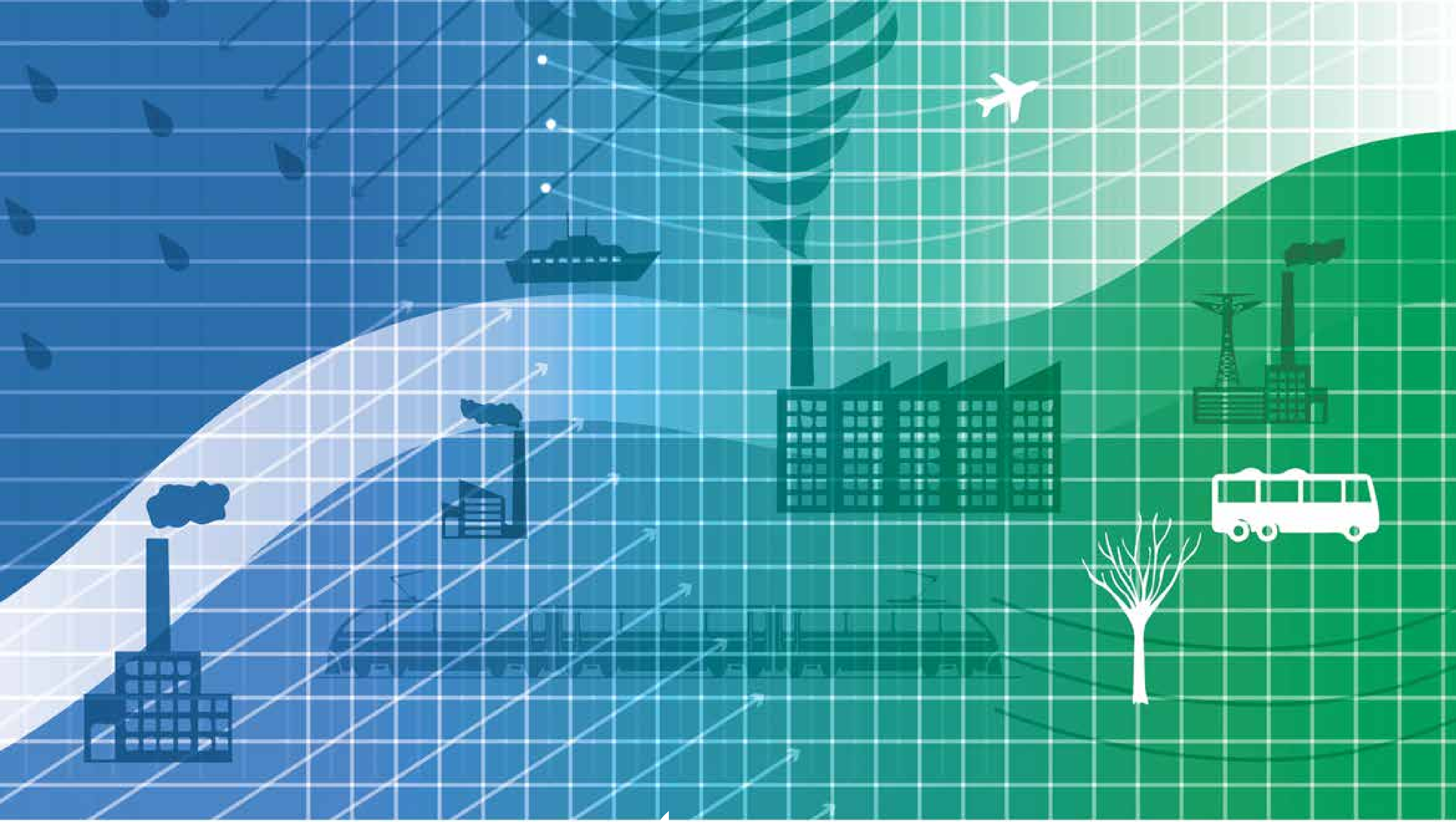

wbcsd climate & energy

Building Resilience in Global Supply Chains

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Foreword

Research conducted by the WBCSD shows that a growing number of businesses are aware of the direct risks to their own facilities and operations from extreme weather events and projected climate change. However, fewer have strategies to understand and manage impacts in their supply chains, despite the fact that climate risks are systemic in nature, affect many sectors and can create enormous financial and operational exposures.

The potential impact has been demonstrated by several recent events. The floods in Thailand in 2011 caused direct losses of US$43 billion and affected companies worldwide because they were unable to get key components [1]. Hurricane Sandy on the US East Coast in 2012 caused losses estimated at US$65 billion [2]. Droughts have affected agricultural production in key producing regions around the world in recent years, driving prices for many of the crops affected to record or near-record levels.

Individual extreme events such as these cannot be attributed directly to climate change. But the conclusions of the Intergovernmental Panel on Climate Change's Fifth Assessment Report are clear: the increase in global average temperatures is very likely to lead to more intense and frequent extreme weather events [3]. We are already seeing this.

Businesses must manage the resulting risks. However, businesses with global supply chains face many diverse, unpredictable and interconnected risks from the climate. The combination of climate unpredictability and complexity in modern supply chains means it is challenging to use the traditional method to estimate risks of all events at all points. The approach described in this report provides guidance from an integrated systems perspective to give companies the capacity to deal with stresses and to manage shocks by understanding their vulnerabilities to climate-related risks and by building resilience.

The framework draws upon two major case studies of supply chains with contrasting characteristics: one for a complex manufactured product; the second based on an agricultural commodity. We describe the complexities and analyze the climate vulnerabilities. The lessons from these cases are applicable and relevant to companies in a diverse range of sectors.

The report represents work led by ERM and DNV GL with the participation of WBCSD member companies. In addition to scoping meetings with members, we carried out a member survey, convened three workshops and sought external input and review from institutions with experience in building resilience. In taking a position on this important issue, we aim to encourage companies to lead by example. Such leaders will inspire others to build resilience throughout the supply network, and create the understanding of mutual dependence between businesses as well as between business and society. If leaders demonstrate how investment in resilience can bring competitive advantage, others will follow.

DNV·GL

Remi Eriksen, Chief Executive Officer, DNV GL

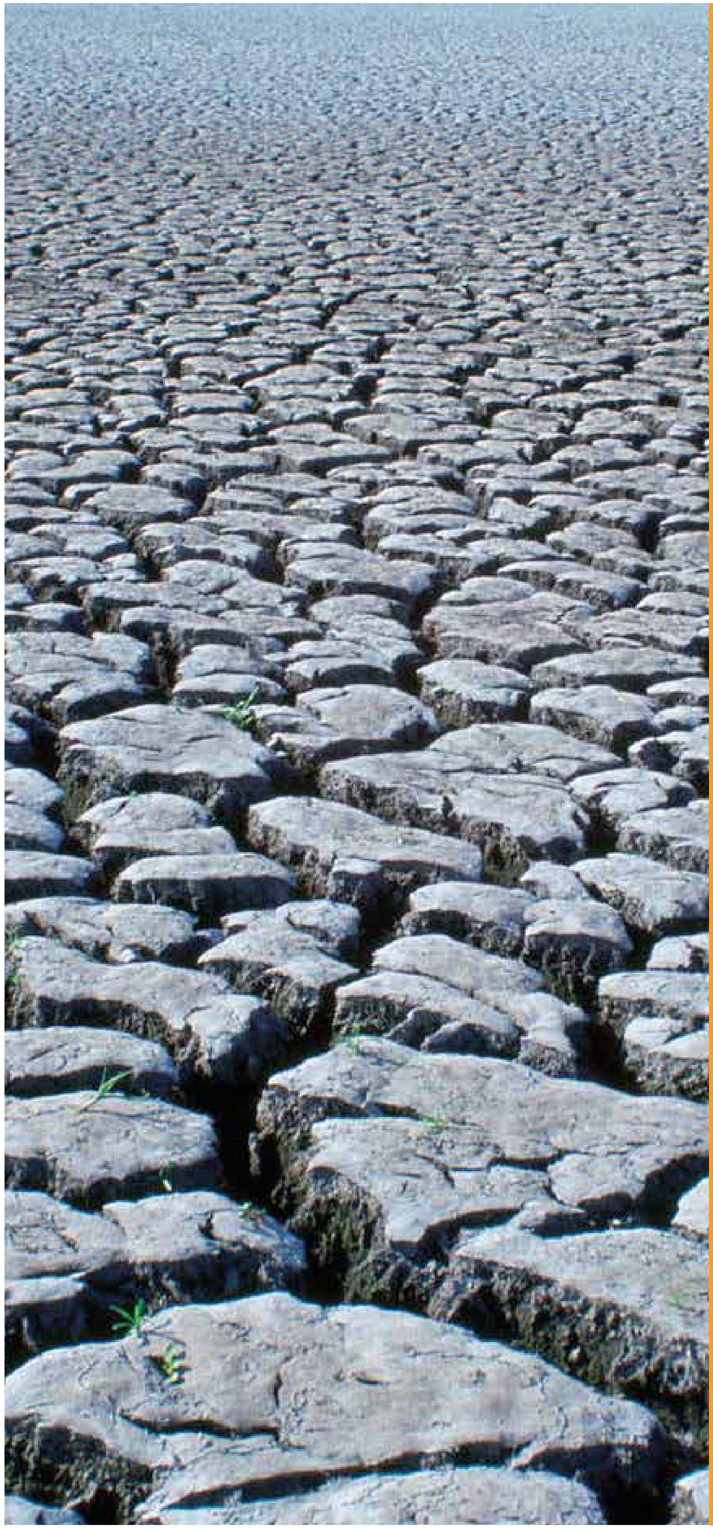
ERM

John Alexander, Chief Executive Officer, ERM

1 'Economic consequences of natural catastrophes: Emerging and developing economies particularly affected – Insurance cover is essential', Munich RE, 9 October 2013, http://bit.ly/1JB944L

2 Aon Benfield, Annual Global Climate and Catastrophe Report: 2012, http://bit.ly/1VvQznN

3 IPCC AR5 2014, Synthesis Report, Summary for Policymakers pp 7-11, at **http://www.ipcc.ch/**



WBCSD, climate change and supply chains

This project is part of **WBCSD Action2020**, a platform for practical and scalable action by business. Action2020 consists of business solutions which contribute to science-based societal goals.

We acknowledge that climate change is already here today, will become more severe before we see improvements, and requires action for business success and a prosperous society. Our climate change goal is to limit the global temperature rise to 2°C above pre-industrial levels, through developing (by 2020) energy, industry, agriculture and forestry systems that:

- Meet societal development needs
- Are undergoing the necessary structural transformation to ensure that cumulative net emissions do not exceed one trillion tonnes of carbon
- Are becoming resilient to expected changes in climate.

In 2008 the WBCSD published “Adaptation: An Issue Brief for Business”, providing an overview of adaptation from a business perspective. It described potential impacts of climate changes, risks and opportunities for business, and why business should consider adaptation planning and measures.

“Building a Resilient Power Sector” followed this work in 2014, exploring the climate risks electric utilities face and examining how the industry should act to build resilience. The report highlighted the risks of gradual climate change and severe hazards such as droughts, storms, flooding and rising sea levels. It drew attention to the danger that climate change could undermine the global supply chains that several other sectors rely on.

Summary for decision-makers

Climate change poses new and not widely recognized risks to global supply chains. The risks are wide-ranging and complex because of uncertainties about climate impacts and the complex structure of modern supply chains. They must be considered across the whole network as well as for individual assets and resources, and this requires an enhanced approach to risk management.

Building resilience helps supply chains withstand the shocks and stresses that climate change will cause. A resilient supply chain has:

- the capacity to deal with changes
- the ability to create new connections, and
- the presence of learning, collaboration, spare capacity and flexibility.

Modern supply chains are more vulnerable to disruption than in the past because of the many participants and because of factors such as just-in-time processes combined with physical distances between some activities. The interdependencies mean that disruption caused by a storm or drought at one remote location can bring a whole supply chain to a halt.

Climate change causes changes in average weather conditions as well as more frequent and more severe extreme weather events. This increases the risk of critical thresholds being exceeded, disrupting production and distribution, threatening employee health and safety and lost revenue throughout the supply chain.

The specific timing and location of weather events are unpredictable, making it impractical to assess and monitor the risks to the many assets and linkages in a supply chain. This requires a broader approach to risk management, focusing on the resilience of the network as a whole to create the ability to tolerate surprises and recover quickly from disruption.

A systems view can build the necessary understanding of the complex dynamics, behaviors, functions, interconnections and changes in the supply chain over time. This is the basis for being able to cope with highly uncertain hazards, using multiple connections and alternatives if a route is inoperable. It requires learning, collaboration, spare capacity and flexibility.
This report provides two detailed case studies to demonstrate the complexities and intersecting vulnerabilities which are typical in many industries and to illustrate the relevance of resilience in practice. Based on these case studies, insights from WBCSD companies and other research, we propose a five-stage framework for resilience (see figure 1).

Adaptation and resilience

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as: 'The process of adjustment to actual or expected climate and its effects'. Resilience is 'The capacity of … systems to cope …. responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation'.

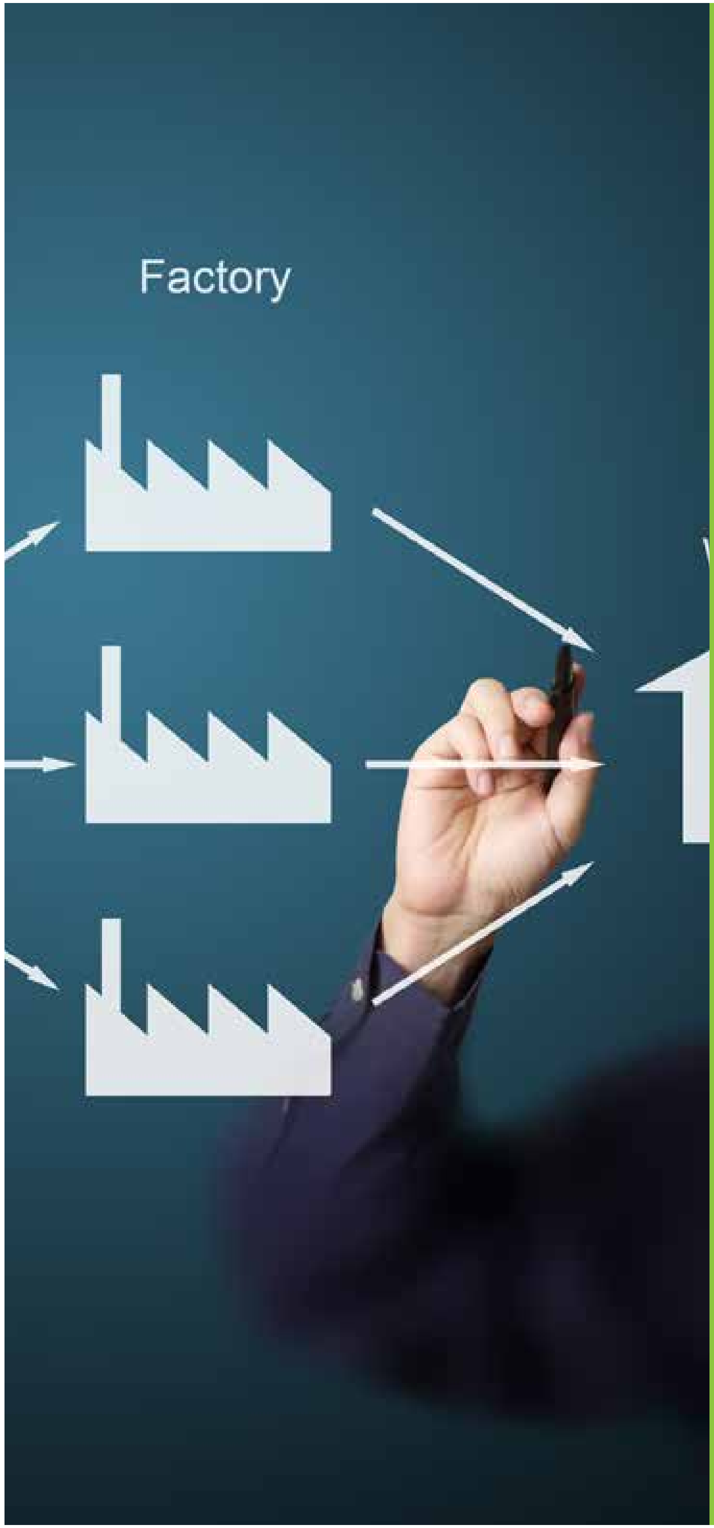
Adaptation is therefore a process which increases resilience and resilience is about the ability to restore functionality after disruption as well as reducing vulnerability. Resilient systems continually adjust to threats so they are able to recover swiftly.

Figure 1: A framework for building resilience to climate change

The first step is to gain an appreciation of the principal material and information flows, stocks and locations as well as to distinguish the critical features. Second is determining the weather-related hazards to individual nodes. The third step identifies vulnerabilities and leads to the fourth step, which is the development of resilience building measures. The fifth step is to monitor and review the measures.

Supply chains are only as strong as their weakest links and it is therefore necessary to encourage all participants to understand and address their vulnerabilities, turning mutual dependence into mutual competitive advantage. This requires action, to:

- learn from the case studies and examples from companies that are already taking action
- understand how climate change hazards affect a supply chain, and
- focus on how to reduce vulnerability and build resilience to climate change.



Chapter 1. The growth and complexity of global supply chains

- **Global supply chains are complex and interconnected**
- **They are only as strong as the weakest link**
- **Several aspects are making them more vulnerable to disruption**

The modern, globalized economy has developed interconnected and complex supply chains. Companies have developed networks with greater physical distances, more interconnections and more participants cooperating and competing with each other. Activities range from primary resource extraction and harvest to transport, manufacturing or processing, assembly, storage and retail. Several enabling functions are also involved, managing aspects such as standardization, security, finance and insurance.

From simple chains to complex networks

At the beginning of the twentieth century, manufacturing empires such as Henry Ford's were linear, integrated and conceptually simple. Ford owned not just the factory that made the cars, but also the steel mill that made the sheet metal and the mine that produced the iron ore for the steel. The materials flowed from the mines to Ford's factories and cars flowed out of the other ends to customers.

By the middle of the twentieth century, businesses accepted that they could not be the best in everything and began to concentrate on their core competences and added value. They sourced components from other suppliers and increasingly outsourced services as well.

As globalization developed, shipping costs dropped, technology transformed communications and regions such as Asia industrialized, supply chains became networked, disaggregated and more complex. No single company owned the entire supply network. Following Toyota's example, companies introduced just-in-time deliveries, lean inventory levels, improvements in quality management and strong relationship with suppliers and customers.

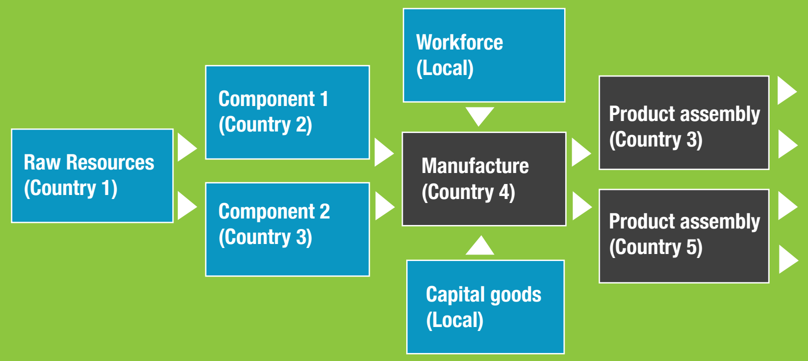
The 21st century has seen "onshoring" beginning to reverse the trend to greater physical distances as brand owners continue to search for the best combination of cost, quality and risk. But networked, disaggregated supply chains remain the norm.

Actors and components in today's supply chains

A network of suppliers cooperate and compete to extract or grow the primary resource, to process and manufacture it and many other ingredients or components, to transport and store intermediate and finished products and to sell to the end user. Therefore, "supply web" is a more accurate term than supply chain. Enabling functions such as security and finance are important elements of this web.

Technology is another vital element. Technological developments have made it possible to cope with extreme complexity. Tools such as enterprise resource planning systems and advanced shipment notification help manufacturers to keep track of activities. These tools have resulted in improved information exchange, better service levels, reduced inventory levels and lower costs.

Figure 2: Illustrative example of a global and defragmented supply chain network



Characteristics vary, depending on the nature of the products – perishable, high fashion, leading brands, or less differentiated manufactured goods. But all modern supply chains have the same fundamental building blocks, shown in simplified form in Fig 2.

The building blocks are:

- **Stocks** (light blue in the diagram) of raw resources, intermediate materials, finished goods and reusable 'capital' goods such as tools, equipment and people involved in the supply process.
- **Flows of**
  - materials – physical flows of parts and products along the supply chain, ultimately to the retailers (the white arrows)
  - money – in the opposite direction up the supply chain
  - information – flowing both upstream and downstream
- **Rules, regulations and delays –** Interactions are governed by a variety of national laws and regulations, international agreements, commercial contracts and industry practices. Delays occur due to physical transfers and the distances often involved as well as physical, organizational and regulatory interruptions and the following specific vulnerabilities.

Vulnerabilities

Supply chains have always been vulnerable to disruption from a variety of sources, including adverse weather affecting crops but also services such as ocean transport or power generation facilities. The scale and nature of modern supply networks have increased these vulnerabilities. A supply chain is only as strong as its weakest link. Several aspects make them vulnerable to cascading failures, with a relatively minor issue at one point in the network causing increasing problems throughout. These are:

Globalization – businesses source parts and services from a huge number of locations across continents. Greater distances, more participants and many time zones make it more difficult to control the risks.

Geographical concentration – activities and industry sectors cluster together in concentrated geographical areas. Disruption in one locality by strikes, social unrest or weather can knock out entire industries.

Complexity – more participants in a supply network, more parts, sizes, styles and product options and more frequent changes make it more difficult to predict the likelihood and consequences of disruption.

Just-in-time processes – lower buffer stocks makes the supply chain less able to withstand shocks.

Transport – goods are transported by road, rail, air and sea. The infrastructure in many parts of the world is old and fragile and therefore vulnerable. However, even new or old but well maintained infrastructure can be severely affected by the consequences of climate change due to designs that follow standards developed decades ago and that are now insufficient to resist the changed weather conditions.

Narrow scope – many supply chain participants have a limited perspective, their horizons restricted to their immediate links in the supply chain, with little attention to the overall system. An excessively self-interested supplier can be a weak link, undermining resilience in the supply network.

Information – complex, interdependent, dispersed networks are dependent on information exchange. However, the supply chain is often poorly integrated and processes are disconnected, with little transparency and information sharing.

Understanding supply chain complexity

Many companies have gone to great lengths to understand and act on environmental and social supply chain risks, which can have direct and indirect impacts on their business. As a result, they know much more about their supply chain than in the past.

Driven by scandals such as child labor, unsafe working conditions and poor environmental protection, companies invest in monitoring and measuring supply chain conditions and include social and environmental clauses in contracts.

Companies such as H&M, HP, Unilever, Coca-Cola, DuPont, Mitsubishi and Walmart have integrated sustainability in supply chain management, implementing standards to demonstrate a commitment to responsible business practices. Leadership from such companies has encouraged whole industries to address supply chain responsibility. Organizations such as the Electronics Industry Citizenship Coalition and the Sustainable Agriculture Initiative Platform have led moves to improved supply chain management in their sectors. At the highest level, more than 8,000 businesses in approximately 145 countries have signed the United Nations Global Compact, whose 10 principles cover human rights, labor rights, environmental protection and anti-corruption.

Applying these principles leads to more resilient supply chains. But only the most forward-looking companies have extended supply chain analysis to climate change risks. Now, as the threat of climate related disasters increases, supply chains must evolve again to factor in resilience and robustness.

Chapter 2. Climate change and business risks

- **Changing climate conditions create new and enhanced vulnerabilities in supply chains**
- **The scale, timing and local impacts are uncertain**
- **Businesses face serious consequences from many aspects of the changing climate**

Weather fluctuates around long-term averages and has always included occasional extreme events such as flooding, heat waves, drought and cyclones. The frequency and severity of such events has been relatively predictable within critical coping thresholds.

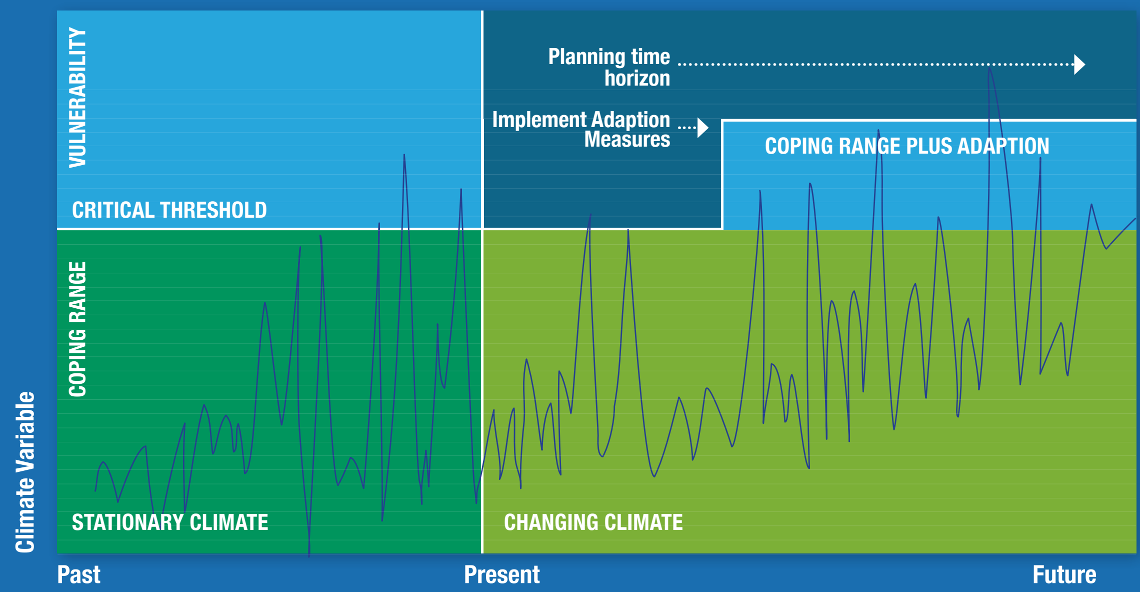
The critical threshold is the point beyond which the consequences are unacceptable. Thresholds may be natural, such as the water level at which a river bursts its banks or a temperature above which machinery cannot operate effectively, or based on risk attitude, such as the frequency of coastal flooding.

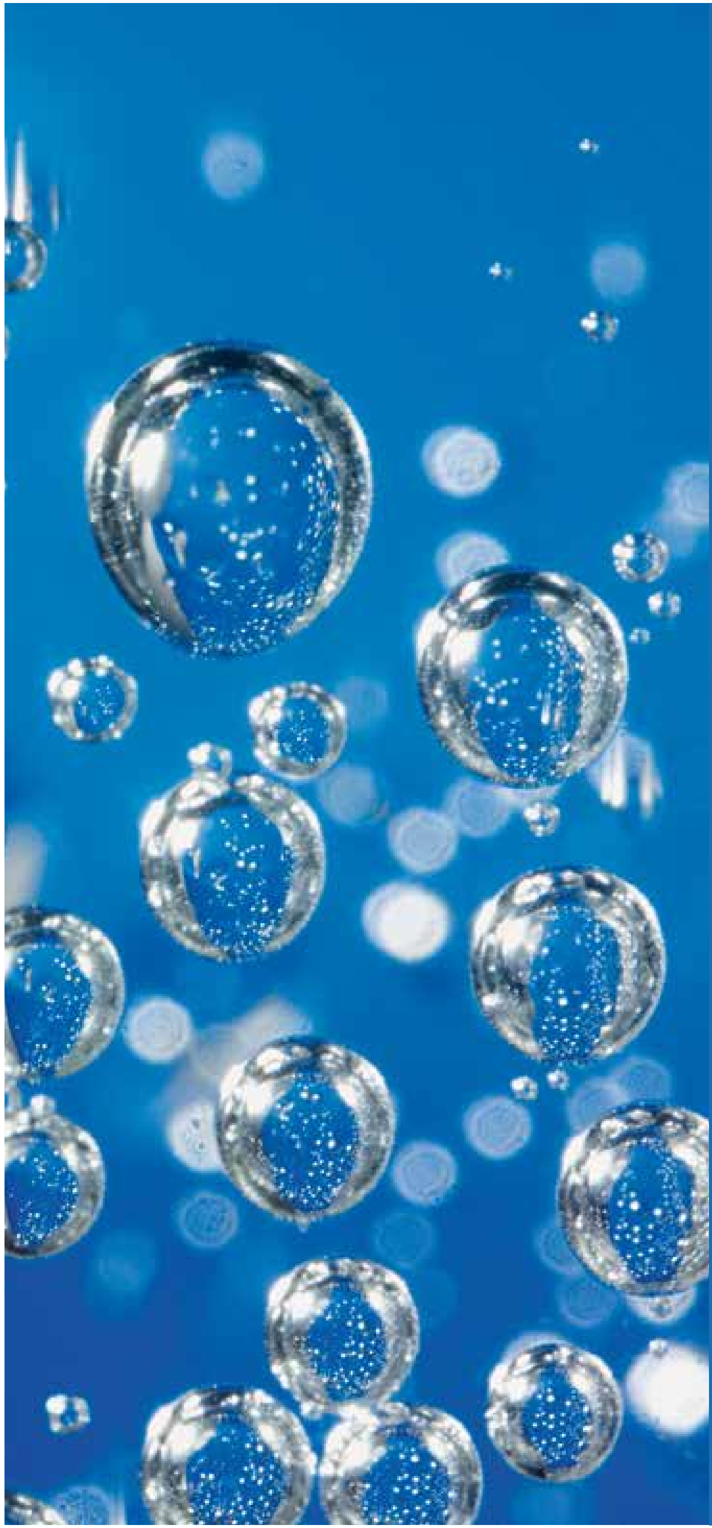
Exceeding critical thresholds

Climate change is causing more frequent and more severe extreme weather events, increasing the likelihood of critical coping thresholds being exceeded. A threshold such as 200mm rain in 24 hours or 160km/hour wind speed is likely to be breached more often and/or more severely compared to 20 years ago. This will be even more likely in future, as figure 3 illustrates, making it essential to introduce adaptation measures.

Climate change is already affecting the financial performance of companies and their suppliers and the environmental and social context they operate in (see examples 1-3). In the past, this was a minor business risk for most organizations. The increasing frequency and severity of disruptive weather events and the projected changes in long-term average conditions are creating a new and business-critical context. Potential impacts on supply chains are among the least recognized of these risks.

Figure 3: Climate change increases the likelihood of exceeding critical coping thresholds





Climate scenarios

The main driver of global warming is the total amount of carbon dioxide and other greenhouse gases in the atmosphere. The concentration of these gases will continue to rise, even with ambitious plans to replace fossil fuels with renewables.

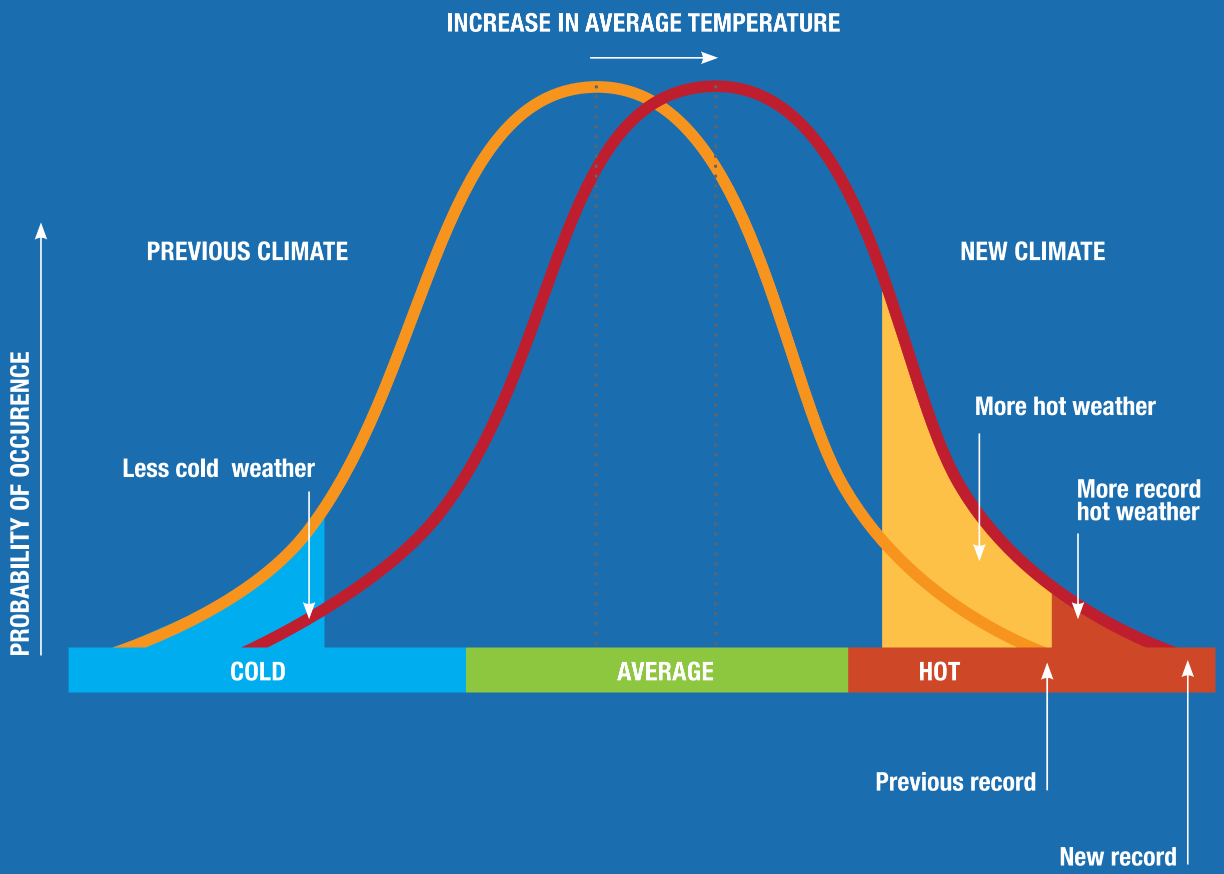
Current emissions are taking us on a higher path even than the most pessimistic of scenarios produced by the Intergovernmental Panel on Climate change (IPCC) which represents rapid population growth and slow adoption of new technologies. The most optimistic scenario is based on emissions peaking in the early 21st century and then falling rapidly.

These result in global average temperatures higher in 2100 than in the pre-industrial era by:

- 3.2 to 5.4°C if emissions are unmitigated
- 0.9 to 2.3°C if there is very strong mitigation

As we have already experienced 0.85°C of global warming it is clear that the climate we have been used to is already changing and will change further.

Figure 4: The effect of a small shift in the normal distribution [4]



Globally we can expect more frequent and severe heat waves and droughts, more intense storms and flooding, and higher sea levels. Figure 4 illustrates that even a small shift in the temperature distribution can result in very significant changes at the extremes. This makes it critical for communities and businesses to adapt the systems we rely on to make them resilient. Supply chains are one of those vital business systems.

Climate models are not able to predict the specific timing and location of weather events beyond the very short term. They aim to predict the statistics of weather over decades and longer. As a result, it is possible to assess the risks to specific assets such as a power station or a port from trend effects such as rising temperature or sea level. But supply chains consist of many assets and linkages which require a broader approach to risk management, focusing on the resilience of the network as a whole.

[4] The Critical Decade 2013: Climate change science, risks and response by Professor Will Steffen and Professor Lesley Hughes (Climate Commission), https://climatecommission.files.wordpress.com/2013/09/the-critical-decade-2013_website.pdf

Increasing business impacts

Changes in climate variables such as temperature and precipitation and extreme weather events may affect critical components of business activity, such as resources, processes, operational activities or infrastructure. Businesses may suffer infrastructure damage, project delays, constraints on water and energy supplies and lost production. The health and safety of employees may be endangered, reputation may be damaged and the social license to operate undermined. The financial impacts can be additional operating and capital costs and loss of revenue. Examples of the consequences and impacts of weather hazards are shown in table 1, while examples 1-3 highlight recent instances.

Table 1: Business impacts of changing conditions

Changing condition	Examples of consequences for business
More and more intense precipitation	Increased flooding in localized sites and more frequent landslides, damaging infrastructure and facilities, disrupting production and distribution.
Lower precipitation	Increased frequency of drought and scarcity of water resources, affecting hydro electricity generation and availability of water for production and causing tensions with local communities. The combination of drought and higher temperatures increases the frequency of wildfires, threatening facilities and employee safety.
Higher average and maximum temperatures	More heat waves during the hot summer months, affecting the performance of infrastructure and production facilities and increasing employee illness.
More intense storms/ cyclones	Increased wind damage for sites and transport networks, threatening employee safety, disrupting production and distribution.
Extreme waves	Changes in maximum wave height impacting coastal and offshore structures and shipping.
Sea level rise	Increased risk of coastal flooding, especially with storm surges, damaging infrastructure and facilities, disrupting production and transport networks.

Example 1: Thailand floods

In late July 2011, Thailand experienced severe flooding, causing widespread damage to local manufacturing industry. This severely disrupted the supply of components to the automobile, IT and other industries worldwide. It took many months for supplies to recover. HP lost approximately US$ 2 billion as a result, while NEC cut 10,000 jobs worldwide due to the global shortage of hard disk drives. While the immediate impact was on the hard disk manufacturers, the domino effect extended across the world and into consumers' pockets.

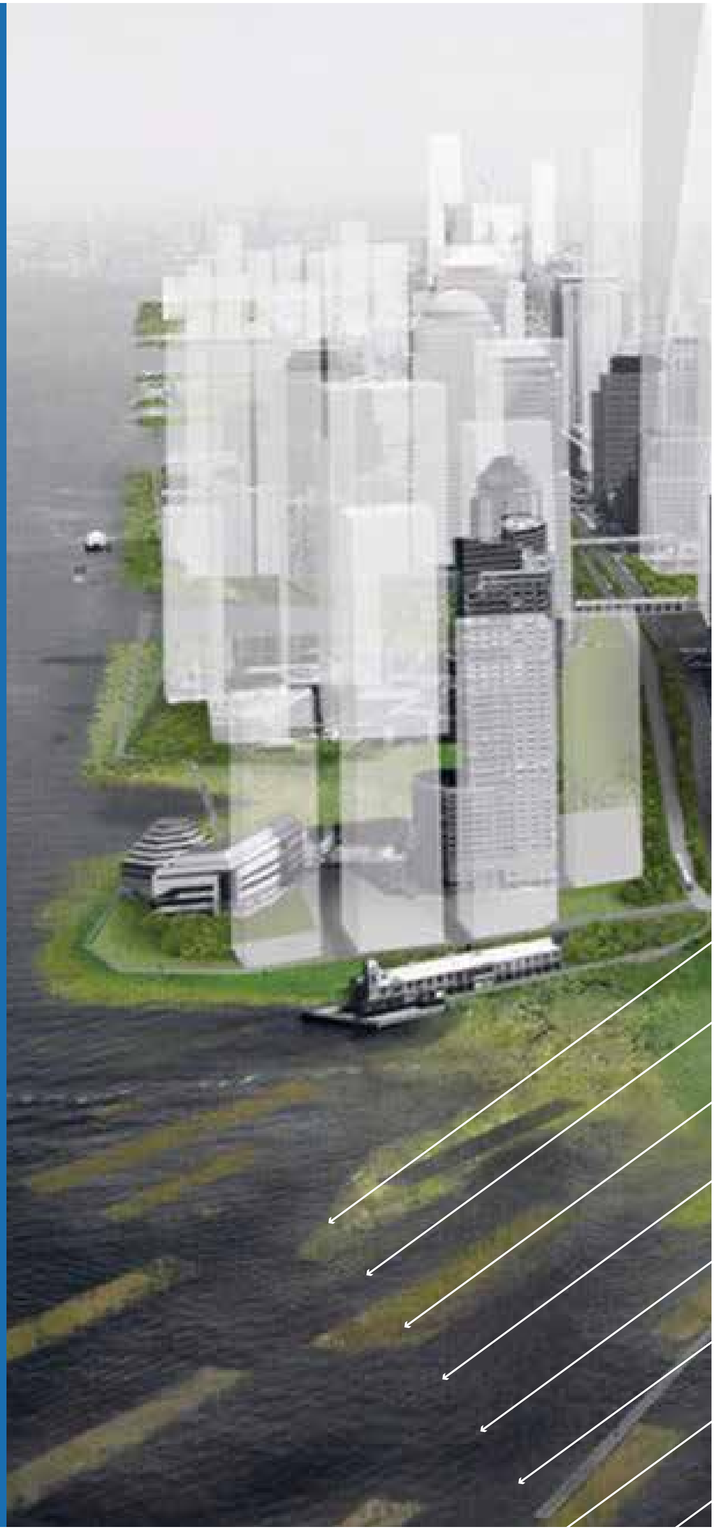
Example 2: Texas hurricanes [5]

Bayer's Baytown operation was affected by hurricanes Katrina (2005) and Ike (2008) even though the storms had minimal direct impact on the plant. The company found that production was affected by the impact on local communities. It saw that rebuilding a community after an extreme weather event is as important as procedures for safely shutting down and restarting the production facilities. Its response was to provide communities with resources including chain saws, flashlights, generators, ready-to-eat meals, water, first aid supplies, and cleaning supplies.

Example 3: Superstorm Sandy and the Port of New York [6]

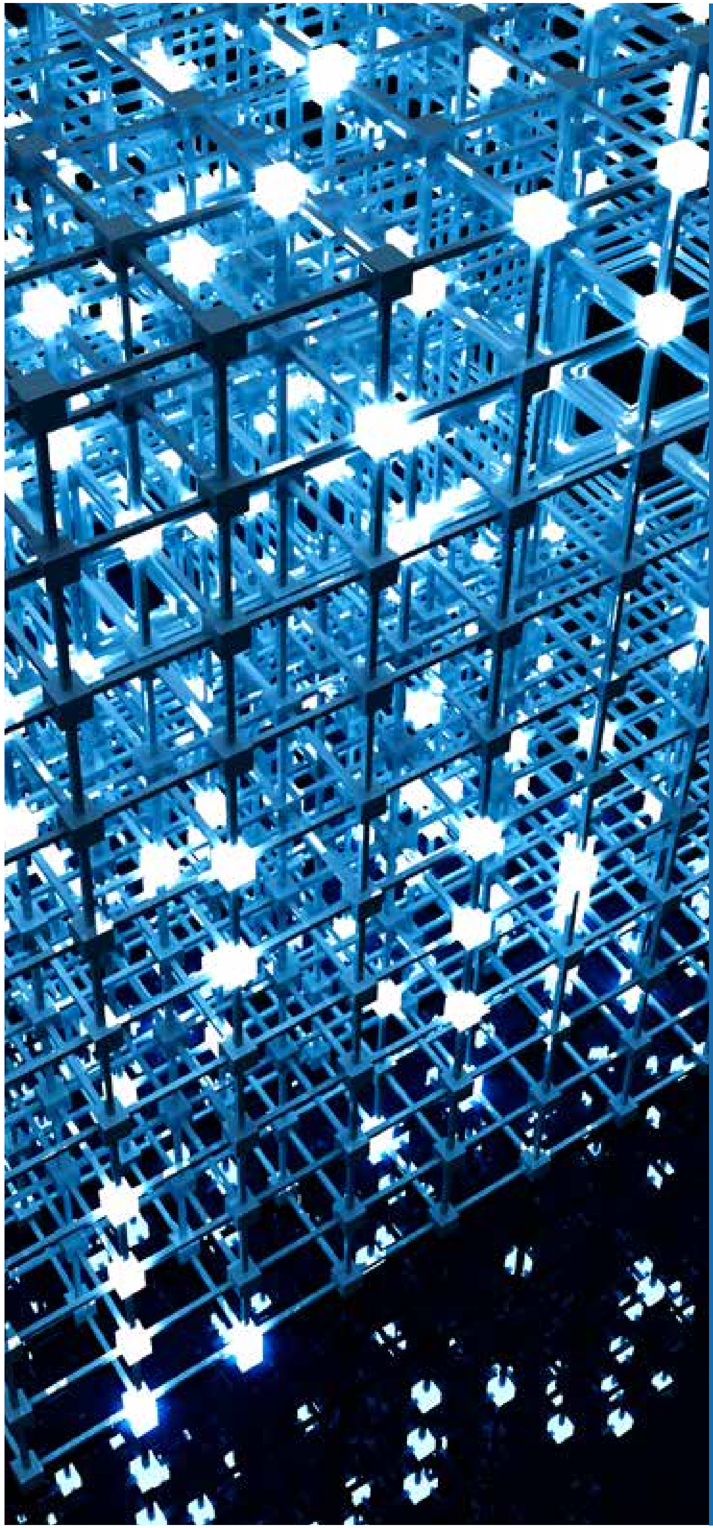
When Superstorm Sandy hit the New York area in October 2012 it disrupted maritime operations and facilities throughout the Port of New York and New Jersey and disrupted power supplies. In the port, the hurricane knocked out electrical equipment including traffic signals, cranes, and pumps that provide water for general use and fire protection. Rail transport to and from the port was halted, and about 16,000 cars were damaged at what is the largest automobile processing port in the United States.

In the city, the storm caused serious damage to generation, transmission and electricity distribution systems, as well as to customers' equipment. Approximately 55,000 customers lost power because of damage to electrical equipment in their buildings, disrupting supplies of goods and services to customers who were not directly affected by the storm. Total damages of $65 billion were attributed to this storm, making it the most costly ever.



5 Weathering the storm: Building business resilience to climate change' - C2ES (July 2013)

6 Extracted from: Christiansen, A. F., Pretlove, B., Bratcher, D., Bitner-Gregersen, E., Friis-Hansen, P., Garrè, L., Libby, B., Quan Luna, B., Urwin, C., and Aalbu, K. (2014): DNV GL Adaptation to a Changing Climate, Høvik, Norway.



Strengthening individual assets and operations

Adaptation measures include altering the physical design of a facility or infrastructure, implementing business procedures, and altering operating patterns. Measures at an individual facility could include:

- **'Hard' engineering features** incorporated during project design to ensure that the technical designs are stress tested in relation to potential future climate changes. For example, where flooding is a major risk, engineers may adapt a design by building flood defenses.

- **'Soft' administrative measures** incorporated into operational procedures or processes. For example, where there is increased risk of extreme high temperatures and heat waves, health and safety measures such as changing shift patterns to avoid working during the hottest part of the day.

- **Revised strategies.** In some cases, climate change may create opportunities and risks which warrant a rethink of the company's strategy. For example, the risk of extreme temperatures or water scarcity may require moving production to a different location or substituting new products which are more appropriate to the expected conditions.

Chapter 3. Key aspects of supply chain resilience

- **New approaches are needed to address risks in the whole supply chain**
- **A systems approach can identify weaknesses**
- **It requires learning, collaboration, spare capacity and flexibility**

The resilience of the supply chain depends on the strength of each constituent. It is therefore necessary for companies to consider the resilience of suppliers and customers as well as their own assets and operations. A company at the head of a supply chain might seek greater resilience through measures such as diversifying supply routes, maintaining up-to-date business continuity plans and procedures, and increased inventory levels. But these measures do not necessarily mean that the resilience of their suppliers will be increased.

Viewing resilience collaboratively rather than competitively, working with suppliers to help them adapt, enhances a company's own resilience. Sharing climate resilient approaches can achieve a collective advantage.

A systems approach

Developing resilient and robust supply chains requires a systems view to understand the complex dynamics, behaviors, functions, interconnections and changes in the system over time. This approach sees supply networks as a collection of many actors, each with their own goals and abilities, acting in an uncertain environment with often limited and/or incorrect information. The behavior of the overall system is affected by feedback and delays to materials and information.

Modelling the supply chain system will help managers identify weak spots, implement resilience-building measures and prepare for the impacts of climate change. The first step is to analyze the supply chain to gain insights into strengths and weaknesses. This can begin a process of working closely with suppliers, which may include supply chain diversification and relocating key sources of supply.

Risk management and resilience

Most companies have risk management procedures which identify, analyze, evaluate and treat risks. The typical approach provides a solid foundation, helping to protect individual vulnerable assets, but is is faced with a number of challenges to providing guidelines for the scale, complexities and uncertainties of global supply chains.[7]

Risk management is generally based on representing risk as a function of the probability and consequences of an event. This is appropriate where potential threats are relatively well-known in advance and the system can be prepared to face the threat, making it more robust through measures such as specifying stronger steel to resist higher wind gusts. However, it is impractical to maintain an estimate of the probability and

[7] Simchi-Levi, D., Schmidt, D., Wei, Y. (2014): From superstorms to factory fires. Harvard Business Review, January-February.

consequences of events for the whole supply chain because of:

- the sheer number of nodes in global supply chains
- the dynamic, frequently changing nature of the network
- the uncertainties inherent in climate change, including the possibility of unpredictable individual events which could have extreme consequences.

It is therefore necessary to take a broader view, thinking about resilience as well as risk management. Resilience is a strategy to deal with unknown or highly uncertain hazards, with the aim of enabling a system to tolerate surprises [8].

It includes strengthening defenses but also developing multiple pathways, providing alternatives if a route is inoperable and creating an ability to recover quickly. Multiple responses are likely to be necessary.

Strategies to build resilience can take many forms. We propose the following four core elements needed to build more resilient supply chains, while the detailed case studies explore how they could be applied to two specific supply chains.

Learning

Understanding the exposure of the supply chain to climate risk is fundamental to implementing suitable measures to deal with disruption. Continual learning, experimenting and gathering information is essential to update and improve the system understanding. Improved data collection and availability is particularly important, requiring trusted relationships when sharing information.

Collaboration

An actor in an interdependent supply network is only as strong as the system. Companies must go beyond the boundaries of their own business, working across industries, disciplines and stakeholders, possibly formalizing the collaboration in contracts.

Ideally, this requires participation from manufacturers, suppliers, distributors and retailers as well as non-corporate players such as communities, governments, NGOs and academia. Effective collaboration should create more resilient supply chain processes and share the benefits of these processes. For some participants it will focus on one specific node while others will focus on the entire supply chain.

While it is ultimately necessary for all companies in the supply chain to build resilience measures in their operations, in the short term, the buyer/supplier relationship is key and is the first connection companies are likely to develop. Other stakeholders will be brought in as appropriate by the buyer and suppliers as collaboration progresses.

Spare capacity

The first line of defense is to build spare capacity (or “redundancy”) into the supply chain – that is, the capacity to cope with a system failure without total collapse. After disruption caused by an extreme weather event, a “breathing space” is needed to continue production. A company can build spare capacity through extra inventory, hiring more workers and calling on idle facilities. Developing relationships with alternative suppliers can also provide the necessary breathing space. These measures can create quality problems and add costs [9] but a buffer is necessary to provide an immediate response to disruption.

Flexibility

Actors in supply networks need to have options to be able to adapt to developments. Flexibility can be achieved through standardized processes (e.g., interchangeable parts, products and production facilities), alternative traffic routes and procedures that can handle emergencies.

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[8] Renn, O. (2008): Risk Governance: Coping with Uncertainty in a Complex World. London:Earthscan.

[9] Sheffi, Y. (2005): The resilient enterprise - Overcoming vulnerability for competitive advantage. MIT Press, Cambridge, Massachusetts.

Example 4 – Climate change adaptation in the tea supply chain

Cafédirect, the fair trade commodity company, wanted to ensure that its tea supply was sustainably sourced and resilient to future events. The company worked with smallholder tea farmers and Kayonza Growers Tea Factory in western Uganda to help them to deal with expected climatic shifts. Prolonged droughts, landslides, soil exhaustion, and irregular rainfall patterns could reduce food and crop harvests, increase pests and diseases.

Small scale tea farmers are more vulnerable to climate change impacts because they have limited options and resources available for adaptation. The result is low tea production, food scarcity and declining household incomes.

A climate change adaptation strategy is being implemented to help farmers cope with climatic changes by minimizing the impacts on farming systems. Elements of the strategy include management of pests and diseases, food security and nature conservation.

Example 5: DNV GL – Energy

This firm is an independent certifier of special grid equipment and as such is a critical part of the electrical supply chain. There are very few testing facilities of this type and the whole electrical power supply chain would be seriously disrupted if it was out of commission. DNV GL's High Power Laboratory (HPL) tests components for electrical grids and is located by the River Rhine east of Amsterdam. The lab's position allows heavy equipment to be moved by ship and tested in place on a barge by the river bank, but there are concerns about flooding due to climate change.

The company has conducted a flood resilience study of HPL, which has a new-build cost of Euro 400 million and would be out of action for several years if flooded.

A future-oriented risk model includes a hydrological model and a spatial analysis of the location to estimate the water levels as well as the potential flooding impact. The analysis was done for the present climate and various climate scenarios using state-of-the-art 3D flooding models. The analysis has prompted the development of a resilience strategy for the facility.

Chapter 4. Building resilience in supply chains

- **Resilience measures will be determined by a supply chain's specific characteristics**
- **Action will strengthen the whole supply chain as well as individual assets and connections**

Resilience-building measures will be dependent on the nature of individual supply chains and the climate vulnerabilities identified. They will therefore vary from company to company and from country to country. In this chapter we provide some general measures which will be broadly applicable.

A holistic approach should be adopted, considering the cost and benefits for the supply chain as a whole rather than for individual points in the system, bearing in mind the interconnections and interdependencies identified in earlier steps. This requires a willingness to consider changes to supply chain structures as well as measures at specific points.

In many cases, a wide range of potential measures may be identified but it is unlikely to be practical or justifiable to attempt full implementation initially. Each action will need to be assessed in terms of its significance, cost and potential benefits, resulting in a prioritized hierarchy of actions. The most urgent measures will therefore be those which promise the most benefit for the least cost across the supply network.

Measures can be identified according to the core resilience elements described earlier: learning, collaboration, spare capacity and flexibility. These have been exemplified below using the two case studies.

Learning

- Assess the flows of information to ensure they support resilience-building measures
- Develop effective monitoring to provide continual understanding of how the supply chain is affected by extreme weather events and recovery processes.

Lithium-Ion batteries	Corn
Increase understanding and monitoring of weather conditions where production is concentrated	Gather data on climate conditions relevant to corn processing

Collaboration

- Apply policies encouraging collaboration across the supply chain, including information sharing
- Require suppliers to carry out assessments of their vulnerabilities and implement resilience building measures.

Lithium-Ion batteries	Corn
Work with the three cathode binder manufacturers	Increase partnerships with corn syrup manufacturers

Spare capacity

- Maintain a measure of the supply chain's capacity and capacity utilization and implement changes to create a margin available in the event of climate disruption.

Li-ion batteries	Corn
Build buffer stocks of Lithium	Investigate potential for buffer stocks of corn and corn products at several stages in the supply chain

Flexibility

- Consider multiple suppliers for critical items
- Explore alternatives to existing logistics arrangements
- Identify potential alternative production sites.

Lithium-Ion batteries	Corn
Develop alternative transport routes for PVDF	Consider alternative sweeteners

This approach is described in the case studies (page 23) concerning two very different industry sectors and supply chains, with relevance to many industry sectors.

Example 6: Climate adaptation in the power sector [10]

Entergy serves 2.8 million customers in the Gulf Coast states of Louisiana, Mississippi, Texas and Arkansas. Following devastating hurricanes in 2005 and 2008, the company adapted its strategy for coping with extreme weather, based on a climate study of the Gulf of Mexico identifying vulnerabilities and engagement with communities and customers.

When Hurricane Isaac struck Louisiana in 2012, it caused widespread damage to power lines and equipment but recovery was speedier than ever before. Virtually every customer had electricity again within a week.

Strong planning and preparedness and mutual assistance were the reasons for the swift recovery. A resilience review had led to some relocation of data and transmission centers. Entergy also reached agreements with other utilities for mutual assistance, which came from 21 other utilities and 138 contractors from 25 states.

Example 7: Cisco [11]

Following hurricane Katrina in 2005, Cisco set out to improve its resilience to such major events. The company began by identifying product lines for which response times were more important than cost. This led to reconfiguring the supply chain for high-value products to create a flexible network of alternative manufacturers. Building on this foundation, Cisco designers and supply chain teams created additional resilience by specifying alternative components, building buffer stocks for key items and working with suppliers to identify and act on unacceptable risks.

Resilience also depends on swift response to disruptive events. Cisco developed this capability by creating a business continuity platform with playbooks detailing appropriate corrective actions, and a permanent global monitoring system to ensure early warning of disruption.

These systems proved their worth when the earthquake and tsunami hit Japan in 2011. Managers were able to swiftly identify the hundreds of suppliers and thousands of components affected and take appropriate action, including communicating with customers. As a result, the company lost virtually no revenue, in contrast to the impact of hurricane Katrina.

[10] See ‘Building a Resilient Power Sector’ for more information http://www.wbcsdpublications.org/viewReport.php?repID=520

[11] For more details, see: Sáenz, M.J. and Revilla E., Creating more resilient supply chains, MIT Sloan Management Review, Summer 2014, and Sáenz, M.J. and Revilla E., Case Study: Cisco Systems, inc., Supply Chain Risk Management. In Chuck Munson (Ed.), The Supply Chain Management Casebook: Comprehensive Coverage and Best Practices in SCM. Financial Times Press.

Case study 1. The Lithium-ion battery supply chain

- **Lithium has many end uses, including Li-ion batteries**
- **The battery supply chain is highly complex**
- **Climate vulnerabilities exist at many points in the supply chain**

This case study maps the Li-ion battery supply chain structure and considers its vulnerability to a changing climate. While it focuses on this specific product, the case is relevant to many technology-based supply chains.

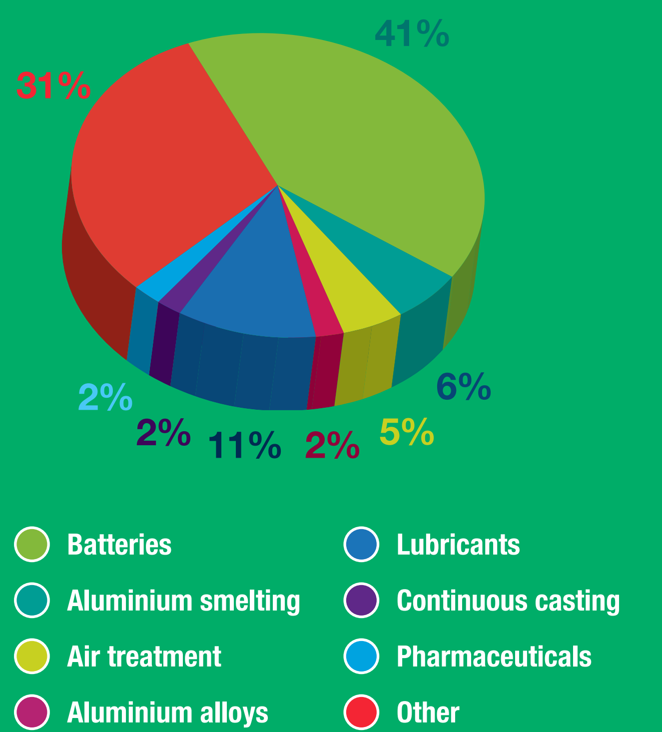
Lithium-ion (Li-ion) batteries are used widely for electrical storage and consumer electronics applications and are seen as one of the most appropriate candidates for widespread use in electric vehicles (EVs) because they have the right combination of weight and performance. EVs are part of the passenger vehicle market which is global and has an extensive supply chain network.

The Lithium Market Context

Lithium is an abundant element with worldwide reserves currently estimated to be around 13 million tonnes[12], compared to annual production of lithium metal of approximately 37,000 tonnes. It is available commercially in mineral ores but extraction from lithium-rich brines is less costly. Brines are often found in underground reservoirs below the surface of dried lakebeds, at high altitudes in areas of low rainfall. Production is concentrated in only a few countries, notably Chile and Australia, which account for 70% of total output. China and other producers represent about one-third of current production levels.

Extraction and treatment produce lithium carbonate, which is a key intermediary because it can be converted into specific industrial salts and chemicals, or processed into lithium metal. The metal form is created in an electrolytic cell using lithium chloride. Batteries represent the largest single use for lithium but the metal and compounds have several end uses (see figure 5).

Figure 5: Market Shares for Lithium Applications



12 'Materials critical to the energy industry – 2nd Edition', 2014 (University of Augsburg / BP)

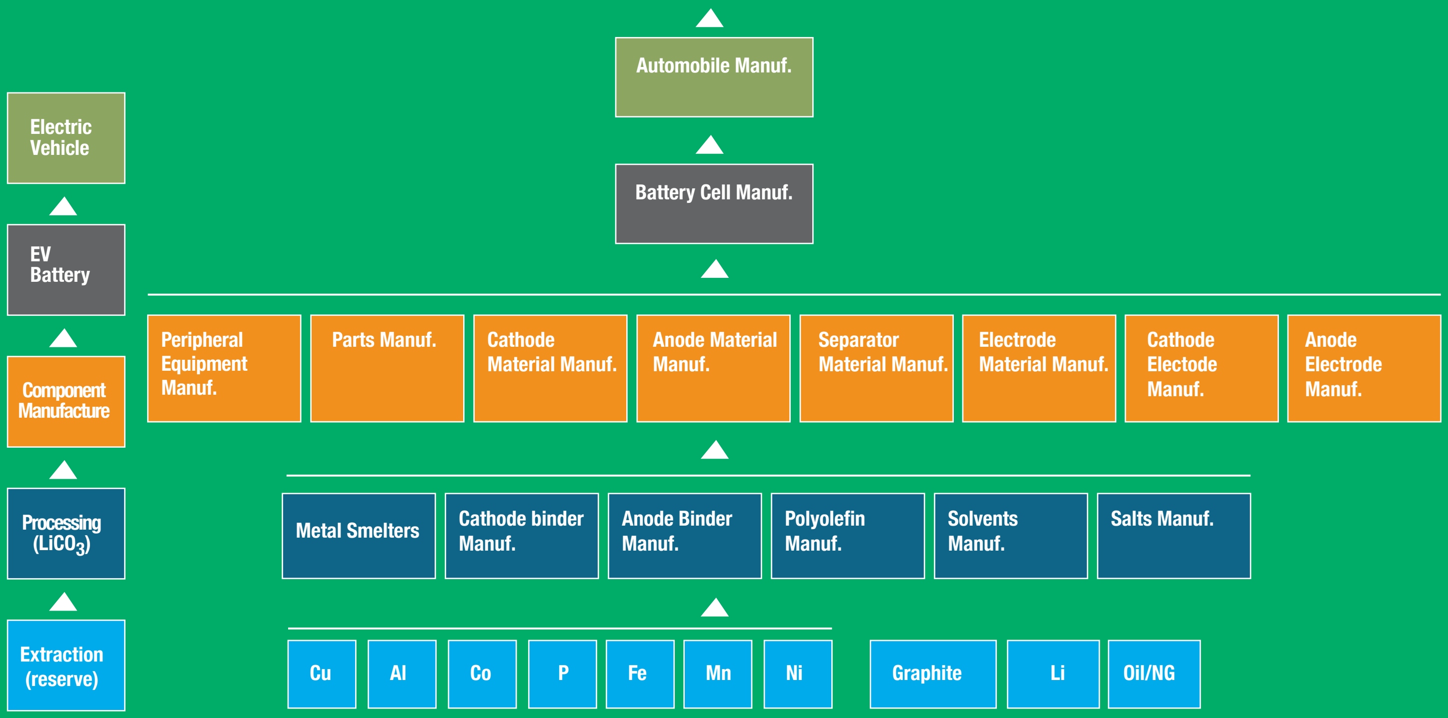
The market for EVs is expanding fast. Global sales more than doubled between 2011 and 2012 and the Electric Vehicles Initiative aims to achieve 20 million passenger EVs on the road by 2020. Li-ion batteries are likely to be a significant pre-requisite, demanding substantially more Lithium.

The Lithium Supply Chain and Li-ion Battery Manufacture

The supply chain is complex, with many elements of extraction, processing and component manufacture, illustrated in figure 6. Such a level of complexity is likely to be similar to multi-step manufacturing supply chains in other industries and markets.

This simplified diagram illustrates the multiple inputs required. The supply chain may be vulnerable where there are few suppliers, or where an individual supplier provides a large proportion of global product.

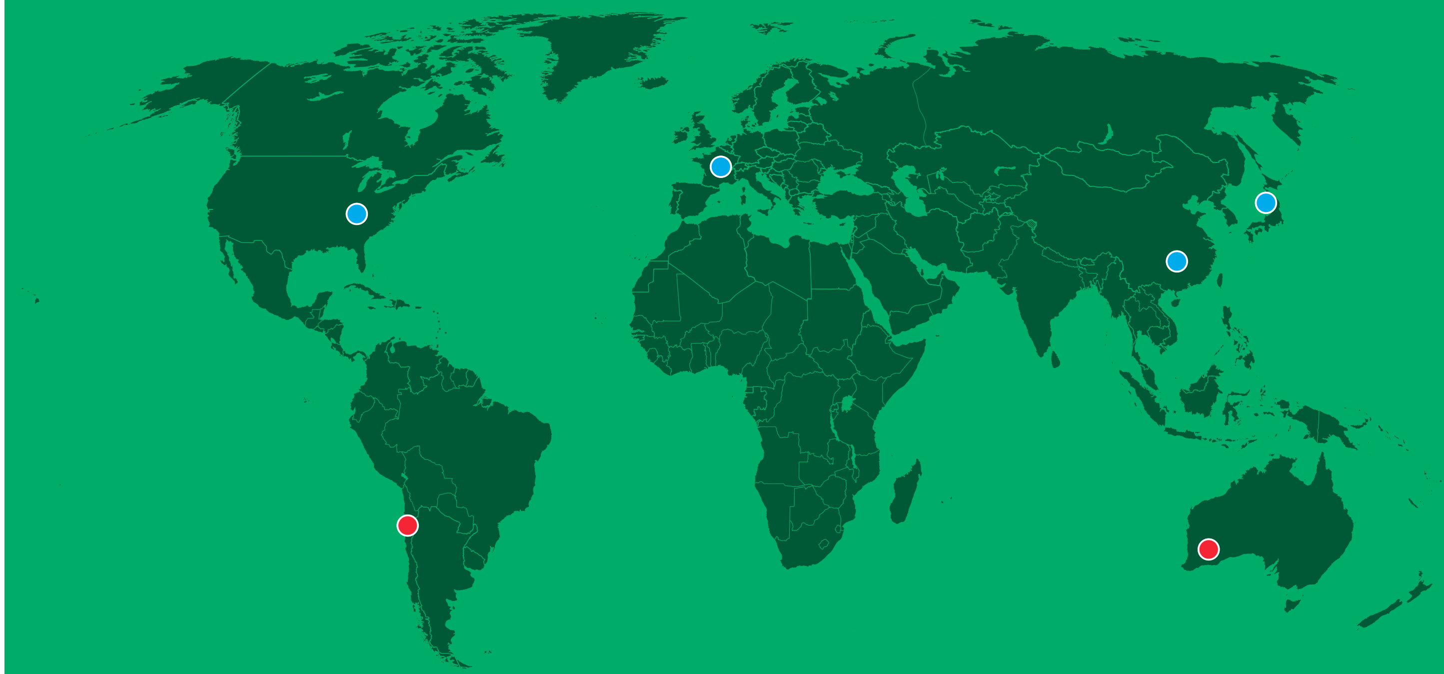
Figure 6: Detailed Structure of Lithium-Ion Battery Supply Chain for EVs



Significant features

Lithium metal mining and cathode binder manufacture are key points of potential vulnerability to climate events.

Figure 7: Key locations in the global Li-ion supply chain



Lithium Metal Mining and Brine Extraction

A shortage of lithium would be felt through a combination of higher prices or shortfalls in supply to the 'Processing' stage.

Mining for lithium takes place in a number of locations worldwide but about two-thirds of total production is concentrated in Chile and Australia. There are few major production sites, the two main areas illustrated by the red dots on the world map above, in Western Australia and central Chile.

Cathode Binder Manufacturers

Polyvinylidene fluoride (PVDF) is a polymer suitable for Li-ion cathode binders [13]. If there was a shortage, the effects would be felt through a combination of higher prices or shortfalls in supply to the 'Component Manufacture' stage.

There are three major PVDF manufacturers worldwide, (Company A, B and C) who produce PVDF as part of a range of chemicals, polymers and similar materials-based activity. Production also goes into applications such as photovoltaic cells.

The manufacturing locations are illustrated by the blue dots on the world map above:

- Company A – Kentucky, USA; Pierre-Bénite, France; Changzhou, China
- Company B – Tavaux, France; Changzhou, China
- Company C – Iwaki, Tokyo, Japan; Changzhou, China

[13] The percentage of PVDF within Li-ion batteries and cathode material varies but is typically around 5% of cathode material

Climate Impacts and Vulnerabilities

The complex global supply chain for Li-ion battery production requires fully-functioning facilities during each stage of manufacture, and also the ability for materials and products to be transported between these facilities.

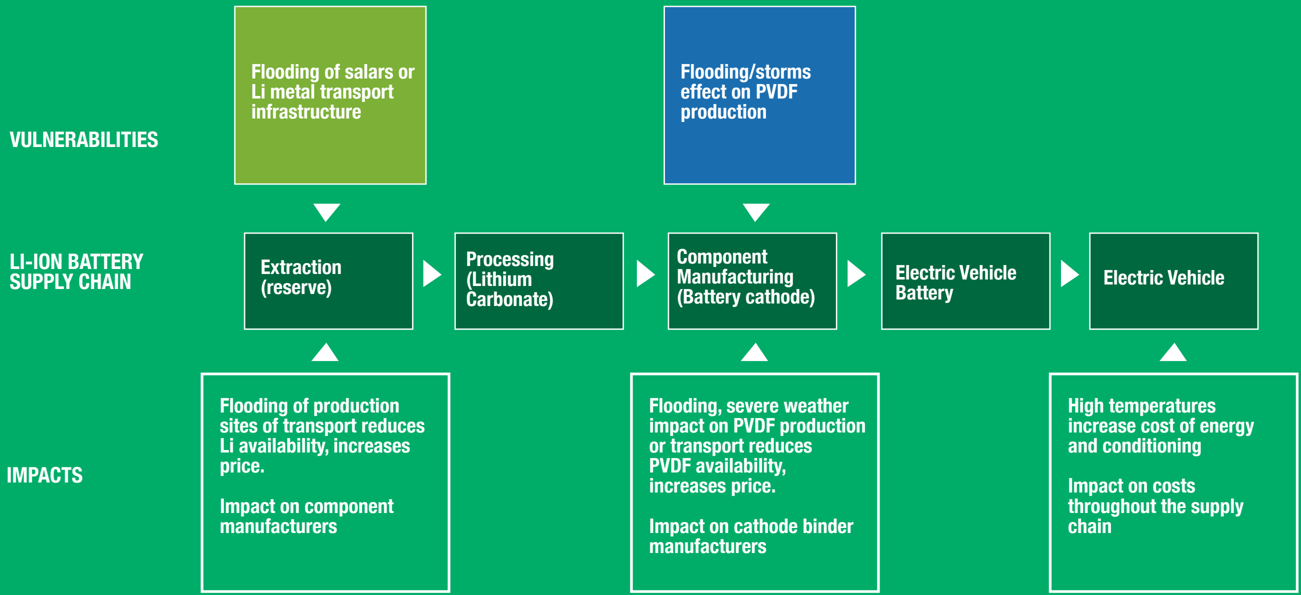
The supply chain is already vulnerable to the impacts of extreme weather events. Climate change could increase the intensity and frequency of these events and create new hazards, particularly at the vulnerable points identified above. The different stages of the Li-ion battery value chain may be vulnerable as shown in table 2.

Table 2: Climate vulnerabilities at each stage

Supply chain stage	Potential climate vulnerabilities
Extraction	Flooding of salars delaying mining operations, particularly in South America which supplies approximately 35% of global lithium
	Floods washing away transport infrastructure, or storms/hurricanes impacting shipping routes. Lithium is shipped through active cyclone areas - particularly in the South China Sea and North Eastern Pacific.
Processing	Changes to humidity or temperatures could affect the carefully controlled processing conditions, leading to increased conditioning costs
Component manufacture	Floods, severe storms or typhoons affecting individual manufacturing facilities, causing delays and/or business interruption. Three out of seven PVDF manufacturers are located in Changzhou, China and could be affected simultaneously
	Large scale flooding or storms restricting transport or logistics for components
	Changes to humidity or temperatures leading to increased conditioning costs for component production.
Battery cell production	Floods, storms and extreme weather affecting individual manufacturing facilities causing delays and/or business interruption – although the relatively large number of manufacturers would limit the impact
	Floods, storms, hurricanes washing away transport infrastructure or impacting shipping routes could affect upstream delivery of components and downstream export of battery cells – likely to affect individual locations only
	Changes to temperature in individual locations leading to increased conditioning costs for battery cell production
Vehicle production and distribution	Floods, storms and extreme weather affecting individual vehicle manufacturing facilities, causing delays and/or business interruption
	Floods, storms/hurricanes washing away transport infrastructure or impacting shipping routes could affect upstream delivery of battery cells and downstream export of EVs

The principal vulnerabilities and potential impacts for the two key aspects are illustrated in Figure 8.

Figure 8: Principal Climate Vulnerabilities and Impacts on the Lithium Supply Chain for EV Batteries



Conclusions

The number of stages, products, and actors makes the supply chain inherently complex. Multiple raw resource inputs are required for processing just one of many battery components. Another aspect of complexity can be seen in the use of lithium in several industries in addition to battery manufacture. Vulnerability is highlighted in this case by the small number of suppliers of key resources as well as the potential impacts of climate change. The four key elements for building resilience apply as follows:

Learning

Analysis, based on sound data, is necessary to fully understand the supply chain and its vulnerabilities. This will enable a company to develop a map of the supply chain sub-structures and will help to maintain an active picture of climate vulnerability issues.

Climate data and projections for the key geographical locations in the Li-ion battery supply chain will help to develop a more detailed understanding of the nature and level of risks faced in the different segments [14].

Collaboration

The complexity of the Li-ion supply chain makes it clear that a manufacturer cannot strengthen resilience without the collaboration of other members of the supply network. A battery manufacturer could begin by working with a small number of the most critical suppliers, as identified by the analysis. Subsequently, the collaboration could expand to include more participants.

Spare capacity

Where a supply chain has in-built spare capacity, vulnerability is reduced by the greater ability to withstand shocks. In this case, the transport links are lengthy because production of lithium is concentrated in the southern hemisphere but it is used in manufacturing processes that occur mainly in the northern hemisphere. These links are therefore vulnerable to disruption at ports or during shipping. This vulnerability could be reduced by developing alternative routes or modes of transport, as well as by keeping buffer stocks at key points in the supply chain.

Flexibility

It is important to ensure sufficient flexibility to withstand disruption. Lack of flexibility exists due to the 'pinch points' and geographical concentration of suppliers:

- 'Pinch points' exist because there are few suppliers of lithium and PVDF. It is especially important to understand the vulnerability to climate issues at these pinch points
- Geographical concentration of suppliers or manufacturers may also create vulnerability to climate events, and this case shows Changzhou, China as an important location of PVDF facilities.

[14] Revilla E. and Sáenz, M.J., Supply Chain Disruption Management: Global Convergence vs. National Specificity. Journal of Business Research, 2014, 67(6), 1123-1135

Case study 2. The corn supply chain for beverages

- **Soft drinks are only one of many end markets for corn**
- **The supply chain is complex and includes several 'pinch points'**
- **It is vulnerable to climate shocks at several points**

This case study examines the use of corn as high fructose corn syrup (HFCS) in the US beverage industry. HFCS is used as a sugar source. Corn refineries produce it by milling corn to produce starch and converting corn starch to syrup. HFCS is used in a variety of products including bread, cereals, soups and soft drinks.

This is one of many uses for corn, which has long been a major agricultural input to food production and animal feed and has become an important raw material for fuel and plastic production as well as drinks.

We map the corn supply chain for beverages and the main stocks and flows. As the flow of corn moves downstream from farmers to retailers, the system becomes more integrated with other industries and heavily immersed in the energy – water – food nexus. The food industry involves a large network of companies in more than 16 industries.

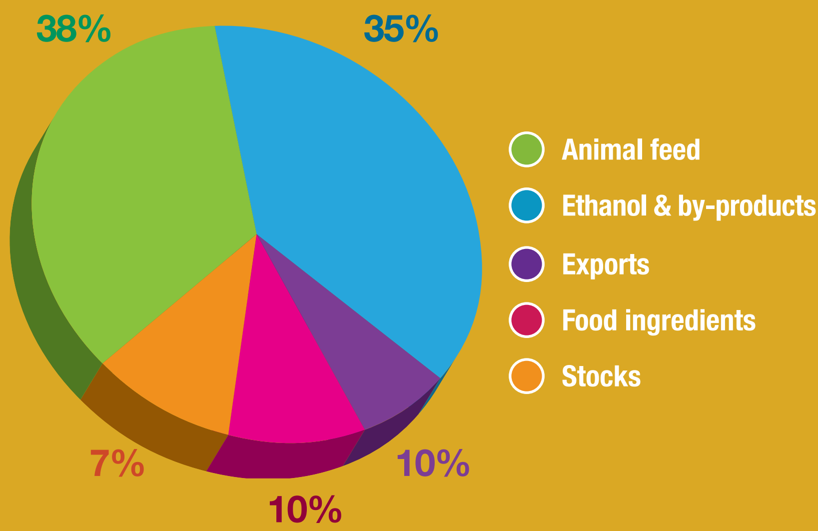
Climate change is one of several long term trends with a profound but poorly understood impact on this supply chain.

The market context

Corn is grown in many countries in both the Northern and Southern hemisphere. The US is the largest producer and exporter, with 36% of world production. China is the only other large producer, with 22% of world production. Brazil, in third place, accounts for only 7% of the total [15].

About one-third of US farmland is devoted to raising corn. It is the biggest crop in the US and production has increased by 88 % since the mid-1990s [16]. Most US corn production now goes into animal feed and ethanol for vehicle fuel. These two end uses account for almost three quarters of total output. See figure 9.

Figure 9: U.S. corn use by segments (Source: USDA, National Agricultural Statistics Service Database).



15 Brooke B and Clark SE (2014): Water & Climate Risks Facing U.S. Corn Production, Ceres.

16 Denicoff, M R., Marvin E P, and Pierre B (2014): Corn Transportation, U.S. Department of Agriculture, Agricultural Marketing Service.

Technology, national policies and international trade have changed the corn market structure over the last two decades. For example, new seed hybrids and biotechnology have increased yields and the demand and federal requirements for alternatives to fossil fuel has driven ethanol production.

Like all agricultural commodities, the corn market is volatile, with several drivers of both demand and supply (see table 3). Prices, production and profitability are cyclical, driven by weather, policy and speculation. The 2012 drought demonstrated that different sectors in the food supply chain have different exposures to price fluctuation. The market price has ranged from $2 per bushel in the early 2000s to $8 per bushel during the drought in 2012, then fell dramatically in 2014. Price increases are very sensitive politically. For example, the near doubling of the corn price from 2006 – 2007 prompted the so called "tortilla riots" in Mexico.

Table 3: drivers of the corn market

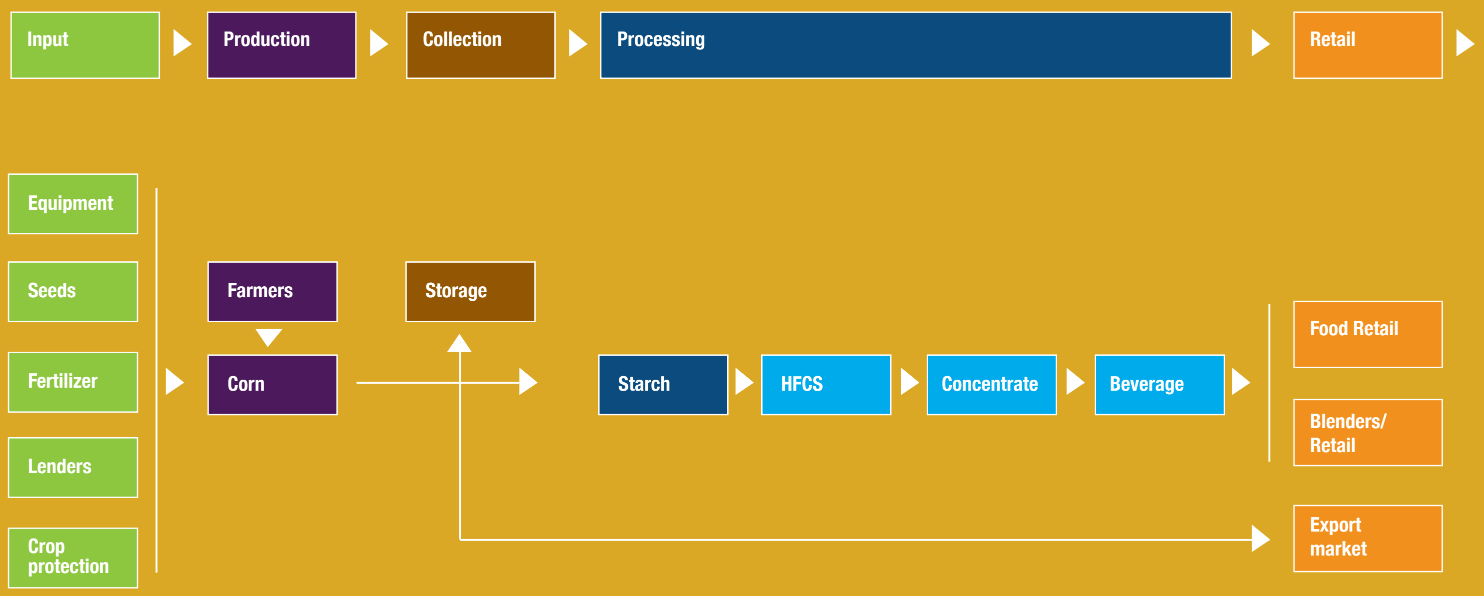
Demand	Supply
Energy - the US Renewable Fuel Standard requires 15 billion gallons a year of ethanol (derived from corn) in the US fuel mix from 2015.	**Technology** – improved seeds and crop management increase crop yields.
Regulation - The US Federal Crop Insurance Program insures weather-related crop losses, encouraging farmers to grow more corn, while water rights promote overexploitation of groundwater sources.	**Speculation** - financial speculators accounted for 70% of the commodities market in 2008, adding to volatility in corn prices.
Population growth and changing consumer patterns have affected the volume and nature of demand.	**Shipping costs** - reduced water levels in the Mississippi River during periods of drought require smaller shipping volumes, increasing the unit cost.

The US corn supply chain

The corn supply chain begins with the inputs used by growers, such as land, seeds, fertilizer and equipment. The next phase is collection, storage and transport, then processing and production of high fructose corn syrup (HFCS) for use in the final products. The final phase is distribution of soft drinks to the market. See figure 10.

At each stage in the chain there are stocks of materials (e.g., equipment, seed, corn, processing products) that buffer the activities in the network. Transport is a critical link between the different phases.

Figure 10: The U.S. corn supply chain for soft drinks



High Fructose Corn Syrup (HFCS)

Corn is shipped from the Midwest Corn Belt mainly by truck and rail to storage and processing plants. Table 4 summarizes critical elements in the market structure and the nature of the processes.

Table 4: Critical Features of the Corn Supply Chain

Supplier concentration	Just a few companies control several inputs [17]: • Farm equipment: 65% between Deere & Co., CNH Industrial NV, AGCO, Toro and Lindsay Corp. • Seeds: 70% between BASF SE, Dow Chemical Co., DuPont, Monsanto, Syngenta AG and Bayer CropScience • Fertilizer: 80% between Agrium, Mosaic, Potash Corp. CF Industries and Koch Fertilizer • Farmers: most are part of larger cooperatives and/or linked to one of three corn traders: Cargill, Bunge, Archer Daniels Midland who own most of the storage capacity • Beverage manufacturers: the many franchisees are linked to the brand owners, dominated by Coca-Cola and Pepsi
Geographic concentration	The majority of US corn production takes place in the Midwest Corn Belt. Six states accounted for more than 65% of the corn production in 2013.
Time to market	Maximum storage time depends on the quality of the corn, its treatment after the harvest and the humidity and temperature in the storage facility. The time to the end users can vary from weeks to years after harvest.
End uses	Corn is an input for many different products, including plastics applications such as car parts after conversion into biopolymer (See box "Corn and car parts"). The many end uses compete for the corn production.

[17] Brooke B and Clark SE (2014): Water & Climate Risks Facing U.S. Corn Production, Ceres.

Corn and car parts

The auto industry has become a significant customer for corn in the form of biopolymers. The starch which is the basis of high fructose corn syrup is also used to create biopolymer pellets that are formed into plastic components. This end use is the result of a supply chain with similar complexities to the beverage example in this case study. The auto industry is global and uses a large number of component manufacturers all over the world and there are many other end uses for the biopolymers. This supply chain is more resilient because oil is a readily available alternative to corn for the plastic manufacturer.

Climate Impacts and Vulnerabilities

Gradual climate change and extreme weather events add stresses to the corn supply chain. Farmers have always had to cope with varied weather but climate change will bring new and heightened hazards. However, there are large uncertainties about the timing, location and severity of these impacts (see Table 5).

Further uncertainty arises because corn is produced in a wide North-South range in the US, with different soil types, water resources and farming systems. Given this complicated and diverse picture, climate hazards differ from place to place.

Corn production affects and is affected by water availability and water quality. Droughts and groundwater availability restrict crop productivity while high fertiliser use to boost production has a negative impact on downstream waters.

Extreme weather events such as drought, flooding, and fluctuations in temperature can disrupt the overall network and influence corn supply and prices. Extreme events also impact water availability.

These are shocks to an already volatile system. Long delays can have a cascading effect on key parts in the supply chain – meaning that the effects of these shocks can take years to play out. As the shocks happen more frequently, they are likely to create more volatility and uncertainty in the corn supply system.

The variety of climate impacts and the complexity of the corn supply network create substantial vulnerabilities – especially considering the network as a whole. The major risks and vulnerabilities are as follows:

Inputs to Corn Production

Equipment producers have global operations that can be disrupted by climate events on nearly any continent. Corn for seed is grown in the same parts of the US as corn for grain, making the yield of corn seed dependent on the same factors that affect grain corn in general. Fertilisers, both imported and domestically produced, are often transported on and along the Mississippi River and applied to fields during short periods in the spring and autumn. Disruptions at this time of year could affect the profitability of corn production.

Corn Production

The majority of corn in the US is grown in a few adjacent states. Extreme cold weather in the early spring can delay tilling while a late frost can destroy planted fields. Growing corn is vulnerable to heatwaves and drought. Excessive rainfall at the end of the growing season can destroy the harvest, or leave the corn useful only as animal feed. In the longer term, warmer temperatures can shift the optimal corn growing belt northward and facilitate movement of diseases and pests, making some corn-growing areas unprofitable.

Corn is a “thirsty” plant. It requires the most irrigation of any crop in the US. Water demand is increasing in areas which are already experiencing water stress and ground water depletion.

Collection

Most corn is moved by road and rail, both of which are vulnerable to high temperatures and heavy precipitation. The ageing of US infrastructure, particularly in the Midwest, makes transport increasingly susceptible to extreme weather events. The majority of corn exports pass through the Mississippi Delta. A climate event in this area such as Hurricane Katrina could disrupt exports.

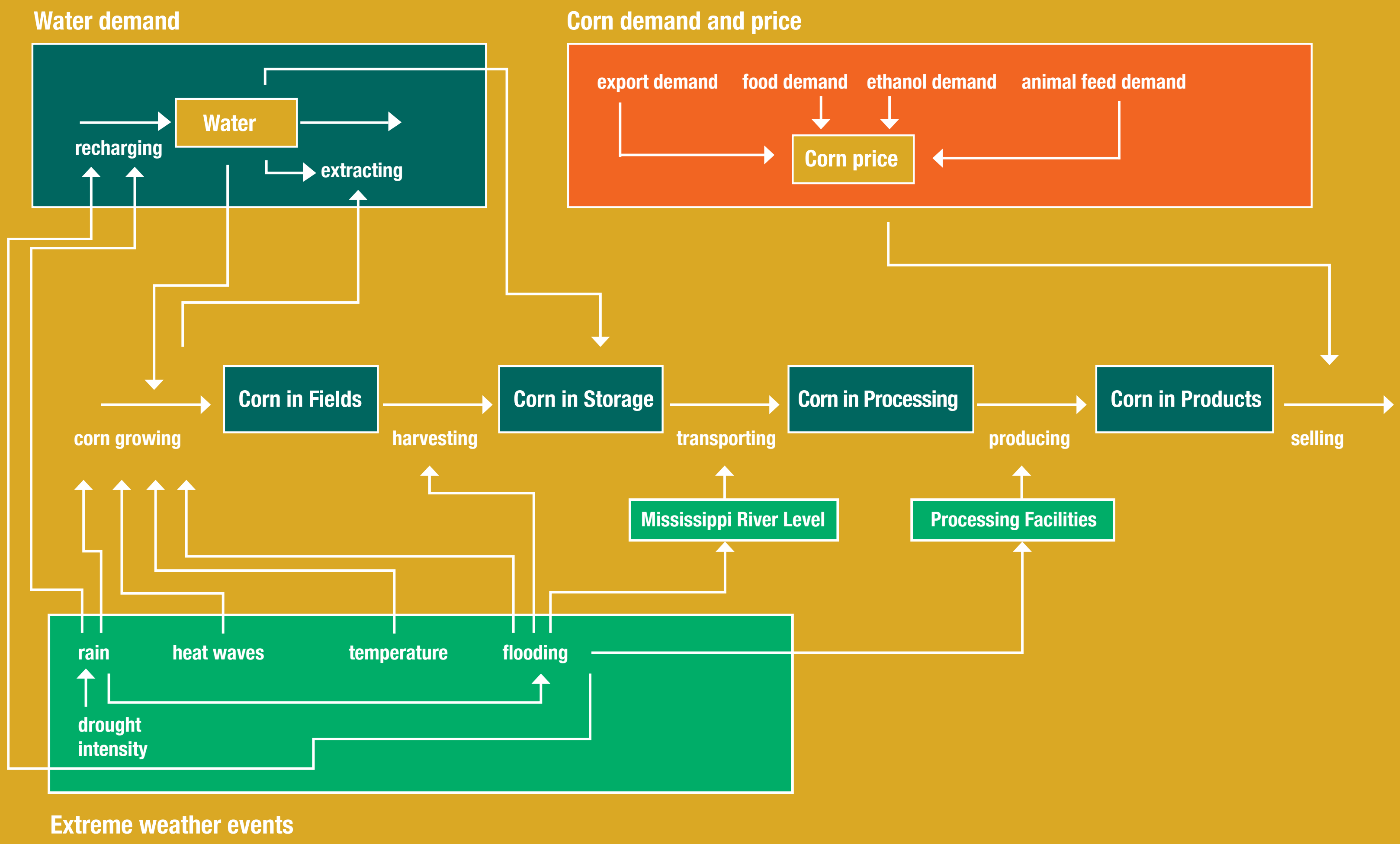
Processing

Processors of corn and producers of HFCS and beverages rely on electricity and clean water. Drought and declining aquifers threaten both water supply and water quality and generally drive up the cost of obtaining suitable water.

Transport

Flooding can also affect transportation infrastructure, delaying transport and jeopardizing corn quality due to higher storage time. A prolonged drought will also affect the water level in the Mississippi, preventing passage of barges and ships due to low water levels.

Figure 11. Critical impacts in the supply chain



The likely climate impacts are illustrated in figure 11 and summarized in table 5.

Table 5: Climate impacts on the corn supply chain [18, 19]

Temperature	Heatwaves are very likely to become more frequent and longer lasting. Extreme temperatures during the corn flowering stage can create stress that affects pollination and grain formation, affecting final yields [20]. Yields are predicted to fall by approximately 20% from 2020 to 2049, even under relatively slow warming. Faster warming would increase losses to as much as 30% [21] Intense cold in winter is possible throughout the US, especially in the Midwest, Northeast and West.
Drought	The combination of rainfall and temperature changes is expected to result in longer and more frequent drought. The drought between 2011 and 2013 affected agricultural productivity in the Midwest as well as the Great Plains region, costing $21 billion.
Precipitation	Rainfall is expected to be more intense in some areas while others will experience more days with no precipitation.
Flooding	Floods are likely to become more frequent and more severe, with flash floods resulting from heavy local rainfall. In particular the central US is expected to face severe flooding by the Mississippi and Missouri rivers. In general there will be discharge peaks in Spring and late Summer.
Hurricanes	Likely to become more severe along the Atlantic coast from Texas to Maine, being most severe in the South.

18 Swiss Re CatNet

19 IPCC, Fifth Assessment Report, 2013

20 Deryng D, Conway D, Ramankutty N, Price J and Warren R (2014): Global crop yield response to extreme heat stress under multiple climate change futures Environ. Res. Lett. 9 034011

21 Gourdji S M, Sibley A M and Lobell D B (2013): Global crop exposure to critical high temperatures in the reproductive period: historical trends and future projections Environ. Res. Lett. 8 024041

Climate Impacts and Vulnerabilities

The corn supply chain is complex and becomes more integrated with other industries in the downstream phases. For example, the US requirement for ethanol in vehicle fuels has influenced the dynamics of the corn industry.

Another aspect of complexity is that water, energy and food are linked throughout the supply chain and affected by climate change. Growing corn requires significant amounts of water. Energy is needed for crop production and transport at a time where corn is also a vital component in US fuel production. Consequently, there is competition for water and land between bio energy and food production. When exposed to extreme events such as droughts, rainfall and flooding, the consequences for the energy – water – food nexus can be far reaching. The four ingredients for building resilience apply as follows:

Learning

It is desirable to increase data collection on subjects like water quality and availability, field conditions and the effect of climate conditions on transport and processing of corn and its products. Trusted relationships are needed when sharing accurate and reliable information to create a better understanding of the risks along the entire value chain.

Collaboration

Coca-Cola Company is partnering with the major corn syrup suppliers to increase transparency and promote sustainable farming practice. Farmers are encouraged to use more advanced tools to improve management of land, water and energy and mitigate greenhouse gas emissions and soil losses.

Spare capacity

The first line of defense against disruption is to have safety stocks. However, this kind of resilience building measure faces a number of challenges in the corn supply chain. Collection and storage of corn takes place on farms, interior/country elevators, river elevators and export terminals. The storage time depends on several factors that limit the potential for buffer stocks.

Flexibility

Different actors have options for flexibility. For example, farmers can grow other crops. Similarly, soft drink manufacturers could consider alternative sweeteners.

Chapter 5. A framework for action

- **Resilience builds on risk management practices and a systems approach**
- **Building resilience is an iterative and continual process**
- **It requires an understanding of the supply chain and its vulnerabilities**

We propose a framework for companies to build resilience to climate risks in global supply chains. It is based on the lessons from this project, a literature review, the findings from the case studies and insight from forward thinking WBCSD companies.

The framework is illustrated in figure 12. It will help decision makers to understand their supply chain and its climate vulnerabilities and to build resilience. Resilience requires a systems approach and is based on learning, collaboration, spare capacity and flexibility. It provides the capacity to deal with changes and stresses and the ability to create new connections. Assessing risks and building climate resilience is an iterative process where results and findings in one step are used as feedback and input to other steps. The framework, divided into five stages, is best implemented through cross-functional participation (e.g. from the environmental, supply chain, and corporate risk functions in a large multinational company) and draws on external knowledge of subjects such as meteorology, climate science and business risk management.

Alongside a strategy for integrating awareness of climate change vulnerabilities, the framework should help companies to develop and implement a balanced set of resilience measures throughout the supply chain.

Figure 12: A framework for assessing climate risks and building climate resilience

Step 1. Map the supply chain and identify critical features

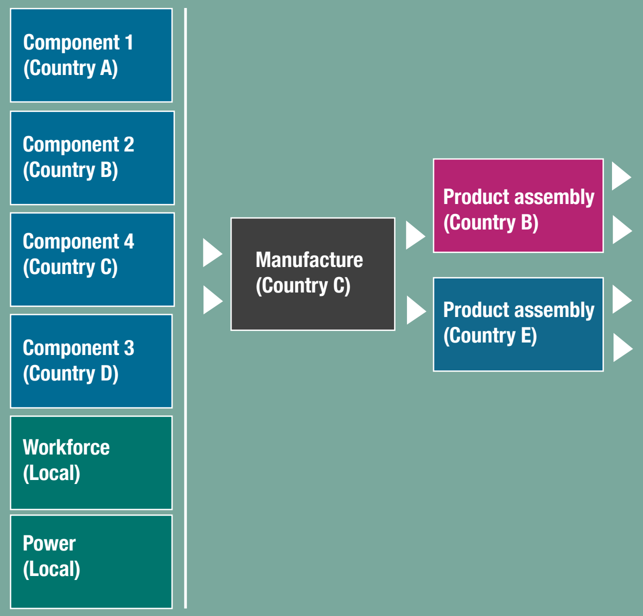
The aim of this step is to:

- understand the principal material flows, stocks and locations in the supply chain;
- identify the numbers, locations and diversity of organizations, products and business connections at each stage of the chain;
- identify interface points with other industries, including utilities;
- identify key international and national laws, policies and regulations that may affect critical features in the event of disruption.

This analysis may be complex for an entire supply chain and the initial stage should be focused on an overall understanding of the key production locations, material stocks and major paths of material movement (see figure 13 for an indicative example). Mapping provides a basis for outlining its critical features and identifying potential climate-related hazards that could disrupt performance (Step 2).

To better understand critical features, companies should consider the issues that are most important for a particular product. For example, the most relevant issue could be the extent of product customization, achieving low cost, or ensuring and maintaining quality. Or the most critical feature could be the recovery time following disruption to restore 100% functionality.

Figure 13: Climate resilience assessment - supply chain structure

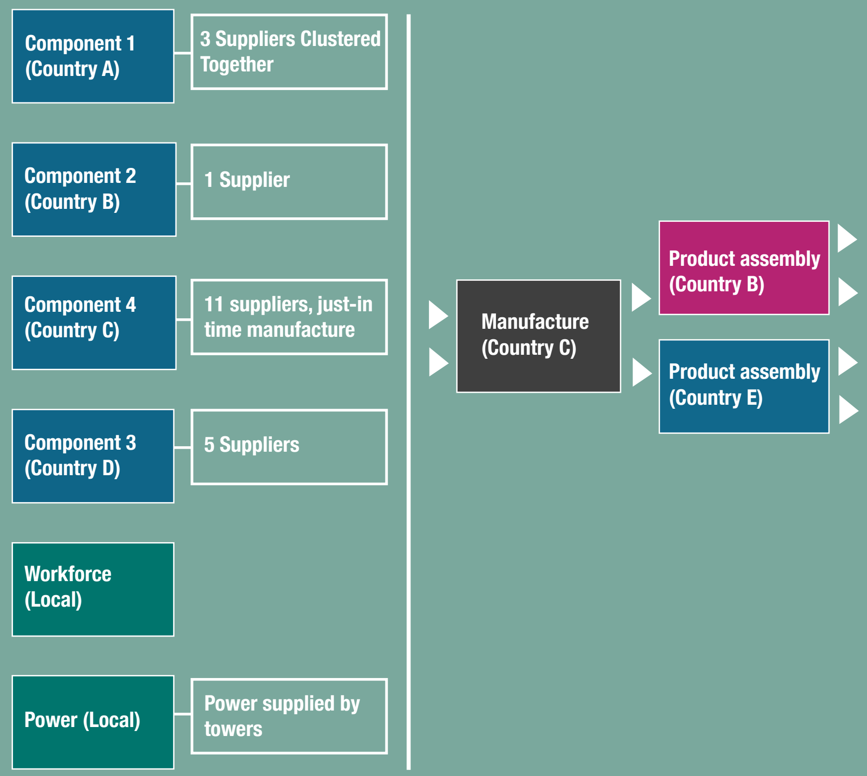


Companies are dependent on services and infrastructure (e.g., utilities, transport, suppliers, customers) and these should be considered as part of the 'critical features' assessment. Legislation may require major infrastructure providers to report on their climate resilience, as in the UK's Climate Change Act.

The critical features may relate to one or more of the following aspects:

- Few supplier locations, or a lack of alternative suppliers;
- Geographical concentration/clustering of supplier locations (or warehousing/storage), or an overall lack of geographical diversity (particularly where geographical concentration is in an area known to be subject to climatic hazards);
- Competition for resources used in the supply chain (e.g., alternative uses for primary materials such as agricultural products or resources such as water);
- Dependence on climate-sensitive materials (e.g. agricultural raw materials that rely on a certain climate and water availability);
- Lack of alternative transport routes or concentration of routes (e.g., via specific ports);
- Legal or regulatory requirements on infrastructure providers;
- A ‘Just In Time’ supply chain or lean production model with minimum inventories;

Figure 14: Climate resilience assessment – critical features of the supply chain



Step 2. Determine weather-related hazards

The supply chain is likely to be affected by current weather events and by future climate change. The relevance of weather-related hazards to different components can be determined through reference to historical disruptions and consequent business losses, for example:

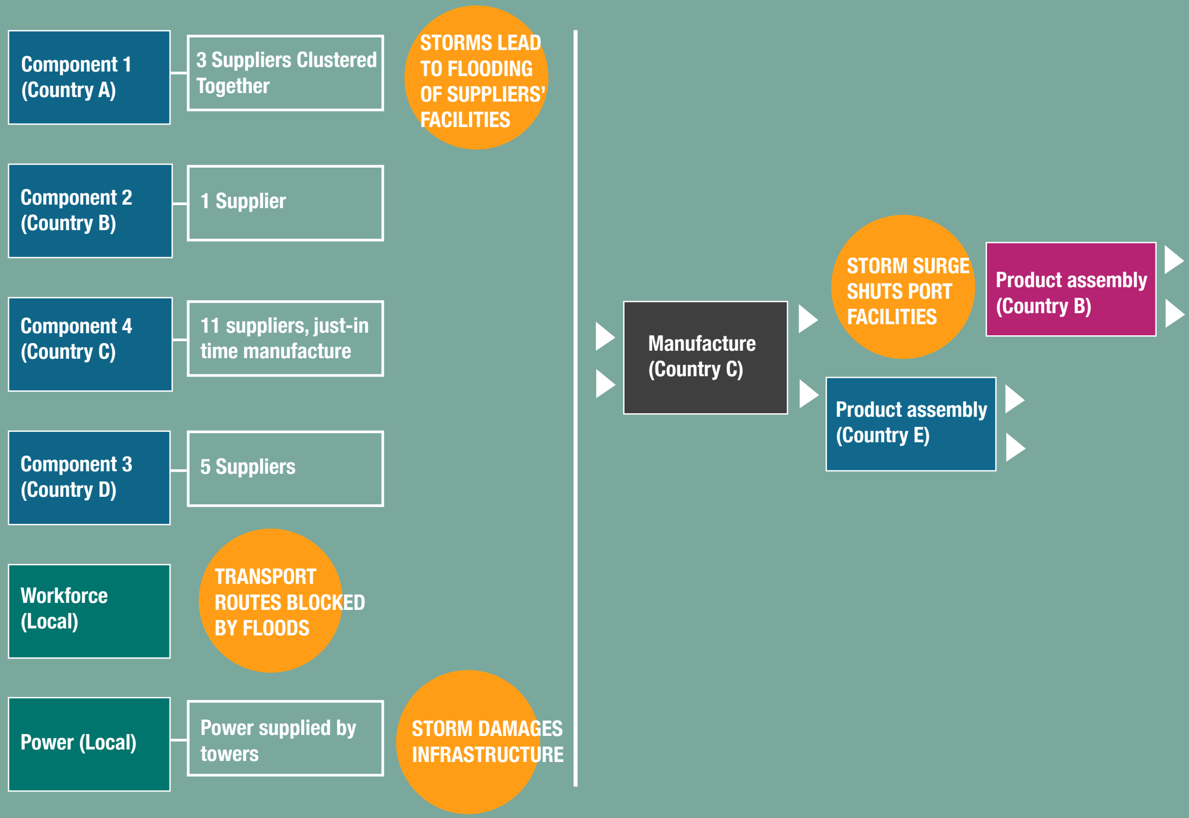
- What weather-related hazards have impacted the supply chain in the last five to 10 years?
- What weather-related hazards are known to occur in the geographical areas where elements of the supply chain are located?

Future climate change projections also serve as input to climate resilience assessments, with potential changes in the frequency, duration or intensity of weather-related hazards or to new hazards. Questions include:

- What are the projected changes in frequency/duration/intensity of weather-related hazards that are relevant to specific elements?
- Are new weather-related hazards appearing as a result of climate change?

Figure 15 illustrates weather-related hazards based on the supply chain structure identified above.

Figure 15: Climate resilience assessment – weather-related hazards

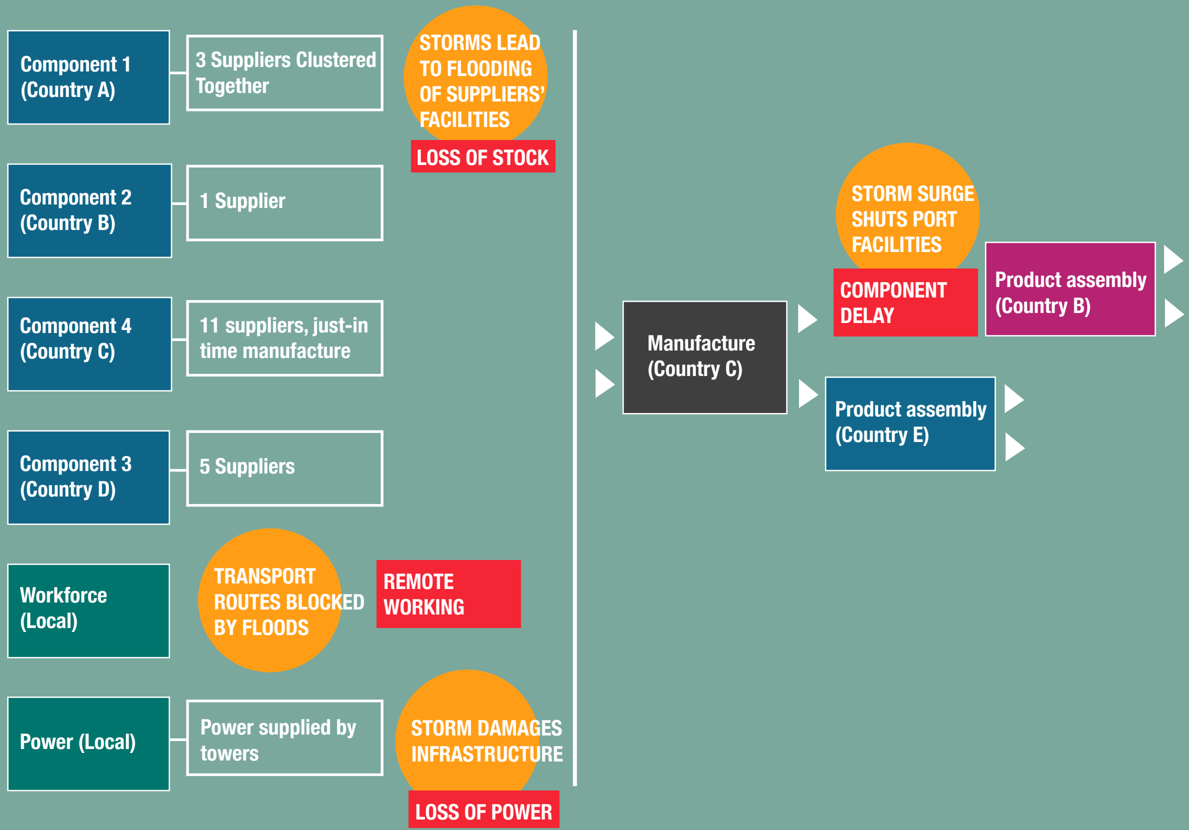


Step 3. Identify vulnerabilities and evaluate the risks

Large companies are likely to have an existing mechanism or framework for assessing supply chain risk. Extreme weather and climate change are additional elements which should be considered within such frameworks.

Information on the impact or cost of previous extreme weather events on similar supply chains can be useful in helping to assess the potential consequences of future events. Climate change will potentially change the likelihood and severity of events so an assessment should consider the existing level of risks and how climate change might amplify those risks.

Figure 16: Climate resilience assessment – identify vulnerabilities and assess risks



Step 4. Define and apply resilience building measures

Once the risks facing the company have been identified, resilience-building measures can be defined. They should ideally be conceived and applied with close attention to benefits and consequences across the supply chain system. This approach requires a collaborative outlook, a holistic approach to considering risks and mitigation, and a willingness to consider changes to supply chain structures as well as to apply individual measures.

Examples of resilience-building measures could include:

- Defining and adopting ‘supply chain stewardship’ policies and approaches encouraging collaboration and information exchange throughout the supply chain. This could include disseminating briefing information to encourage better mutual understanding of the issues;

- Assessing the flows of information and the adoption of standards, to ensure that they are compatible with and complement resilience-building measures;

- Maintaining an understanding of the supply chain’s overall capacity and its capacity utilisation. Ideally there should be a margin so that spare capacity can be brought into play in the event of climate disruption to minimize business impacts;

- Effective monitoring and documentation of how the supply chain is affected by extreme weather and weather-related events and the approach to associated recovery processes. This helps to understand the nature of the risks in more detail and allows wider resilience to be built by learning from previous experiences;

- Requiring a statement of climate resilience as a relevant part of contractual conditions for suppliers, and requiring suppliers to undertake vulnerability assessments in relation to climate change and weather-related events. This will enable suppliers to build awareness and develop contingency/recovery plans which can be used as positive marketing material for their dealings with customers and with their own suppliers;

- Exploring ways in which risks can be minimized (e.g. exploring alternatives to logistics arrangements, transferring production processes within or between sites, ensuring that facilities are designed to withstand severe weather events while maintaining operation).

- Collaboration with Administrations to identify critical infrastructure and promote resilient and robust transportation networks;

Resilience-building measures are illustrated in figure 17. The overall analysis process for supply chain vulnerability, weather-related hazards, resulting risks and resilience measures is summarized in table 6.

Figure 17: Climate resilience assessment – resilience building measures

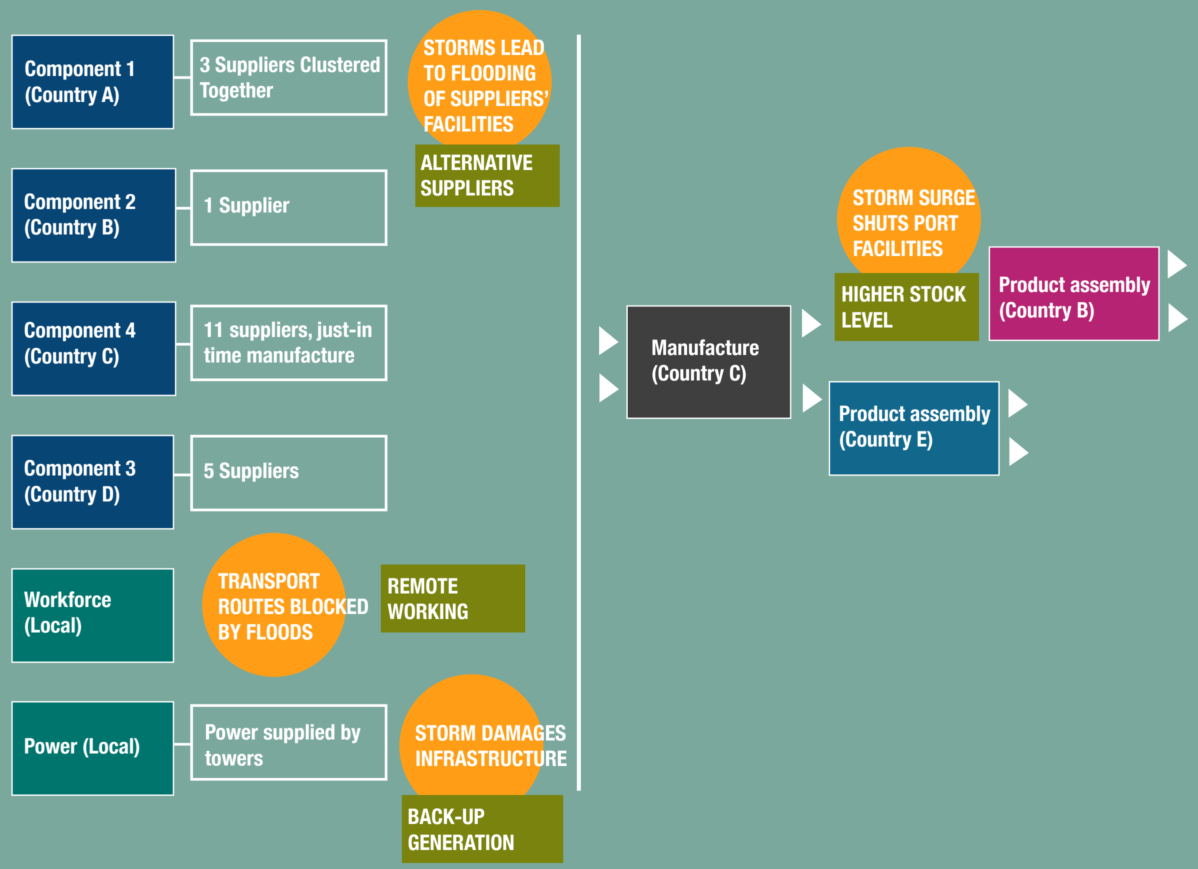


Table 6: Climate resilience assessment – illustration of the overall analysis

Supply Chain Element	Critical Features	Weather-related Hazard	Vulnerability & Risk	Resilience Measure
Component Supplier 1	Suppliers are geographically clustered	Storms lead to flooding of supplier's facilities. Storms projected to become more frequent with climate change	Loss of stock due to flooding of facilities	Availability of alternative suppliers to maintain supply following disruption
Manufacturer	Single manufacturing location	Storm surge shuts port facility. Port is in an area anticipated to suffer more storms and typhoons over time.	Insufficient stock due to transport delays	Increase stock levels to provide buffer against supply disruption
Local Power Generation	Vulnerable to high winds	Storm damages infrastructure. Future change to storm frequency not known	Loss of power due to storm damage to infrastructure	Back-up power generation to provide continuity
Local Workforce	Single transport route for workforce	Transport route blocked by floods. Future severity of floods anticipated to increase	Floods block transport route leading to remote working	Develop remote working contingency plans

Table 6 summarizes the analysis in Steps 1 to 4 of the framework. In practice, elements of the supply chain may face more than one vulnerability, or more than one risk arising from each vulnerability. There may also be a variety of potential resilience measures that could be applied to mitigate the consequential risks.

Step 5. Monitoring and review

The analysis process will be iterative, with monitoring and review an important aspect. Information should continue to be gathered to:

- Review how the supply chain has been affected by extreme weather events, to improve understanding of relevant risks;
- Interpret logs of climate-related impacts to gain further insight into risk ratings;
- Review the effectiveness of resilience-building measures.

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To contact the WBCSD about this report:
Rasmus Valanko
Manager, Climate & Energy
valanko@wbcsd.org

For general enquiries at WBCSD:
María Mendiluce,
Managing Director, Climate & Energy
mendiluce@wbcsd.org

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World Business Council for Sustainable Development
Geneva secretariat Maison de la Paix, Chemin Eugène-Rigot 2, Case postale 246, 1211 Geneve 21,
Tel: +41 (0)22 839 31 00
New York Office 115 Fifth Ave, 6th Floor, New York, NY 10003
India Office DLTA Complex, South Block, 1st Floor, 1 Africa Avenue, New Delhi 110 029, India,
Tel: +91 11 3352 1527