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WWF SOUTH AFRICA

POLICY BRIEF

FUTURE PROOFING SUPPLY CHAINS FOR CLIMATE RESILIENCE

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SUMMARY

The drive for supply chain efficiency and optimisation over resilience has left global supply chains vulnerable to shocks and disruptions, as the COVID-19 crisis has clearly illustrated.

Supply chains that value efficiency over resilience can exacerbate the negative socio-economic impacts of disruptions, such as pandemics or climate disasters, and spread them across the global economy.

Improving supply chain resilience to disruptions is critical for mitigating negative impacts of future climate disasters; strengthening climate change adaptation strategies and building climate resilience.

Five high level activities are recommended for improving supply chain resilience to climate disasters and other shocks:

1. **Identify strategic priorities** for improving resilience;
2. **Map supply chain vulnerabilities** and improve network visibility;
3. **Improve collaboration and coordination** throughout the supply chain network;
4. **Improve supply chain agility, flexibility and responsiveness** through postponement of manufacturing and delivery, and identifying multiple transport links**;**
5. **Improve knowledge management** through continuous monitoring and evaluating of supply chain risks, potential disruptions and mitigation strategies**.**

This policy brief seeks to provide insight into the importance of enhancing supply chain resilience as a climate change adaptation measure for mitigating potential socio-economic impacts from disruptions such as climate disasters.

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INTRODUCTION

History is replete with examples of anthropogenic activity undermining critical natural processes leading to the eventual collapse of human societies (Diamond, 2005; Willett, 2016). Climate change presents a new chapter in this history, one in which the world's addiction to carbon-intensive development is "adding fuel to the fire". There is significant evidence to suggest that climate change will increase the frequency and intensity of meteorological disasters, threatening global socio-economic sustainability and human well-being (Felbermayr & Groschl, 2014; IPCC, 2018).

In addition, highly efficient global supply chains[1], that seek to maximise asset utilisation, reduce inventories, peruse just-in-time delivery and minimise costs, have inadvertently removed important buffers and flexibility from the system, leaving it unable to absorb and adjust to disruptions (Kilpatrick, 2020). To this end, globalisation and the pursuit of supply chain efficiency over resilience has increased the global economy's exposure to "climate disaster" [2] risks (Abe & Ye, 2013).

The recent COVID-19 pandemic is testament to this "efficiency-induced" vulnerability of global supply chains. The outbreak disrupted production and manufacturing in China, the "world's factory", reducing the supply of goods into the global supply chain and eventually impacting production across the world. This disruption to the global supply chain, without any damage to or destruction of productive assets and critical infrastructure, is expected to cost the global economy approximately US$1.1 trillion (~R18.7 trillion) in lost income (Betti & Hong, 2020).

Enhancing supply chain resilience to shocks, such as the COVID-19 pandemic, geopolitical tensions and climate disasters, is critical for improving risk competiveness and militating against negative socio-economic impacts of such disruptions.

STREGNTHENING GLOBAL AND LOCAL SUPPLY CHAIN RESILIENCE TO CLIMATE DISASTERS IS CRITICAL FOR:

- **Minimising direct short-run impacts** in affected areas by ensuring effective and efficient provision of life saving aid and relief supplies;
- **Providing support for recovery** and rebuilding efforts to prevent long-term poverty traps;
- **Reducing broader indirect socio-economic spill-over effects** through ridged global supply chains, such as reduced production, job losses, decreased international competitiveness and price increases, amongst others;
- **Strengthening climate change adaptation strategies and measures;**
- **Enhancing climate resilience**

SUPPLY CHAIN RESILIENCE

Supply chain resilience is defined as: *"the ability to proactively plan and design the supply chain network for anticipating unexpected disruptive (negative) events; respond adaptively to such disruptions while maintaining control over operations, and potentially gaining competitive advantage"* (Ponis & Koronis, 2012, p. 925).

"Ridged" supply chains refer to those that prioritise traditional performance metrics of cost, quality and delivery over resilience, responsiveness and re-configurability, and are therefore, generally more susceptible to disruption.

[1] Supply chains are defined as "the material and informational interchanges in the logistical process stretching from acquisition of raw materials to delivery of finished products to the end user. All vendors, service providers and customers are links in the supply chain." (CSCMP, 2013, p. 186).

[2] For the purpose of this paper, climate disasters refer to meteorological disasters that have been influenced by anthropogenic-induced climate change.

Building resilience into supply chains must also be understood as a critical activity for improving climate change adaptation strategies and measures, and for strengthening climate resilience (Kreie, 2013; Klomp, 2016; Willett, 2016; Sawanda & Takasaki, 2017).

Climate change adaptation policies and measures aim to minimise short- and long-term socio-economic and human well-being impacts of climate change, such as rising sea levels and global temperatures, droughts, floods, hurricanes and fires (UNFCCC, 2020). While there are a number of factors that contribute to the severity of disasters and their impacts, supply chains (and their level of resilience) play an important role in either exacerbating or mitigating such impacts (Kreie, 2013; Willett, 2016). To this end, improving supply chain resilience to climate shocks must form a critical part of any business strategy or public policy, but particularly for climate change adaptation strategies, whether at a regional, national, community or organisational level.

This is particularly important for developing countries that do not necessarily have the safety nets (such as access to credit markets or insurance, for example) to deal with climate disasters as and when they strike, and to mitigate their long-term socio-economic impacts. South Africa, in particular, is susceptible to the physical impacts of climate disasters, which threaten to perpetuate inequality, poverty and unemployment. These socio-economic challenges are also at risk of being amplified by international climate disasters should we not implement effective adaptation strategies and enhance the resilience of both formal and informal supply chains within and across our borders.

While the South African Government has developed a draft National Climate Change Adaptation Strategy (DEA, 2017), it does not sufficiently speak to the critical importance of improving supply chain resilience for mitigating against the negative impacts of climate disasters. While the strategy acknowledges the threat of such disasters to supply chains, it does not advocate for improving supply chain resilience as a key feature of climate change adaptation.

The policy brief seeks to provide insight into the importance of enhancing supply chain resilience (at an international, national and organisational level) as a climate change adaptation measure for mitigating potential socio-economic impacts from climate disasters. Public and private entities are encouraged to strengthen their supply chain resilience through a 5-step process identified in the paper.

THE ECONOMIC IMPACTS OF THE COVID-19 PANDEMIC

- The pandemic is impacting all sectors around the world, from tourism to manufacturing and research to agriculture (Letzig, 2020).
- Disruptions to global supply chains are expected to cost the global economy approximately **R18.7 trillion** in lost income (Betti & Hong, 2020).
- China's economic growth is expected to drop to 4.5% in the first quarter of 2020 – the lowest it's been since the 2008 financial crisis (Betti & Hong, 2020).
- The virus has affected suppliers to and supply chains of 938 companies of the Fortune 1000 (Betti & Hong, 2020).
- Reduced production in China threatens to prevent India from reaching its target of producing 100 gigawatts of electricity from solar power by 2022 as 80% of the solar panels are produced in China (Letzig, 2020).
- China is South Africa's largest trading partner and as such, various industries can expect adverse impacts from the pandemic, including construction, mobile operators, tourism and hospitality, automotive manufacturing and retail (Strategy&, 2020).
- The reduction of Chinese tourists visiting South Africa is estimated to cost R200 million in lost spending by those tourists (Strategy&, 2020).

SOCIO-ECONOMIC IMPACTS OF CLIMATE DISASTERS

The last decade saw some of the most devastating climate disasters in recorded history, such as the record breaking 2017 hurricane season in the USA and Central America (Palin, et al., 2018; Abe & Ye, 2013). The 2019 Tropical Cyclones Idai and Kenneth, affected large parts of south east Africa and were dubbed two of the most destructive tropical cyclones in history and the worst meteorological disasters in the southern hemisphere (Yuhas, 2019; Miller, 2019). In a matter of a few hours, Cyclone Idai destroyed 90% of the city of Beira in Mozambique and disrupted electricity supply to South Africa, resulting in load shedding (Slabbert & Slatter, 2019). Zimbabwe also fell victim to load shedding as a result of a climate disaster – a drought, with the lowest rainfall in 40 years, lowered water levels at Kariba Dam to a point where the hydropower facility could no longer provide a secure supply of electricity (Thompson, 2019).

More recently, devastating wildfires in Australia burnt about 73 000 km^2 of land across all six states, destroyed more than 2 000 homes and released approximately two thirds of Australia's annual GHG emissions (350 million tonnes of carbon dioxide equivalent) into the atmosphere (Yeung, 2020; Hutt, 2020). It is estimated that it could take forests more than a century to re-absorb emissions released by the wildfires (Hutt, 2020). Air quality and human health in surrounding areas were also affected, with Sydney having an air quality reading of more than 11 times the hazardous level in early December 2019 (Yeung, 2020).

Climate disasters, therefore, have a number of direct and indirect impacts. Direct impacts include loss of life and damage to capital, property and infrastructure, such as damage to utility systems that provide water, food, fuel and medicine (Cavallo & Noy, 2011).Direct impacts can, therefore, prevent the supply of basic commodities required for a functioning society, leading to a number of indirect impacts (Palin, et al., 2018). Hurricane Harvey, which hit the USA in 2017, generated an estimated US$125 billion (≈R1.8 trillion) in direct infrastructure and property damages, making it the second most costly hurricane after Hurricane Katrina (Palin, et al., 2018).

Indirect impacts, on the other hand, refer to the absence of economic activity as a result of the direct impacts from a climate disaster (Cavallo & Noy, 2011). They can extend beyond declared disaster sites via supply chain disruption, affecting the broader national, regional and even global economy (Sawanda & Takasaki, 2017). Indirect impacts include reduced production, transport, consumption and international competitiveness; price increases; job losses and can even exacerbate inequality and poverty via a global recession, as we are currently witnessing with the impact of COVID-19 (Cavallo & Noy, 2011).

While global supply chains have increased efficiency in the production and delivery of commodities, they have also increased the global economy's exposure to risks from external shocks, (Abe & Ye, 2013) such as climate disasters or pandemics like Covid-19. Efficient supply chains that pursue cost minimisation and facilitate just-in-time delivery, for example, rarely stockpile goods in case of disruptions, suggesting that in the event of a shock there will be an immediate suspension of production or sales. We have witnessed this globally in the last few months with the COVID-19 pandemic. For example, the global automotive industry felt the shock early on as its just-in-time supply chain could not adapt to disruptions caused by the virus. China's automotive industry production rate is 50% lower than it was before the outbreak reducing automotive production around the world (Betti & Hong, 2020).

Global supply chains can, therefore, cause the indirect spill-over of negative effects of climate disasters across geographical boundaries in much the same way the COVID-19 pandemic has. For example, the 2011 floods in Thailand disrupted Nissan's and Toyota's supply chains, causing production to be suspended, despite the fact that the companies' production facilities were not directly affected by the floods (NISSAN, 2011; Toyota, 2011; Abe & Ye, 2013). This caused further disruptions to Toyota's production sites across the world, including in Vietnam, Pakistan, the USA and Canada (Abe & Ye, 2013).

TEXT BOX 1: HOW COVID-19 IMPACTED GLOBAL SUPPLY CHAINS – A WINDOW INTO THE FUTURE OF CLIMATE DISASTER IMPACTS?

In the space of just a few months, the COVID-19 pandemic has sent shockwaves through the global economy. With over 2.6 million recorded cases and over 184 000 deaths (Worldometer, 2020), and counting, the virus has forced businesses around the world to close their doors, in part because the workforce has been compromised by the virus (either directly through infection or indirectly through public lockdowns), but largely due to the disruption of global supply chains (Betti & Ni, 2020). Is this a glimpse into the future impacts of climate disasters that risk disrupting global supply chains on a similar scale?

Over the last three decades, China has become the hub of global manufacturing. It is the world's factory that produces the majority of processed materials, key inputs, components, parts and commodities that feed the global economy. Since the outbreak of COVID-19 started in China, it immediately reduced the supply of goods to the rest of the world, creating a knock-on effect that negatively impacted major industries around the world, including pharmaceuticals, medical equipment and supplies, the automotive and electronics industries, tourism and manufacturing (Letzig, 2020; Betti & Hong, 2020).

In response, some companies and manufactures implemented a variety of short-term solutions, including shifting orders from primary suppliers to secondary or tertiary suppliers (ordering from the suppliers that would normally supply their suppliers) and reabsorbing some core functions back into their own business or factories (Betti & Ni, 2020). Others re-tooled their production systems to manufacture alternative products, such as face masks or ventilators that are currently in high demand, in an attempt to minimise financial losses and ultimately support the global effort in tackling COVID-19. For example, Shanghai-GM-Wuling (SGMW), an automotive manufacturer in China, repurposed its production system to manufacture face masks after losing 90% of their core business in February 2020 as a result of the virus (Betti & Ni, 2020).

However, these short-term adjustments have done little to minimise the socio-economic impacts of the COVID-19 outbreak, which has highlighted the vulnerability of global supply chains to external shocks. The virus has also exposed how numerous governments, multinational companies and small businesses are not fully aware of the interconnectedness of their supply chain networks to the global economy or the vulnerabilities they face (Kilpatrick, 2020). Longer-term resilience needs to be built into the global supply chain system to prevent such wide spread impacts during future disruptions, such as climate change and climate disasters.

The socio-economic impacts of the COVID-19 pandemic are unique in that the virus is simultaneously reducing both the supply (workers cannot go to work) of and the demand (consumers are self-isolating, in lockdown or have lower disposable income from job losses) for goods and services around the world. Can we expect similar disruptions from future climate disasters, which, unlike the COVID-19 pandemic, will almost certainly damage property, infrastructure and productive assets, adding to the overall cost of climate disasters and which will take time to rebuild? Will we heed the lessons from the pandemic and build a more sustainable, climate resilient future post-COVID-19, or will we bury our heads in the sand and continue to ignore the threat of climate change?

THE ECONOMICS OF CLIMATE DISASTERS

Global supply chains, as mentioned previously, can spread indirect impacts of climate disasters (reductions in production, international competitiveness and job losses, for example) beyond the declared disaster site and affect the broader national, regional or global economy (Sawanda & Takasaki, 2017). Therefore, thinking about and understanding climate disasters as economic phenomena[3], rather than purely exogenous events, allows us to better understand their socio-economic impacts (beyond the obvious damages to property and infrastructure); improve mitigation and recovery plans to reduce negative impacts; strengthen climate change adaptation strategies and build climate resilience; and identify fundamental structural determinants that influence the severity and distribution of those impacts outside of the disaster itself (Cavallo & Noy, 2011; Felbermayr & Groschl, 2014; Klomp, 2016).

However, measuring damages and socio-economic impacts from climate disasters is difficult, leading to some disagreement in the empirical literature as to their true socio-economic costs (Cavallo & Noy, 2011; Cavallo, et al., 2013; Felbermayr & Groschl, 2014; Gignoux & Menendez, 2016; Klomp, 2016). Economic theory is also divided on this topic, suggesting different types of natural disasters[4] (including climate disasters) can have diverse, even opposite impacts on economic growth (Felbermayr & Groschl, 2014; Gignoux & Menendez, 2016; Klomp, 2016). Standard *neoclassical growth theory* suggests natural disasters that destroy productive capital (human or physical) will lower economic growth in the long-run and potentially lead to a poverty trap[5] (Cavallo, et al., 2013; Felbermayr & Groschl, 2014; Gignoux & Menendez, 2016; Klomp, 2016).

THINKING OF CLIMATE DISASTERS AS ECONOMIC PHENOMENA:

Examining climate disasters as economic phenomena, rather than exogenous events, allows us to:

- **Better understand their socio-economic impacts** beyond the obvious damages to property and infrastructure;
- **Improve mitigation and recovery plans** to reduce negative impacts;
- **Strengthen climate change adaptation** strategies to build climate resilience; and

Strengthening supply chain resilience will help reducing the negative socio-economic impacts of climate disasters and strengthen climate change adaption strategies and practices.

[3] It is widely accepted that anthropogenic activities and carbon-intensive global development have caused climate change and ultimately created more frequent and intense meteorological/climate disasters (Cook, et al., 2016; IPCC, 2018). The impacts of these disasters are inherently economic as well - the destruction of working capital, infrastructure, reduced output and income. Thus, both the cause and effects of climate disasters are inherently economic in nature.

[4] Natural disasters include both climate disasters and geological disasters, such as volcanoes and earthquakes.

[5] A poverty trap is a self-reinforcing mechanism that causes poverty to persist. Individuals, households, even countries may be subject to a poverty trap.

Endogenous growth theories, on the other hand, are less clear as to the impact of natural disasters. For example, *Schumpeter's creative destruction theory* proposes that higher economic growth rates can occur as a result of a natural disaster (Cavallo, et al., 2013; Klomp, 2016). Disasters can be a catalyst for reinvestment and upgrading of capital goods and assets, using new technologies for improved efficiency, productivity and output, thereby fostering higher economic growth, international competitiveness and job creation.

Countries with well-designed interventions and financial capacity can also upgrade local infrastructure for the benefit of local producers and supply chains. Infrastructure upgrades following a disaster can be adapted for current needs and possibly generate higher gains relative to before the disaster (Gignoux & Menendez, 2016).

However, while the theory of creative destruction should improve the lives of all disaster victims, in reality it seldom does. It is often the case that "*disaster capitalism*" takes over, where political elites wait for disasters to capitalise and profit at the expense of disaster victims (Klein, 2017). While such an argument is extremely nuanced, it is argued that disaster capitalism stems from decades of neoliberal policy and its neglect of public infrastructure (Klein, 2017). Unfortunately, as with most neoliberal policies, there are winners and losers, with the poor usually getting the short end of the stick.

SHORT-RUN SOCIO-ECONOMIC IMPACTS

For the sake of simplicity, socio-economic impacts from climate disasters are organised into short-run (up to five years after the disaster) and long-run (longer than five years) impacts (Cavallo & Noy, 2011). Short-run impacts include loss of life and damages to private property and public infrastructure, such as energy grids, transport networks, water and sanitation systems. These damages disrupt important supply chains that provide aid and relief after the initial disaster and prevent normal civic functions from resuming thereafter (Gignoux & Menendez, 2016). This can lead to a number of indirect socio-economic impacts in the short-run and into the long-run.

Destruction of private capital, such as crops, livestock or machinery; or collective capital, such as irrigation systems and transport infrastructure reduces individuals', companies' and governments' income earning potential and economic growth in the short-run (Cavallo, et al., 2013; Felbermayr & Groschl, 2014; Gignoux & Menendez, 2016). Those who cannot afford to fix, replace or substitute their damaged capital are forced to reduce their consumption or liquidate productive assets for rebuilding essential non-productive assets, such as houses. In doing so, victims can potentially fall into a poverty trap in the long-run (Cavallo, et al., 2013; Felbermayr & Groschl, 2014; Gignoux & Menendez, 2016).

The extended drought in South Africa (from 2015 to 2018) caused substantial damage to private capital in the form of crop damages and significantly reduced agricultural output. Agricultural income in the Western Cape province alone was estimated to have decreased by R5.9 billion between 2017 and 2018 (Smith, 2018), leading to job losses and reduced international competiveness for agricultural exports such as maize, grains and fruits (BFAP, 2016; Pienaar & Boonzaaier, 2018).

Such high economic losses are in line with other empirical studies that suggest natural disasters can reduce output, economic growth and GDP per capita in the short-run, particularly in the first year after the disaster, see Table 1 (Felbermayr & Groschl, 2014).

Climate disasters can also induce negative welfare impacts that threaten to propagate into a poverty trap in the long-run. Unemployment, for example, can increase - an estimated 15 000 jobs were lost in the agricultural sector between 2015 and 2016 as a result of the drought in South Africa (RSA, 2016). Wages can also be negatively affected by climate disasters, even in different sectors and regions not directly affected by the disaster itself (Kirchberger, 2017).

There is also evidence to suggest that disasters can increase poverty and reduce human development[6] (Mechler, 2009), with one study (Sawanda & Takasaki, 2017) developing a formal disaster-poverty nexus to better understand the relationship between the two. Education, gender equality and fertility can also be negatively affected in the short-run (Cavallo & Noy, 2011).

Empirical evidence, therefore, suggests that natural disasters have, on average, negative socio-economic impacts in the short-run. This should sound alarm bells for South Africa where GDP growth is almost stagnant and unemployment and inequality rates are amongst the highest in the world (Slater, 2013). This is in addition to the country's vulnerability to climate disasters.

LONG-RUN SOCIO-ECONOMIC IMPACTS

Again, there is some disagreement in the literature (both theoretically and empirically) as to the true nature of long-run socio-economic impacts of climate disasters. For example, a review of the empirical literature[7] suggests 25% of studies found a negative impact on real GDP per capita in the long-run, while 15% found a positive effect (Klomp, 2016).

There are a number of possible reasons for this disagreement. Firstly, accurately measuring the long-run impacts of natural disasters is made difficult by the number of different variables and mechanisms at play (Gignoux & Menendez, 2016). Secondly, it is difficult to construct appropriate counterfactuals for estimating what would have happened to various socio-economic variables in the absence of a climate disaster (Cavallo & Noy, 2011).

Table 1: Natural disasters' average impact on GDP per capita in the short-run across the world

Disaster severity	Decrease in GDP per capita
Devastating disasters	6.83%
Moderate disasters	0.46%
Mild disasters	0.01%

Source: (Felbermayr & Groschl, 2014). *Note: These studies include all natural disasters and are not limited to climate disasters*.

In 2017 Hurricane Harvey caused an estimated US$125 billion (≈R1.8 trillion) in infrastructure and property damages, making it the second most costly hurricane after Hurricane Katrina (Palin, et al., 2018).

[6] Human development was measured by the World Bank's Human Development Index (HDI).

[7] Note that the review of empirical literature by Klomp (2016) is not isolated to climate disasters and includes both geophysical and meteorological disasters.

Lastly, there are also issues surrounding the availability and accuracy of economic and welfare data that could potentially skew empirical results by creating false positives or false negatives. This is particularly challenging in developing countries, where economic and welfare data can be unreliable or non-existent (Klomp, 2016).

Nonetheless there are a number of studies that support traditional growth theory and suggest natural disasters have a negative long-run impact. For example, Hallegatte *et al.* (2007) and Hallegatte *et al.* (2017) found that disasters can potentially overwhelm the reconstruction capacity of a country, leaving it stuck in a poverty trap due to the amplification effect[8]. This is particularly true for developing countries that do not have the necessary safety nets to prevent a poverty trap, hence the importance of introducing the Warsaw International Mechanism for Loss and Damage[9] under the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC, 2020).

Another study found a lasting impact on GDP per capita 10 years after the disaster, where the affected countries' GDP per capita decreased by 10% on average, relative to an estimated 18% increase in the counterfactual scenario (Cavallo, et al., 2013). Felbermayr and Groschl (2014) suggest that natural disasters, on average, harm economic development, period.

A number of other studies (although fewer in number) find evidence to support the theory of creative destruction. Skidmore and Toya (2002) found positive long-run effects on economic growth following disasters and Crespo Cuaresma *et al.* (2008) find evidence to support creative destruction, all-be-it only in developed economies. Klein (2017) finds evidence of disaster capitalism across a number of different disasters, but particularly in the case of Hurricane Katrina.

SHORT-RUN IMPACTS OF THE DROUGHT IN SOUTH AFRICA BETWEEN 2015 AND 2018:

- The drought caused substantial damage to private capital in the form of crop damages and significantly reduced agricultural output.
- An estimated **15 000 jobs were lost** in the agricultural sector between 2015 and 2016 (RSA, 2016).
- Agricultural income in the Western Cape alone was estimated to have decreased by **R5.9 billion** between 2017 and 2018 (Smith, 2018).
- South Africa went from a net exporter to a net importer of maize, losing its international competitiveness for maize and other agricultural exports including grains and fruits (BFAP, 2016; Pienaar & Boonzaaier, 2018).

[8] The economic amplification effect, or ratio, is a multiplier effect from direct capital destruction to indirect economic losses (Hallegatte, et al., 2007).

[9] The Warsaw International Mechanism for Loss and Damage seeks to assist developing countries that are vulnerable to climate impacts and disasters by implementing Article 8 of the Paris Agreement and promoting approaches to address impacts that result from climate disasters (UNFCCC, 2020). The mechanism aims to improve knowledge and understanding of climate risk management approaches; improve action and support (including capacity building, technology and finance) and enhance coordination and dialog amongst stakeholders to address loss and damages from climate disasters (UNFCCC, 2020).

However, outside of the empirical data limitations, each country exists within its own particular context adding to the difficulty of measuring socio-economic impacts of climate disasters. It is nonetheless important to understand how a country's economic, social and political context influences the severity of socio-economic impacts from climate disasters.

ECONOMIC, POLITICAL AND SOCIAL FACTORS INFLUENCING CLIMATE DISASTER IMPACTS

Climate disaster impacts are generally more severe in developing countries relative to developed countries, for a number of reasons. Firstly, developed countries generally have more resources to spend on prevention and restoration efforts (Raddatz, 2009; Gignoux & Menendez, 2016; Felbermayr & Groschl, 2014). This is already acutely visible in response to Covid-19 crisis, with the USA announcing a $2 trillion (equivalent to ~R36 trillion or roughly seven times the size of the South African economy)[10] COVID-19 stimulus package (Wasserman, 2020).The G20 has also been urged to provide $8 billion (~R16 billion) in relief funds to developing countries for combatting the pandemic (Elliott, 2020).

Secondly, developed countries generally have stronger policy interventions and legal enforcement, including building codes, land-use planning and engineering interventions for example, which are likely to reduce the impacts of climate disasters (Cavallo & Noy, 2011).

Access to insurance and credit markets is also important for climate disaster resilience and recovery, from a household through to national level, allowing victims to rebuild productive assets without the risk of falling into a poverty trap (Gignoux & Menendez, 2016). In the absence of insurance and credit markets, victims may be forced to reduce their consumption to finance rebuilding or repairing productive assets. Alternatively, these households might have to sell off productive assets to rebuild their homes and maintain a minimum consumption level that is necessary for survival. This can reduce their welfare in the short-run and potentially push them into a poverty trap in the long-run (Gignoux & Menendez, 2016).

Other macro-economic conditions, such as greater trade and financial openness; higher levels of government spending and domestic credit; and more foreign exchange reserves provide resilience to the initial impacts of climate disasters and prevent long-run spill-over effects (Noy, 2009; Cavallo & Noy, 2011; Felbermayr & Groschl, 2014). For example, an open economy can increase investment for rebuilding and replacing productive assets without reducing consumption. This allows such countries to converge back to their original growth path faster and potentially even surpass it (Felbermayr & Groschl, 2014). Countries without access to strong financial markets may not be able to finance reinvestment and, therefore, risk falling into a poverty trap. The monetary system also plays a critical role here, where interest rate increases can ration recovery investments.

Stronger domestic institutions, including more stable democratic regimes, stronger property rights security and greater political accountability also contribute to reducing disaster impacts. These factors can encourage foreign direct investment by signalling a stable economy, which fosters quicker recovery (Healy & Malhorta, 2009; Noy, 2009; Cavallo & Noy, 2011; Felbermayr & Groschl, 2014).

Inequality is another important determinant of resilience. More unequal societies generally spend less resources on disaster prevention and mitigation measures, thereby increasing their risk and exposure to climate disasters (Anbarci, et al., 2005). This trend is evident in South Africa, one of the most unequal economies in the world, where only R500 million was allocated to disaster management and relief in the 2020 National Budget (RSA, 2020). Interestingly, literacy rates are also closely linked to disaster resilience – countries with higher literacy rates tend to be more resilient (Noy, 2009).

[10] South Africa's GDP at the end of 2019 was estimated at R5.18 trillion (SARB, 2020).

THE IMPORTANCE OF SUPPLY CHAIN RESILIENCE FOR CLIMATE CHANGE ADAPTATION

Supply chains also play an important role in mitigating or amplifying the negative socio-economic impacts of climate disasters (Palin, et al., 2018; Willett, 2016; Kreie, 2013). Enhancing and strengthening supply chain resilience will allow for more effective and efficient aid and relief immediately following a climate disaster and better support recovery efforts. In addition, resilient and flexible supply chains prevent the spill-over of socio-economic impacts to other geographic locations (Palin, et al., 2018; Willett, 2016; Kreie, 2013). To this end, supply chain resilience must be seen as a critical component of climate change adaptation strategies, practices and measures for both private business and government. It is equally important, however, that supply chain resilience be mainstreamed across public policies and private business and not isolated to climate policy.

Climate change adaptation aims to improve social, economic and ecological systems' resilience to the various impacts of climate change and climate disasters by changing and adapting structures, practices and processes (UNFCCC, 2020). In doing so, various impacts are mitigated and/or moderated, while benefits can also be generated where opportunities for synergy exist to address ecological and socio-economic challenges. For example, providing low-income households with solar panels can help to address energy poverty while avoiding GHG emissions from coal-based grid electricity. There is no "one-size-fits-all" solution for climate change and adaptation policies and measures must be designed to suit specific contexts.

Adaptation policies and measures range from establishing early warning systems to building flood resilient infrastructure and sea level rise defences; from climate smart agriculture to improved communication systems and business operations (UNFCCC, 2020). Enhancing supply chain resilience to climate disasters is a crucial adaptation measure for business operations to continue and endure in a future characterised by more frequent and more intense hurricanes, floods, droughts and fires (Abe & Ye, 2013; Palin, et al., 2018; Ngwenya & Naude, 2016).

Globalisation and the development of global supply networks have improved the efficient delivery of goods and services around the world. Global supply chains are essentially the lifeblood of the global economy and the engine that drives economic development and growth (WEF, 2019). They provide us with everyday commodities, often taken for granted, which are not only vital for basic survival but for the efficient functioning of society and the global economy (Abe & Ye, 2013).

Traditionally, supply chains are measured against three key metrics: cost, quality and delivery. However, optimising supply chains according to cost minimisation, just-in-time delivery, reduced inventories and maximising asset utilisation has made them vulnerable to disruptions, which was made painfully evident by the COVID-19 pandemic (Betti & Ni, 2020; Kilpatrick, 2020).

The COVID-19 outbreak has clearly illustrated the need for governments and companies to improve their risk competitiveness rather than solely striving for efficiency and cost competiveness of their supply chains (Betti & Hong, 2020). To this end, strengthening supply chain resilience to external shocks and disruptions is critical for improving risk competitiveness.

Strengthening supply chain resilience is a dynamic, pro-active and holistic approach to managing supply chain risks and enhancing risk management strategies (Scholten, et al., 2014). It refers to an organisation's ability to adapt, survive and grow when faced with unexpected disruptions and events. It can also be understood as the supply chain's ability to absorb shocks between its various nodes and transport linkages (Scholten, et al., 2014).

Considering the various economic, social and political factors discussed above, improving supply chain resilience is something of a low-hanging fruit for building climate resilience. In doing so, climate change adaptation strategies will be strengthened, ultimately mitigating negative socio-economic consequences of climate disasters in South Africa, such as loss of life, damages to infrastructure, job losses, poverty traps, higher prices and reduce competitiveness in key export markets, amongst others.

Understanding supply chain vulnerabilities and the importance of resilience can inform both business strategy and public planning and policy in South Africa on how to strengthen climate resilience. This is critical given the already high levels of inequality, poverty and unemployment in addition to the country's vulnerability to climate change. This includes both the vulnerability to the physical impacts of climate disasters, but also the global economy's responses to climate change, often referred to as "transitional risk"[11].

SOUTH AFRICA'S TRANSITIONAL RISK

South Africa's exports will, in the near future, begin to face significant "carbon trade barriers" (Maguire, 2020). Carbon trade barriers stem from our trading partners' desire to reduce their GHG emissions, including those they import from other countries. Given South Africa's continued dependence on coal-based electricity, our exports account for approximately 45% of South Africa's total GHG emissions, significantly higher than the global average. The economy also has a high trade to GDP ratio (between 50-60%), suggesting that most of South Africa's GDP relies on carbon intensive trade (TIPS, 2013). Therefore, in an increasingly carbon constrained global economy, South Africa will lose its comparative advantage for such carbon intensive export commodities (TIPS, 2013), exposing the economy to trade vulnerabilities, reducing international competitiveness and bringing with it a host of additional socio-economic challenges.

Domestically, carbon-intensive industries are also at risk as we begin to transition to new, low-carbon industries. Such a transition threatens livelihoods of individuals in carbon-intensive industries and thus we must pursue a just transition to a low-carbon economy.

Lastly, South Africa is at risk of losing critical financial resources as various financial institutions are pulling out of fossil fuel-based economies. For example, the Swedish Central Bank sold off bonds in Australia and Canada because it felt GHG emissions in both countries were too high (Reuters, 2019).

[11] Transitional risks include those associated with market responses to climate change, mitigation and adaptation policies and measure. For example, fossil fuel-based sectors carry significant transitional risk in that the global economy is beginning to transition away from fossil fuels towards renewable energy in an effort to mitigate climate change.

UNDERSTANDING SUPPLY CHAINS AND THEIR VULNERABILITY TO CLIMATE DISASTERS

THE FOOD SUPPLY CHAIN

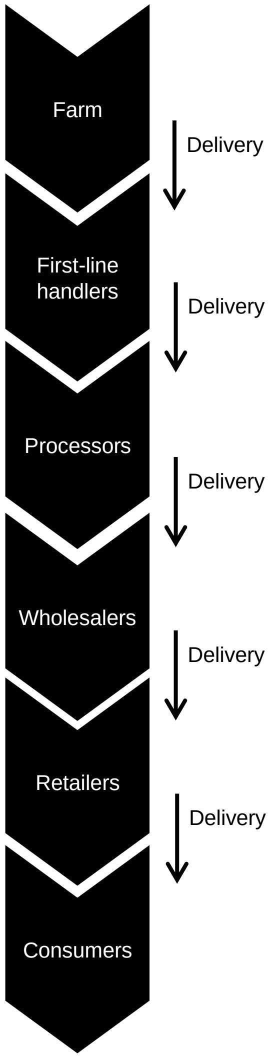
Food is a vital commodity for everyday life but is particularly critical during disasters. Figure 1, which leaves out raw materials inputs utilised by primary producers, provides a simple representation of the food supply chain from crop to table.

There are various elements along the food supply chain that support the efficient functioning of each production node and transport link. For example, wholesalers and retails rely on regular deliveries of food, electricity to store and refrigerate products, network connectivity to process payments and customers need to be able to access their stores to purchase their products (Palin, et al., 2018). Each of these elements along the supply chain can fail[12] during a climate disaster, limiting the supply of food products, fuel for transporting those products and electricity for storing and refrigerating those products.

There are a number of other factors to consider as well, such as the mode of transportation (ship, truck or train) for transporting food products, and the location and density of retailers within a particular area (Palin, et al., 2018). These factors can determine how efficiently food reaches areas where it is needed most during or after a disaster.

This is also true for other stages in the supply chain. Should a climate disaster impact or disrupt any of the supply chain nodes, transport links, or infrastructure on which the supply chain depends, (for example if crops are damaged, or food processors cannot function, or bulk storage facilities are destroyed during a hurricane or flood) then there may be food supply shortages. Food supply shortages, in turn, can cause additional indirect socio-economic impacts, either within the region of the disaster or elsewhere. For example, food price increases, job losses, poverty traps and reduced international competitiveness. Understanding these elements of the food supply chain can help identify vulnerabilities to climate disasters and is the first step in building resilience. See Text Box 2 for examples of how floods and droughts impacted food supply chains in South Africa.

FIGURE 1: THE FOOD SUPPLY CHAIN



Adapted from (Palin, et al., 2018)

[12] Supply chain failure or disruption refers to a major breakdown in a production node or distribution link in what forms part of the supply chain. Climate disasters are one cause of supply chain failure among other political and social causes (Abe & Ye, 2013).

TEXT BOX 2: THE IMPACT OF FLOODS AND DROUGHTS ON MAIZE PRODUCTION IN SOUTH AFRICA

Maize is a very important summer cash crop in South Africa. It provides staple food products for about 70% of the population and supports a number of secondary industries, such as livestock, with over R1.5 billion worth of business annually (Schreiner, et al., 2018). Maize is also a key export commodity. South Africa is the largest producer of maize on the African continent and supplies about 40% of its maize to trading partners in the Southern African Development Community (SADC), contributing to food security in the region (AgriSA, 2016). Between 2006 and 2016, South Africa produced an average of 1.5 million tonnes of maize per year for export, with an average annual value of R3.5 billion (AgriSA, 2016).

Flooding impacts

While there appears to be more research into the impacts of droughts on agriculture in South Africa, floods have also had significant negative impacts on the food value chain. In the summer of 2010/2011, the South Africa government declared disaster areas in eight of the nine provinces due to heavy rains and flooding. In addition to destroying about R1 billion worth of agricultural infrastructure, the floods also reduced agricultural production by about R1 billion, with maize being among the most affected crops. Not only did this result in reduced exports of maize directly (from reduced production) but also indirectly from disruptions to trains and railways used for transporting maize exports (M&G, 2011; Conway-Smith, 2011).

Drought impacts

Droughts too can have significant long-term impacts on the food value chain, reducing agricultural output, for example, for consecutive seasons. The extended drought between about 2015 and 2018 caused significant direct and indirect impacts across the maize value chain and secondary sectors (Schreiner, et al., 2018).

The total area of maize planted in South Africa decreased by 25% between 2015/16 and 2016/17 seasons and extreme temperatures negatively affected pollination, all of which resulted in significantly lower maize yields (AgriSA, 2016). Lower yields of maize and other domestic food crops caused food prices in South Africa to increase - maize for example, was said to increase by between 47% (AgriSA, 2016) and 75% (Maré & Willemse, 2016) on a year-on-year basis during the drought.

Lower maize production also meant that South Africa went from a net exporter to a net importer of maize, losing its international competitiveness and comparative advantage in maize and other agricultural markets. According to AgriSA (2016), the reduction of maize exports was valued at R12 billion in lost export revenue, with an estimated direct impact on the South Africa's Balance of Payments of about R4.7 billion. The increase in imports of maize put significant pressure on already inefficient ports and rail/road logistics systems, creating a bottle neck effect, which not only delayed the supply of maize but other imported products as well (Maré & Willemse, 2016).

The drought also caused a number of indirect impacts, having long-term employment, financial and debt implications for agri-business and placed increased pressure on the fiscus (BFAP, 2016; AgriSA, 2016). These additional pressures were felt both upstream and downstream of the maize supply chain and even in secondary sectors. For example, seed producers reported severe decreases in maize seed sales throughout the drought, which could not be stored and solid in subsequent seasons (AgriSA, 2016). Higher maize prices meant that millers had to reduce their production of maize meal. The feedlot industry also felt the impact of higher feed crop prices resulting in reduced demand for calves and lambs and higher red meat prices (Maré & Willemse, 2016).

In secondary sectors, annual tractor and combine harvester sales reduced by 11% and 30% respectively throughout the drought (AgriSA, 2016) and agri-businesses in the Free State saw a 50% reduction in revenue and jobs (Hlalele, et al., 2016). These examples highlight the critical need to improve the agricultural sector's resilience to climate disasters, one aspect of which would be to improve overall supply chain resilience. Doing so will minimise both the direct and indirect impacts of floods and droughts echoing through supply chains.

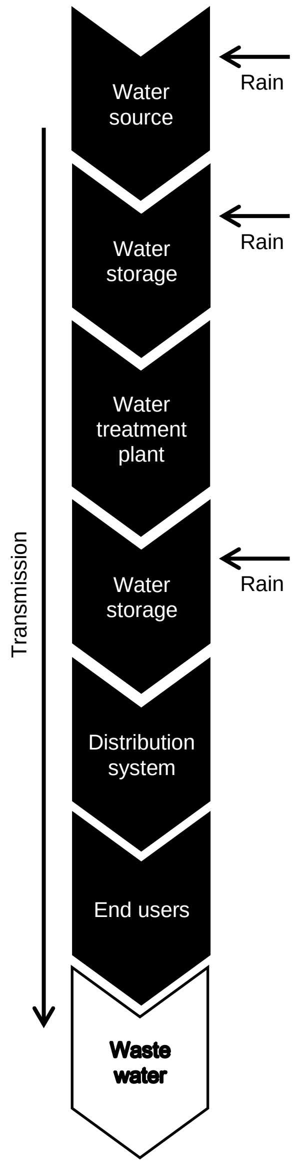
THE PUBLIC WATER SUPPLY CHAIN

Water supply and waste water services are critical for drinking, cleaning and cooking; and especially during disasters, for sanitation and fire suppression. Figure 2 provides a simplified representation of the public water supply chain, which requires a significant amount of infrastructure to function effectively and provide safe, reliable water supply services.

A unique feature of the water supply chain is that most locations rely on local supplies of water due to the expensive nature of transporting such a low value-high volume commodity over long distances (although this doesn't consider the water/diamond paradox[13] or the true value of water) (Palin, et al., 2018). Therefore, should the local water supply be affected by a climate disaster, it can be extremely difficult and expensive to source water from elsewhere. Water shortages can have widespread negative effects throughout a city, country or region, reducing economic activity and international competiveness across different sectors, threatening job losses and increasing various health risks depending on the disaster itself.

Some cities have, for various reasons, overcome these risks by sourcing water from other locations, which is a means of building supply chain resilience (Palin, et al., 2018). Johannesburg, for example, relies on inter-basin water transfer schemes that source water from other locations to meet the high water demands of the city. There are several inter-basin transfer schemes in South Africa, transporting water between all of the county's major water basins. While this has the potential to increase resilience to drought, should the infrastructure fail it could potentially bring about full system collapse.

FIGURE 2: THE PUBLIC WATER SUPPLY CHAIN



Adapted from (Palin, et al., 2018)

[13] The water/diamond paradox was first described by Adam Smith, the founder of modern economics, where he compared the high value of a diamond (which is not essential for human life) to the low value of water (which is essential for human life). Smith determined that "value in exchange" (the market price of a good or service) was irrationally separated from "value in use" (the intrinsic value of a good or service from which someone derives utility). So while the market price of water may be low, its intrinsic value for human life and economic activity is significant (Ross, 2018). This intrinsic value increases during the time of crisis.

While water systems are generally reliable, they are vulnerable to breakdowns during disasters (Palin, et al., 2018). Water source areas[14] can dry up in times of drought; pipelines, dams and storage tanks can break during floods and pumps can fail during power outages.

Should any of these dependencies fail then the supply chain can fail as a whole, negatively impacting on other secondary industries and supply chains that depend on water. The severe water shortages in the Western Cape between 2015 and 2018 illustrate some of these impacts (see Text Box 3).

It is, therefore, critical to review supply chain networks to identifying risks and vulnerabilities of failure or disruption during a climate disaster. The nature of the supply chain failure and how to repair or bypass it is also important since different disasters will require different solutions. Understanding how to avoid and/or remedy supply chain failure is critical for improving resilience and ensuring the disruption is corrected as quickly as possible (Palin, et al., 2018).

To this end, it is also necessary to consider the distribution of power and agency within a supply chain network and the relationships between its various role-players. Any linkages between formal and informal supply chains are also important in this regard.

According to Fayezi *et al*. (2012), supply chain managers, either private or public, can take advantage of agency theory's[15] descriptive and predictive qualities for managing relationships within a supply chain network and building resilience.

Agency theory, particularly positivist agency theory[16], can provide valuable insights for relationship engineering, understanding and mitigating unwanted behaviours and responding to transaction cost issues across supply chains (whether formal or informal) (Fayezi, et al., 2012). In doing so, agency theory can help remedy any unwanted behaviours, such as corruption; build trust across the supply chain; better understand how different role-players might respond to a climate disaster and encourage more collaboration among stakeholders (Fayezi, et al., 2012).

The COVID-19 pandemic, for example, saw a shift in bargaining power in certain industrial sectors, such as the electric vehicle (EV) industry. Here, bargaining power shifted from equipment manufacturers to suppliers. In response, Tesla announced a new partnership with CATL (a Chinese battery manufacturing company) who would supply EV batteries to Tesla, in addition to continued supply of EV batteries from Panasonic (Betti & Ni, 2020). Understanding how disruptions to supply chains will shift power dynamics and foster new collaborations is critical for strengthening supply chain resilience.There is also a need for regulatory bodies, such as the Competition Commission to oversee and facilitate power dynamics and agency issues in and across supply chains when addressing resilience to climate disasters (Fayezi, et al., 2012).

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14 A water source area is one that provides important water resources (due to higher than normal average annual runoff) to a region of interest. They can be regarded as natural "water factories", supporting economic development and human well-being to areas that are often a distance away (Nel, et al., 2013).

15 Agency theory is "a principle that is used to explain and resolve issues in the relationship between business principals and their agents" (Investopedia, 2019).

16 "Positivist agency theory" overcomes many of the shortcomings in principal-agent research, such as the issue of complexity surrounding real world relationship. The theory seeks to incorporate expert agency, political science, sociology and the law of agency into a single framework to explain how relationships develop in and between business and government. It also offers suggestions as to how they might be managed more effectively. Positivist agency theory is also useful for explaining irrational behaviour when sensitive information is not shared due to lack of trust (Fayezi, et al., 2012).

TEXT BOX 3: THE LOOMING THREAT OF DAY ZERO

In 2018, Cape Town, and indeed the Western Cape, survived one of the worst droughts in their history and narrowly escaped Day Zero – the day when all the taps would run dry. Dam levels hit all-time lows, causing disruption to the water supply chain that supports the Cape Town economy and important industries in the greater Western Cape, such as tourism and agriculture. In response, the city had to impose strict water restrictions, not only on its residents but businesses, industry and agriculture as well (Groenewald, 2018; Crabtree, 2018).

Socio-economic impacts

The water crisis had a number of negative socio-economic effects across the province and Day Zero would have only amplified those impacts. In 2017, the City of Cape Town earned a reported R3.9 billion from water services revenue, which represented about 10% to 15% of the city's total revenue (Groenewald, 2018; Tshwame, 2018; Toyana & Macharia, 2018; MSG, 2020). With water shortages and water restrictions in place, the City's finances took a hit as their income from water sales decreased significantly. This loss in revenue was compounded further by the increase in expenditure on emergency services and infrastructure in addition to higher operational costs that the City incurred while implementing water crisis management strategies (Groenewald, 2018; Tshwame, 2018; Toyana & Macharia, 2018; MSG, 2020).

Ratings agency Moody's also saw the drought as a significant risk to Cape Town's debt rating, which was already at the lowest ratings grade of Baa3, and exposing it to potential further downgrades. This would not only hamper much needed investment but increase the cost of obtaining critical funds for the city (Groenewald, 2018). In addition, Moody's reported that the water crisis, and Day Zero in particular, would expose the city to the threat of social disorder, amplified by already high levels of inequality (Groenewald, 2018; MSG, 2020).

The drought also affected businesses, particularly those reliant on water for primary production. According to a survey conducted by the Cape Chamber of Commerce, about 80% of businesses saw the water crisis as a significant threat to their operations (Tshwame, 2018). Two industries in particular, agriculture and tourism (two of the largest water consumers in the Western Cape), were the hardest hit by the water crisis (Groenewald, 2018).

Tourism impacts

Tourism is an important sector in South Africa, directly contributing about 3% to national GDP (similar to agriculture) and provides employment for just under 690 000 people, or 4.4% of South Africa's labour force (Stats SA, 2018). Between 2012 and 2016, tourism added about 40 000 new jobs to the economy, more than mining, manufacturing, utilities and trade sectors did over the same period (Stats SA, 2018). According to Wesgro, Cape Town's official tourism agency, about 1.6 million people visit the Western Cape every year and contribute about R40 billion to the local economy (Odendaal, 2018) and losing these tourists could have significant income and employment implications.

Unfortunately, the prospects of having to stand in queues for water, losing out on activities or adventures, poor services and potential health concerns as a result of the drought was enough to prevent some tourists, local and foreign, from visiting Cape Town and the greater Western Cape. Wesgro reported a 10% to 15% reduction in hotel bookings for the first few months of 2018 (Rangongo, 2018), carrying a potential loss of between R660 million to R1 billion in foregone tourism revenue and thousands of jobs. The tourism sector, and the supply chains on which it depends (such as water), therefore, need to be protected from climate disasters to avoid negative impacts on jobs and economic growth.

Agricultural impacts

The agricultural sector, particularly irrigated agriculture, is highly dependent on a functioning water supply chain and saw significant losses during the Western Cape water crisis. Cape Town is world famous for its wine production, which saw a 20% decrease in production and losses of about R591 million in 2018 as a result of the drought (Pienaar & Boonzaaier, 2018). Table grape production declined by 18% with a loss of R787 million. A number of other fruit, vegetable and grain products also saw significant reductions in production and revenue losses. In total, the water crisis caused a decline in agricultural production of about 20%, valued at R5.9 billion and just of 30 000 workers lost their jobs in the Western Cape (Pienaar & Boonzaaier, 2018, p. 13).

The socio-economic impacts of the drought and the failing water supply chain in the Western Cape were not isolated to the province alone. Since the Western Cape economy makes up about 13% of South Africa's national economy, in theory, for every 1% reduction in the province's GDP as a result of the drought, there would be a potential reduction in the country's GDP of about 0.13% (Groenewald, 2018; Crabtree, 2018). The drought, therefore, has the potential to spread various knock-on effects throughout the country. This illustrates the importance of enhancing the water supply chain's resilience to climate disasters, to prevent job and economic losses and maintain South Africa's competiveness, particularly in the tourism and agricultural sectors.

THE ROLE OF RESILIENT SUPPLY CHAINS IN THE CONTEXT OF CLIMATE DISASTERS

PROVIDE AID, RELIEF AND RESCUE SERVICES

Supply chains provide lifesaving aid, relief and rescue services to affected areas and victims, and should those supply chains fail, their lives would be put at further risk. A successful relief operation, therefore, depends on productive and resilient supply chains for procurement, warehousing, transportation and distribution of aid and relief supplies (Ngwenya & Naude, 2016). The appropriate supplies need to find their way to the right place, at the right time and to the right people. The benefit of establishing resilient supply chains in this context is minimising loss of life and suffering of affected people and communities during or immediately after a climate disaster (Ngwenya & Naude, 2016).

MAINTAIN SUPPLY OF CRITICAL COMMODITIES AND SERVICES

Resilient supply chains are important for maintaining the supply of critical commodities required for short-term disaster recovery. This includes correcting or bypassing supply chain failures to re-establish productive supply chains to affected communities as quickly as possible (Palin, et al., 2018). Without functioning supply chains recovering from a disaster can be prolonged, increasing the risk of short-run welfare losses and even threatening more long-term poverty traps (Palin, et al., 2018; Felbermayr & Groschl, 2014).

The 2017 Atlantic Hurricane Season provided important lessons in this regard. The severity of the storms themselves and the complexity of supply chain disruptions were significant contributors to the overall impact of the storms (Palin, et al., 2018). Experiences in the USA highlighted the need for more resilient supply chains and their importance for reducing the short-run impacts of climate disasters. If the importance of supply chain resilience is recognised in developed economies such as the USA, then it is certainly critical for developing countries like South Africa.

MINIMISE SPILL-OVER EFFECTS OF CLIMATE DISASTERS

Improving international supply chain resilience can minimise the spill-over of indirect socio-economic impacts of climate disasters. While increased globalisation; just-in-time delivery; outsourcing and offshoring; consolidating suppliers and concentrating production activities in centralised locations have all contributed to more cost efficient supply chains, they have also increased vulnerability to disruption (Abe & Ye, 2013). Should a disaster affect any of these concentrated production locations or distribution facilities, it can result in significant losses across the entire international supply chain. This is due to the inherent interdependence global supply networks have created between companies, governments and trading partners across the world (Abe & Ye, 2013). In such circumstances, alternative supply substitutes may not be readily available, making the impact of the disaster last longer and transgress international borders.

Examples of such indirect impacts crossing international borders include the 2011 floods in Thailand, which affected Toyota’s and Nissan’s production across Asia and North America (NISSAN, 2011; Toyota, 2011; Abe & Ye, 2013); the drought in Panama which restricted ship movements through the canals and impacted supply chains in the USA and China (Zamorano & Franco, 2019) and Tropical Cyclone Idai that hit Mozambique and disrupted electricity supply to South Africa (Slabbert & Slatter, 2019).

Given the fact that South Africa is a developing country with an open economy, vulnerable to climate disasters, it is critical that government, private business and regulatory authorities begin to strengthen their supply chain resilience as a means of mitigating against socio-economic impacts of climate disasters and strengthening climate change adaptation strategies.

IMPROVING SUPPLY CHAIN RESILIENCE

The COVID-19 pandemic has reminded us that new strategies need be developed and implemented into future supply chain designs. While traditional metrics of cost, quality and delivery remain important, new supply chain performance metrics are also required, such as resilience, responsiveness, flexibility and re-configurability (Betti & Ni, 2020). Ensuring that supply chains are better equipped to deal with future disruptions, uncertainty and complexity in the long-term, including climate disasters, requires a greater focus on risk competitiveness rather than cost competiveness alone (Betti & Hong, 2020).

Reconfiguring supply chains to protect against risk requires multi-stakeholder collaboration, particularly between government and private business (Scholten, et al., 2014; Abe & Ye, 2013; Palin, et al., 2018). Individual companies or government departments cannot build resilience across their supply chain networks alone and must work together with both upstream and downstream stakeholders.

While there is no one-size-fits-all solution, the following five-step process provides high level guidance for improving supply chain resilience. It must be noted that each of the steps are not mutually exclusive and continuous learning and feedback between each of them is critical. For example, mapping supply chain vulnerabilities might identify gaps in knowledge management, while knowledge management might not only provide insight in how to overcome vulnerabilities, it may also identify vulnerabilities previously overlooked.

FIVE HIGH LEVEL STRATEGIES FOR IMPROVING SUPPLY CHAIN RESILIENCE:

1. **Identify strategic priorities**
2. **Map supply chain vulnerabilities**
3. **Improve collaboration and cooperation**
4. **Improve flexibility and responsiveness**
5. **Improve knowledge management**

IDENTIFY STRATEGIC PRIORITIES

For an efficient and effective response to supply chain disruptions, resilience must be built into the supply chain beforehand by identifying strategic priorities and making strategic trade-offs (Scholten, et al., 2014; Abe & Ye, 2013; Sáenz & Revilla, 2014). Identifying strategic priorities speaks to a trade-off between supply chain efficiency and disaster risk preparation (Abe & Ye, 2013). This requires identifying competitiveness priorities for a particular product and matching it with its supply chain capabilities – does cost or resilience matter more for that product? (Sáenz & Revilla, 2014).

This is a decision for both business and government and depends, to some extent, on whether customers value quality over price and if the product/service can be standardised or not. In general, more standardised products suggest supply chains can be designed to maximise cost efficiency and sourced from low-cost factories. In this case a trade-off is made for lower costs over resilience.

On the other hand, if the product needs to be customised, or quality is valued over cost, then reducing vulnerability to shocks (improving resilience) must be prioritised over cost efficiency (Sáenz & Revilla, 2014). For example, farmers in South Africa might make the strategic decision to source drought resilient seeds, where quality is valued over cost, and therefore building resilience is critical. Water, despite being a low-value product, carries significant strategic importance for farmers, since without it they cannot grow crops. Therefore, water resilience should be valued over cost.

Supplier consolidation[17] might improve cost efficiency but it increases climate disaster risk and vulnerability. While sourcing from multiple suppliers might increase costs, it reduces disaster risk (improves resilience) by securing supply substitutes (Abe & Ye, 2013). It can also be beneficial to secure informal sources of supply, depending on the context of the organisation. Again, South African farmers seeking drought resilient seeds should source them from several different suppliers in case one of them is unable to supply the necessary seeds during or after a climate disaster.

Strategic decisions need to be implemented to improve supply chain resilience, including, for example, identifying where inventory should be stored, in what form and how much; selecting suppliers based on risk criteria rather than cost, and diversifying risk by using different suppliers and distribution channels, including both formal and informal sources/channels where necessary (Abe & Ye, 2013; Scholten, et al., 2014).

MAP SUPPLY CHAIN VULNERABILITIES

To achieve the correct balance between efficiency and resilience, organisations should conduct more holistic reviews of their supply chains (both upstream and downstream) to improve network visibility (Betti & Hong, 2020). Mapping the supply chain network and its potential vulnerabilities enables organisations and governments to strategically prioritise potential risks. It also assists with developing mitigation strategies and risk avoidance practices, and strengthens contingency planning and financing (Scholten, et al., 2014; Abe & Ye, 2013).

For example, supply chains that focuses on cost efficiency over resilience might provide higher velocity but with lower elasticity[18]. The adaptive capacity of such a rigid supply chain is, therefore, very low and highly vulnerable to disruption by climate disasters. However, while it might be a strategic priority to maintain cost effectiveness, identifying and understanding the vulnerability of such a rigid supply

[17] Supplier consolidation refers to the process of reducing the number of suppliers and focusing on the most cost effective suppliers within a market, which can be influenced by power and agency dynamics (Abe & Ye, 2013).

[18] Velocity refers to a supply chain's speed with which it can deliver a product or service and elasticity refers to its ability to change according to changes in consumer preferences, demand and prices.

chain means contingency and mitigation strategies can be put in place before the disaster occurs (Sáenz & Revilla, 2014). To this end, mapping supply chains and their potential vulnerabilities has three broad activities (again, these are not mutually exclusive from another).

Improving supply chain visibility

The first deals with improving an organisation's supply chain network visibility (Scholten, et al., 2014; Betti & Hong, 2020). Identify key stakeholders and supply chain nodes - who produces critical parts, who supplies raw materials and where are they sourced, produced and manufactured? What is their inventory status, where do they store their inventory and for how long? Identify important transport links - how are goods transported, who transports them and where do they come from? Different power relations and agency dynamics between stakeholders across the supply chain network also need to be considered and understood.

Assessing vulnerability to disruption

The second deals with the comprehensively assessing the organisation's and its supply chain network's vulnerability to potential disruptions by a climate disaster or other potential shocks (Abe & Ye, 2013). How might a drought or flood impact upstream suppliers' (or downstream customers') ability to produce, transport and purchase particular goods, and how do potential impacts of those disruptions differ from one another?

Knowledge of stakeholders' location and potential risks allows for improved mitigation strategies, effective targeting of supply and enhanced collaboration (Palin, et al., 2018). For example, with rising sea levels and ever intensifying storms, Cape Town harbour is at risk of disruption and should be accounted for by any importers/exporters that utilise it. During the 2011 floods in South Africa, critical transport links – railways and trains – transporting maize and coal were disrupted, negatively affecting exports of both commodities (M&G, 2011; Conway-Smith, 2011).

Futures thinking[19] and strategic foresight provide a variety of useful methodologies and tools for analysing and preparing for uncertain future risks, such as horizon scanning, scenario planning and causal layered analysis, for example (Scholten, et al., 2014; Betti & Hong, 2020).

Governments at all levels play a critical role in coordinating risk-reduction strategies to achieve long-term supply chain resilience, particularly in the context of climate change adaptation (Abe & Ye, 2013). From this perspective it is also necessary to identify the most at-risk and densely populated areas, including their geographic location and technological dependencies when mapping supply chain vulnerabilities.

Dense populations tend to be at greater risk of disruption due to higher demand for resources (which cannot be easily replaced) and the complex dependencies for successfully supplying key resources after a disaster (Palin, et al., 2018). The City of Cape Town, for example, would have been identified as a high-risk area during the water crisis, given its population density and relative isolation on the western coast of South Africa. Small populations, on the other hand, have their own unique challenges, particularly if they are located far from other neighbouring cities (Palin, et al., 2018).

Geographic location of dense populations, or supply chain nodes, and their proximity to neighbouring cities is also a key variable in evaluating supply chain vulnerabilities. Cities that are relatively close together can provide relief for one another, or they could both be impacted by the same disaster. It is also important to factor in and recognise regions that have a high concentration of global supply chain nodes and/or commodities.

[19] Futures thinking or strategic foresight is a process-based form of inquiry into alternative futures, in terms of what is probable, possible, preferable and plausible, with the aim of anticipating and influencing those futures. WWF-SA is developing a policy brief on "Futures Studies Approaches and Methodologies", which will soon be available on the WWF-SA website, for more information on futures studies.

For example, Puerto Rico is a hub of intravenous saline fluid manufacturing, which was disrupted by Hurricane Maria in 2017 and became a major concern for the global medical industry (Palin, et al., 2018).

Identifying and prioritising potential bottle necks
The third critical activity is identifying and prioritising hourglass structures, or bottlenecks. Supply chains are at risk of developing hourglass structures at key nodes or transport links during a climate disaster (Palin, et al., 2018). A wide variety of supplies might be concentrated at a port before being transported by road to other locations, for example. Should that particular port be affected by a climate disaster, directly or indirectly, then its ability to supply other locations can be severely affected and a bottleneck can develop.

Bottlenecks that develop at global supply chain nodes can amplify the indirect impacts of climate disasters. For example, the increase in maize imports to South Africa during the extended drought between 2015 and 2018 put significant pressure on already inefficient ports and rail/road logistics systems. This created a bottleneck effect, which not only delayed the supply of maize but also delayed other imported products as well (Maré & Willemse, 2016).It is, therefore, critical to identify such nodes and mitigate against the risk of bottlenecks (Palin, et al., 2018).

These three activities should be conducted by both government and private business to develop a more informed and holistic picture of their supply chain networks. It is equally important to review both formal and informal supply chains – the latter playing a critical role in developing countries like South Africa.

IMPROVE COLLABORATION AND COORDINATION

Collaboration and coordination are essential elements needed to build resilience within and across supply chain networks as stakeholders work together to achieve common goals (Scholten, et al., 2014; Abe & Ye, 2013; Palin, et al., 2018; Ngwenya & Naude, 2016). They are primarily concerned with the exchange of information and the application of shared knowledge across different elements of the supply chain to reduce uncertainty and improve supply chain efficiency and effectiveness (Scholten, et al., 2014)

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THE IMPORTANCE OF INFORMAL SUPPLY CHAINS IN SOUTH AFRICA

The informal economy is estimated to account for about 20% of total employment in South Africa, providing critical livelihood opportunities and access to essential goods and services for many vulnerable and marginalised communities (Rogan & Skinner, 2019). Informal markets and supply chains are particularly vulnerable to disruption by climate disasters as they often have limited or no access to various safety nets and support structures such as infrastructure, insurance and credit markets, for example.

They can also be negatively affected by formal responses to disruptions, as was the case during the initial COVID-19 lockdown period. The informal food economy, for example, was essentially brought to a standstill by the lockdown, where small farmers, street vendors and spaza shops could no longer buy and sell food (PLAAS, 2020). This had a significant impact on communities that rely on such informal supply chains and markets for their livelihoods and food security. Informal traders lost their income, consumers lost their access to affordable food and formal supper markets began to flood with consumers, causing a bottle neck.

These disruptions culminated into the very real risks of not only increasing the spread of COVID-19 but also perpetuating food insecurity, poverty, inequality and unemployment, while balancing on the edge of violent conflict and widespread looting (PLAAS, 2020). Therefore, it is equally important, if not more so, to support and enhance the resilience of informal supply chains to disruptions.

While this could be challenging in terms of competition regulations, regulating authorities, such as the Competition Commission, should encourage collaboration and coordination, while managing power and agency dynamics within supply chain networks and overseeing where sensitive information can and cannot be shared.

Collaboration and coordination supports the identification of interdependencies between supply chain nodes, transport links and organisations, and promotes the sharing of different resources among actors within a network (Abe & Ye, 2013). In short, coordination and collaboration is the communication of supply chain vulnerabilities, activities and operations across the supply chain.

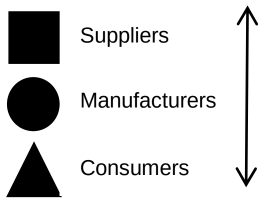
Collaboration can take place vertically and/or horizontally within the supply chain and can be operational (how to better work together to support supply chain efficiency) or strategic in nature (Scholten, et al., 2014). On the supply side, it provides actors with important information regarding which facilities are operational or running at limited capacity. It informs actors of any bottlenecks or time delays and where to source supply substitutes. All this information about the performance of a supply chain network during a disaster is key for improving knowledge management, situational awareness and resilience (Ngwenya & Naude, 2016; Palin, et al., 2018). On the demand side, coordination and collaboration provides important information regarding transactions (what are people buying, where are they buying and how much are they buying); payment methods; stocks of key resources and general population information (Palin, et al., 2018).

All this information allows organisations, governments and international aid providers to target the most vulnerable and worst affected communities, supplying exactly what they need, when and where it is needed (Palin, et al., 2018; Ngwenya & Naude, 2016). Information and Communication Technology (ICT) systems have a critical role to play in this regard and present a significant opportunity for improving collaboration between supply chain actors.

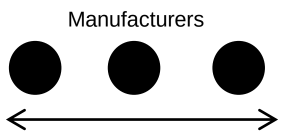
Co-ordination ensures all actors in a supply chain make informed decisions before and during a climate disaster (Ngwenya & Naude, 2016), but most importantly after the disaster (Scholten, et al., 2014). Sharing experiences after a disaster increases the resilience of the supply chain network as a whole.

VERTICAL VS HORIZONTAL COLLABORATION

- **Vertical collaboration** takes place between different levels of the supply chain, from suppliers, through to manufacturers and eventually to consumers.



- **Horizontal collaboration** occurs among actors at the same level of the supply chain, such as between manufacturers (Scholten, et al., 2014)



This can be achieved through public-private partnerships for collecting disaster risk and risk reduction information, implementing ICT systems to facilitate knowledge sharing and establish relevant databases, such as the Trusted Information Sharing Network (TISN) in Australia (Abe & Ye, 2013). During the Cape Town water crisis, there was large degree of knowledge and information sharing, specifically on different ways people, businesses and farmers were saving water, for example, keeping a bucket in the shower or removing alien invasive vegetation from farms.

Access to data and digital networks are key components for enhancing supply chain resilience, from geotagging shipping containers to tweeting about potential disasters. Other examples of coordination and collaboration include the enforcement of building codes during normal times to ensure resilient buildings, issuing extreme weather warnings (and other early warning systems) and retrofitting productive assets to be more resilient to shocks (Abe & Ye, 2013).

IMPROVE AGILITY, FLEXIBILITY AND RESPONSIVENESS

The aim of agility and flexibility is to improve supply chain responsiveness to changes in demand and supply of resources during and after disruptions (Ngwenya & Naude, 2016). Supply chain agility is the ability to effectively deal with and remain successful in the face of uncertainty and to absorb and contain any disruptions (Ngwenya & Naude, 2016). Agility enables organisations and/or governments to respond quickly and effectively to changing, dynamic and uncertain outcomes of disasters, which is critical for relief and aid operations.

The key to improving supply chain agility is the concept of postponement, in conjunction with effective coordination and collaboration (Ngwenya & Naude, 2016). Postponement is a supply chain management concept where certain activities are only carried out when they are needed. It is generally implemented during inventory management processes where generic products are stockpiled for use when their need is required by customers. This practice is often followed by humanitarian organisations when preparing for climate disasters, for example, the stock piling of clean water and sanitary products (Ngwenya & Naude, 2016). Agility also needs to account for different modes of transport that might be available during or after a disaster. For example, how easily can a product be shifted from rail onto road or into the air?

Supply chain flexibility is the ability of an organisation to efficiently supply or source different products when required (Scholten, et al., 2014). This is extremely important in regions that face a variety of different climate change impacts and disasters. For example, during the COVID-19 pandemic, a number of companies are adjusting their production lines to manufacture face masks and ventilators that were in short supply and critical for fighting the virus (Betti & Ni, 2020).

IMPROVE KNOWLEDGE MANAGEMENT

Knowledge management refers to a variety of activities, including mapping supply chain vulnerabilities and monitoring supply chain resilience to shocks; learning from experiences across the supply chain network; re-integrating learning from risk assessments back into supply chain design and consistently monitoring disruptions as much as possible.

Mapping and monitoring supply chain resilience allows managers and product designers to think about resilience as a key attribute of both products and supply chains. It also allows for continual identification and correction of resilience gaps and disruption vulnerabilities (Sáenz & Revilla, 2014).

Futures thinking, as mentioned previously, provides a variety of methodologies and tools for identifying vulnerabilities and strengthening supply chain strategies to better deal with uncertainty. It can broaden contextual awareness by better understanding

alternative cultural and worldviews – an important tool considering global supply chains operate across different cultures and contexts (Gidley, 2016). Futures thinking, particularly scenario analysis, can also provide insight into the best means of managing different disruptions, while accounting for second and third order consequences so as not to create any negative, unintended impacts. Participatory futures methodologies can also foster greater collaboration among stakeholders and create new capabilities by introducing stakeholders that might otherwise have never collaborated previously (Gidley, 2016).

Disruption anticipation and monitoring is also important. For example, proactive steps must be taken to anticipate, monitor and evaluate the development and path of a hurricane and react to it (Sáenz & Revilla, 2014). Identifying when climate disasters might occur (during hurricane season for example) and where they might impact on an organisation's supply chain allows organisations to proactively implement disaster management strategies and operations, and align them with local emergency agencies. This information must be shared with the supply chain network (via meaningful collaboration, coordination and ICT systems) and all the relevant actors so they too can begin implementing their disaster mitigation and management strategies (Sáenz & Revilla, 2014)

CONCLUSION

Climate change is said to increase the frequency and intensity of meteorological or climate disasters, such as hurricanes, floods, fires and droughts. Minimising the socio-economic and human well-being impacts of these climate disasters is a significant challenge and requires effective climate change adaptation strategies. One such adaptation strategy involves strengthening domestic and international supply chain resilience to climate disasters.

While there are a number of factors that contribute to the severity of climate disasters and their impacts, supply chains play an important role in either exacerbating or mitigating such impacts and are, therefore, critical for climate change adaptation and strengthening climate resilience (Kreie, 2013; Willett, 2016). Improving supply chain resilience allows for more effective and efficient delivery of aid, relief and rescue services to affected communities. Improved resilience means supply chains can better provide important commodities (such as food, water, electricity and fuel) required for recovery after a disaster. Should supply chains fail to deliver either of these as a result of disruption from a disaster, it could result in more damaging impacts and potential long-term poverty traps.

This is particularly important for developing countries like South Africa, which face a number of socio-economic challenges and are highly vulnerable to the physical impacts of climate disasters.

Global supply chains, while improving cost effectiveness and efficiency, have inadvertently increased the global economy's exposure climate disasters risks. Should a disaster affect centralised production sites, or render key transport links immobile, then production activities along the supply chain might freeze. This can result in the spill-over of indirect impacts, such as output reductions, wage decreases and even job losses, to other regions outside of the affected area.

The COVID-19 pandemic has clearly illustrated the interconnectedness of global supply chains and their vulnerability to disruptions. There is clearly a need for

governments and companies to improve their risk competitiveness rather than focusing their efforts solely on promoting efficiency and cost competiveness of their supply chains (Betti & Hong, 2020). To this end, strengthening supply chain resilience to external shocks and disruptions, such as the COVID-19 outbreak, geopolitical tensions and climate disasters, is critical for improving the risk competitiveness of supply chains.

Five high-level activities are recommended for improving supply chain resilience, noting that they are not mutually exclusive and continuous learning and feedback between each of them is critical: (1) identify strategic priorities – where is resilience of more strategic value than efficiency; (2) map supply chain vulnerabilities and improve supply chain network visibility; (3) improve collaboration and coordination through the supply chain network; (4) improve supply chain agility, flexibility and responsiveness to disruptions; and (5) improve knowledge management.

Improving supply chain resilience can support humanitarian efforts during and after a disaster. It can provide the necessary commodities for faster recovery after a disaster, minimising the threat of welfare losses, reductions in international competiveness and poverty trap scenarios. More resilient supply chains can also avoid and prevent the spill-over of negative impacts from disruptions into geographic locations outside the disaster area. Therefore, while there are a number of social, political and economic factors that influence the severity of disaster impacts, improving supply chain resilience is critical for climate change adaptation and building climate resilience, particularly in South Africa given the country’s structural challenges, openness to international trade and vulnerabilities to climate disasters. As Covid-19 crisis is making us all realise the fragility of our supply chains, it is pertinent that resilience is prioritised for future proofing our supply chains to climate change and climate disasters.

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FUTURE PROOFING SUPPLY CHAINS FOR CLIMATE RESILIENCE

WWF South Africa's Policy and Futures Unit undertakes enquiry into the possibility of a new economy that advances a sustainable future. The unit convenes, investigates, demonstrates and articulates for policy-makers, industry and other players the importance of lateral and long term systemic thinking. The work of the unit is oriented towards solutions for the future of food, water, power and transport, against the backdrop of climate change, urbanisation and regional dynamics. The overarching aim is to promote and support a managed transition to a resilient future for South Africa's people and environment. The organisation also focuses on natural resources in the areas of marine, freshwater, land, species and agriculture.

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