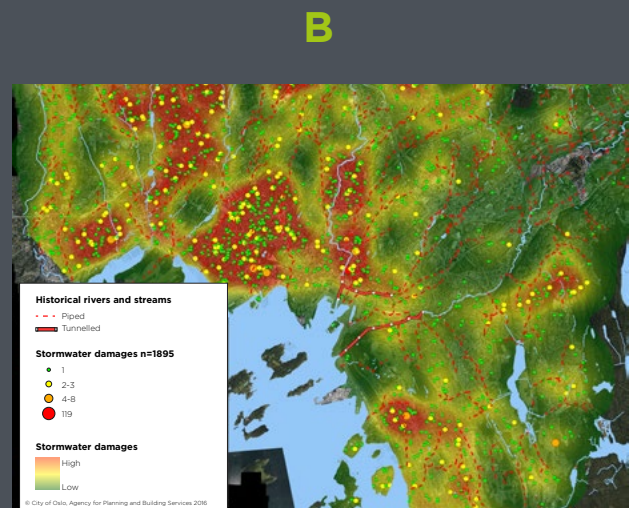


Figure 6 (B)

Insurance sector data on economic losses.

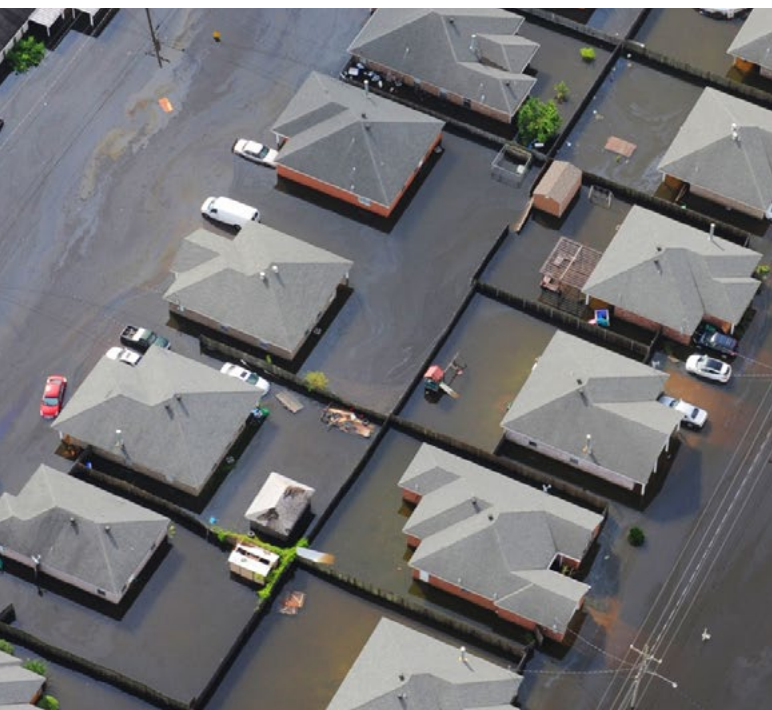
Source: Hauge et al. (2018).

Bank, 2010). Qualitative data regarding the narratives of payouts that did and did not occur can enable an understanding of underlying causes of economic losses and damages, which may allow cities to select and design the appropriate adaptation measure that addresses the risk and not simply the hazard. The imperfect correlation between the triggering event and the actual loss is called basis risk and while insurers know this challenge, sovereign and sub-sovereign entities or private utility/service providers should also be clear when structuring the coverage. The insurance coverage can be refined and adjusted to the needs of the insured.

With regards to floods, there is no existing flood model on the market when insuring climate risk in cities. This data needs to be provided otherwise it is difficult to comprehensively assess an insurance policy from an insurance perspective. Flood payouts are, as a result,

often linked to precipitation in a certain area, sometimes combined with water levels of a river. Insurers assess the surroundings of infrastructure such as rivers and coasts and look at a specified area. Data is taken from weather stations or satellites to base insurance premiums on rainfall, but not on the flood itself. As flood is determined by many factors, insuring against floods can be a complex exercise.

Finally, it is important to note that cities must adopt a holistic approach (see box 4). Insurance is one solution, but not the only solution, nor is it the first step in understanding and addressing interdependencies. From a risk reduction perspective, simply relying on insurance policies means cities are not reducing the climate risk at all; it means you are not protecting the city and citizen against risks.



Insuring climate risks

With regards to floods, there is no existing flood model on the market when insuring climate risk in cities. This data needs to be provided otherwise it is difficult to comprehensively assess an insurance policy from an insurance perspective.



At times prevention is too expensive and the hazard probability is too low (in cities), that's when insurance comes into play. But generally, cities need a holistic approach; insurance is one of the solutions but not the only solution or first step

Antoine Denoix
CEO AXA Climate



CONCLUSION

To achieve long-term climate resilience, it is vital that cities understand the interdependencies of their infrastructure systems – and what their critical points of failure are. Cities are continuing to expand, and the breakdown of a single part of an infrastructure system – within even high-capacity cities – can rapidly deplete their ability to stage an effective response.

Interdependencies analysis from a climate risk perspective presents several challenges. It requires effective participation across a wide range of city operations and external stakeholders, as well as complex and evolving datasets, which are needed for evidence-based decision making. It requires access to accurate, reliable and comprehensive data which presents many challenges – from collection and access through to use. Another key barrier mentioned by cities, is a lack of capacity and resources.

There are, however, examples of several best practices that tackle these governance, data and resource issues. Establishing strong partnerships is crucial to addressing the interdependencies. Public-private partnerships can often provide the funding, data and resources that cities lack and which are critical for understanding and addressing infrastructural interdependencies. Within these public-private partnerships, the role of insurance should also be explored further. In this report, we introduced several ways in which insurers and cities can work together to assess and quantify climate risks to assets and infrastructure.

This research captures the latest and cutting-edge best practices from cities on the ground and provides recommendations and resources to advance the understanding of infrastructure interdependencies. Although not every solution presented will apply to every city, these best practices provide a menu of options or ideas for cities to consider, based on their context and the particular challenges they face in understanding their infrastructure interdependencies to strengthen climate resilience.

As the risks from climate change increase, understanding and acting on infrastructure interdependencies is crucial now more than ever. Cities need to collaborate with the relevant stakeholders to map out and quantify their interdependencies and identify where the critical points are that can lead to system failure. This report calls upon cities and all relevant stakeholders to review urban systems from a climate risk perspective to avoid system collapse in the face of inevitable extreme events and disasters.



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Appendix I: Methodology

Desktop Review

We carried out an initial desktop review to understand infrastructural interdependencies in cities and how cities are including interdependencies analysis in their city planning. The review focused on the adaptation plans of 49 C40 cities across the world and also looked at additional articles, reports and other literature recommended by AXA and C40 experts. As the desktop review progressed, we found that in many cases the adaptation plans did not reflect the entire picture of cities' understanding and work on infrastructural interdependencies, and there was a need to collect additional data.

City Surveys

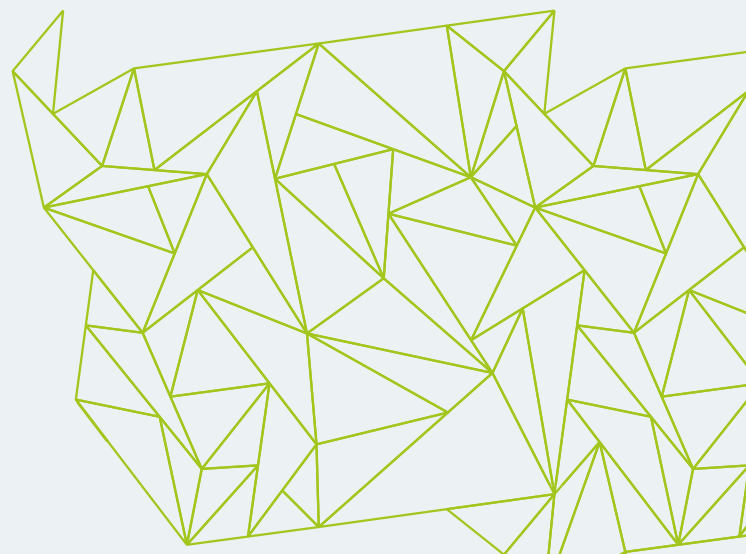
The city surveys aimed to collect additional information from cities that was not being captured in their adaptation plans and to ensure that there weren't other city documents that would need to be reviewed to understand cities' efforts on interdependencies. Although the adaptation plans of 49 C40 cities were reviewed, the survey was shared with only 53 cities that are a part of C40's adaptation networks and have adaptation plans. This was based on the assumption that cities interested in the topic of interdependencies are already part of C40 adaptation networks; focusing on these cities would allow us to assess the willingness to participate in the project and shortlist a few best practice cities. The survey results delivered on all of these goals. We saw a significant gap between the information provided in the adaptation plans and that provided via the survey, with the latter being more detailed. The survey also provided valuable information to inform work on interdependencies beyond this study: the information about barriers (outlined in chapter 2) also provided a clearer picture of what solutions and recommendations might be useful to cities.

City and Expert Interviews

Based on the survey responses, we then selected cities with which to hold interviews. We interviewed 11 cities, all at varying levels of progress, from those that are just starting an interdependencies analysis to those that are more advanced and could provide recommendations to other cities. This allowed us to get a broad sense of the challenges facing cities at different stages and to identify possible solutions. We reached out to C40 network managers, who provided information on how cities within C40 networks have been engaged with the topic of interdependencies. This allowed us to establish what knowledge and data might be available to cities to help them conduct a robust interdependencies assessment and provided insights for cities that previously noted identifying data as an issue.

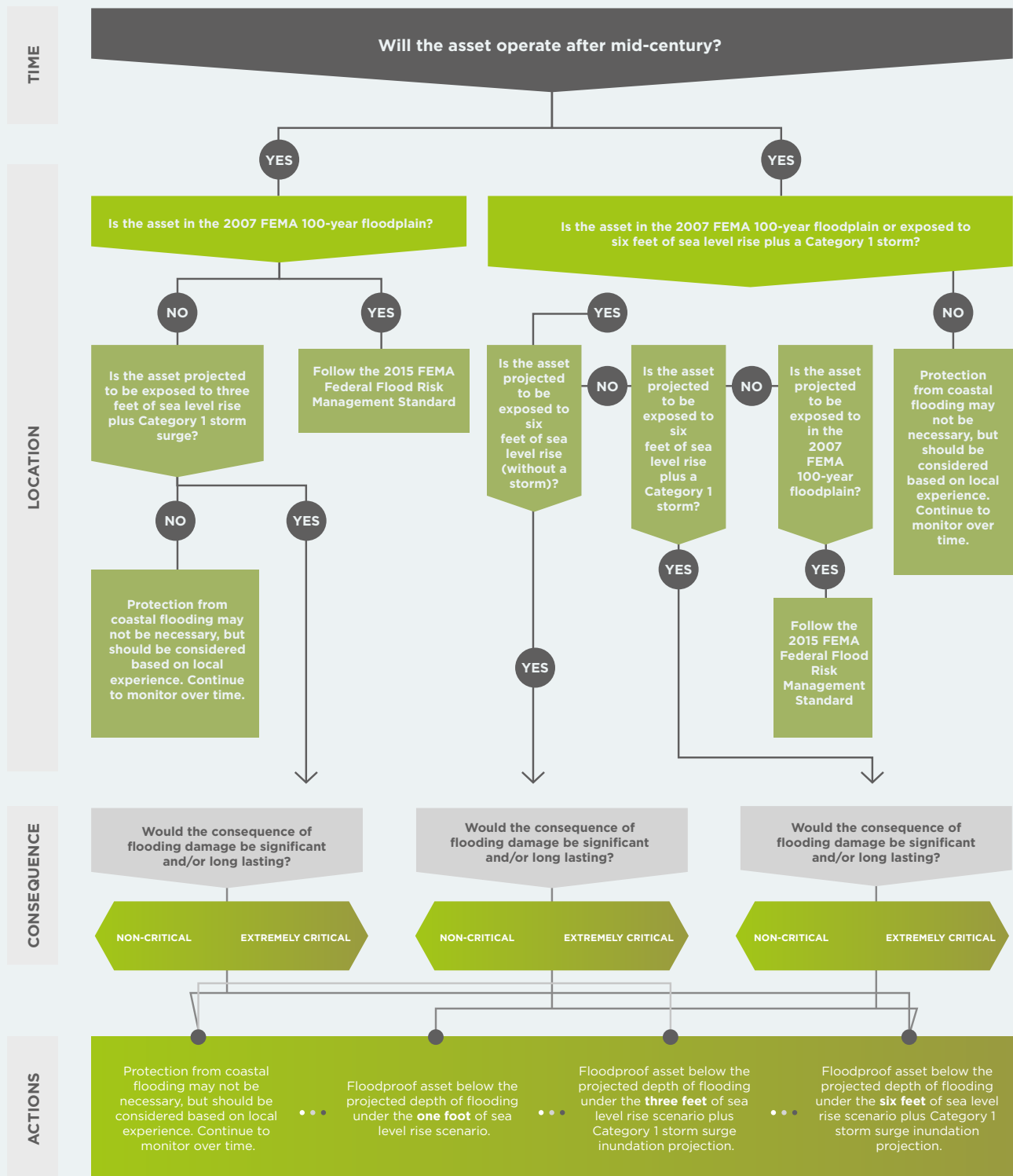
Analysis

After conducting 23 interviews with 11 cities, 9 C40 network managers and 3 industry experts, interview results were reviewed and analysed. Key themes emerged across the cities as did recommendations and best practice solutions where cities had responded to particular challenges or barriers mentioned by others. Figure 7 below shows the flood protection planning guidance Philadelphia has developed to identify concrete interdependencies actions demonstrating reduced risks to critical assets.



Appendix II: Example of interdependencies planning to safeguard assets

Figure 7 below shows the flood protection planning guidance Philadelphia has developed to identify concrete interdependencies actions demonstrating reduced risks to critical assets.



Match range of flood protection actions to consequence of failure.

FIGURE 7

Flood protection planning guidance

(adapted from *Growing Stronger: Toward a Climate Ready Philadelphia*, 2015).



UNDERSTANDING INFRASTRUCTURE INTERDEPENDENCIES IN CITIES

