Climate impacts on South African transport infrastructure

Council of Scientific & Industrial Research (CSIR)
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CESA Infrastructure Indaba: SESSION 3 - Infrastructure upgrade, Investment and Development in an era of climate change

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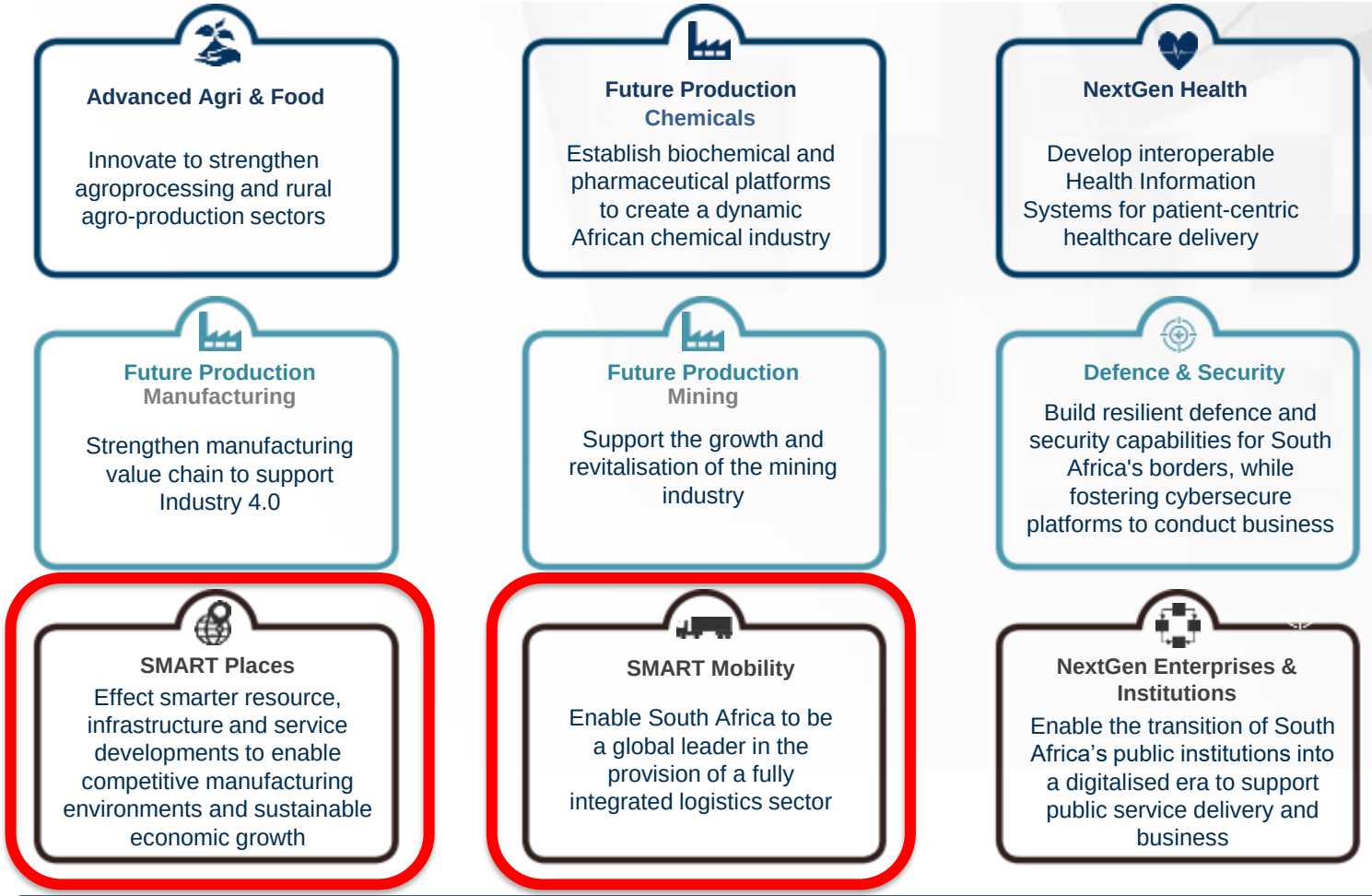
CSIR Sector Clusters *Positioned to drive industrialisation*



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Presentation structure

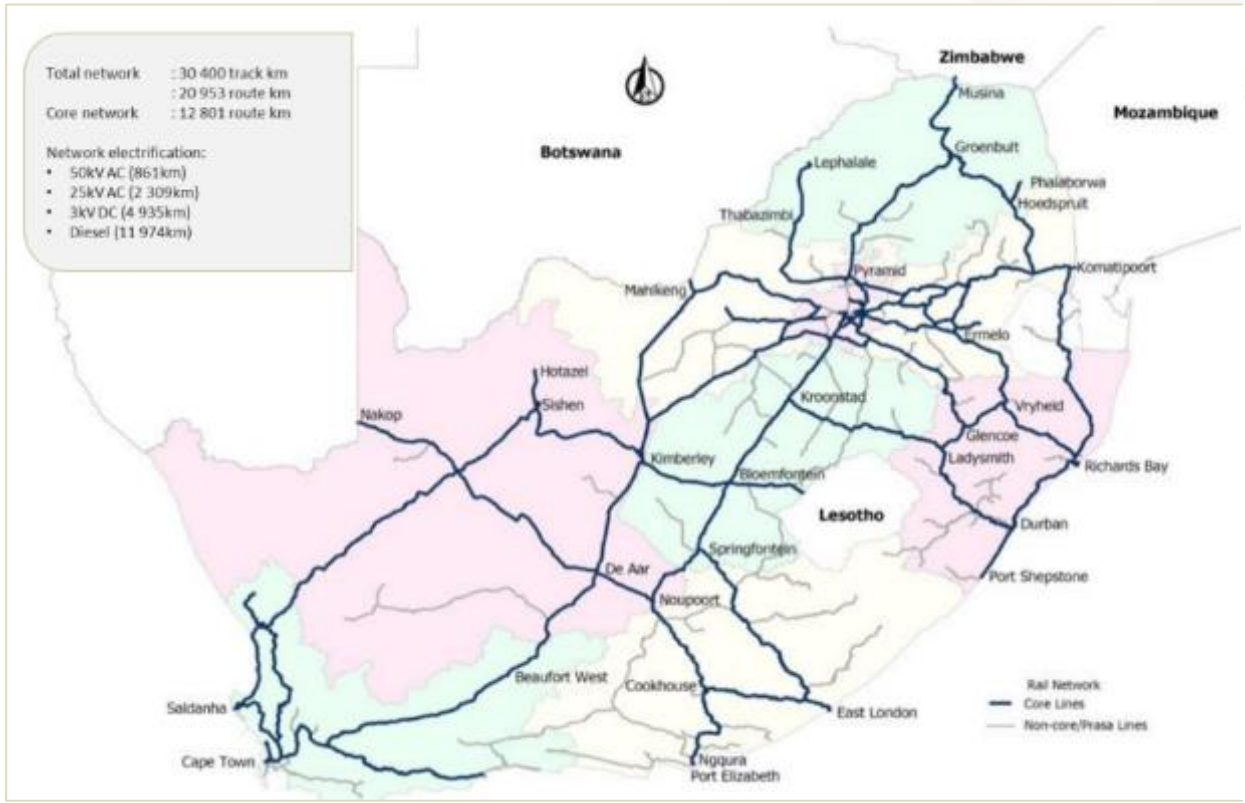
- Vulnerability of SA freight infrastructure to climate change
  - Dr Njabulo Siyakatshana
- Extreme wind events & Cape Town port terminal operational disruptions
  - Vuyo Ndayi
- Climate change impacts on road infrastructure
  - Refiloe Mokoena

VULNERABILITY OF SA FREIGHT INFRASTRUCTURE TO CLIMATE CHANGE

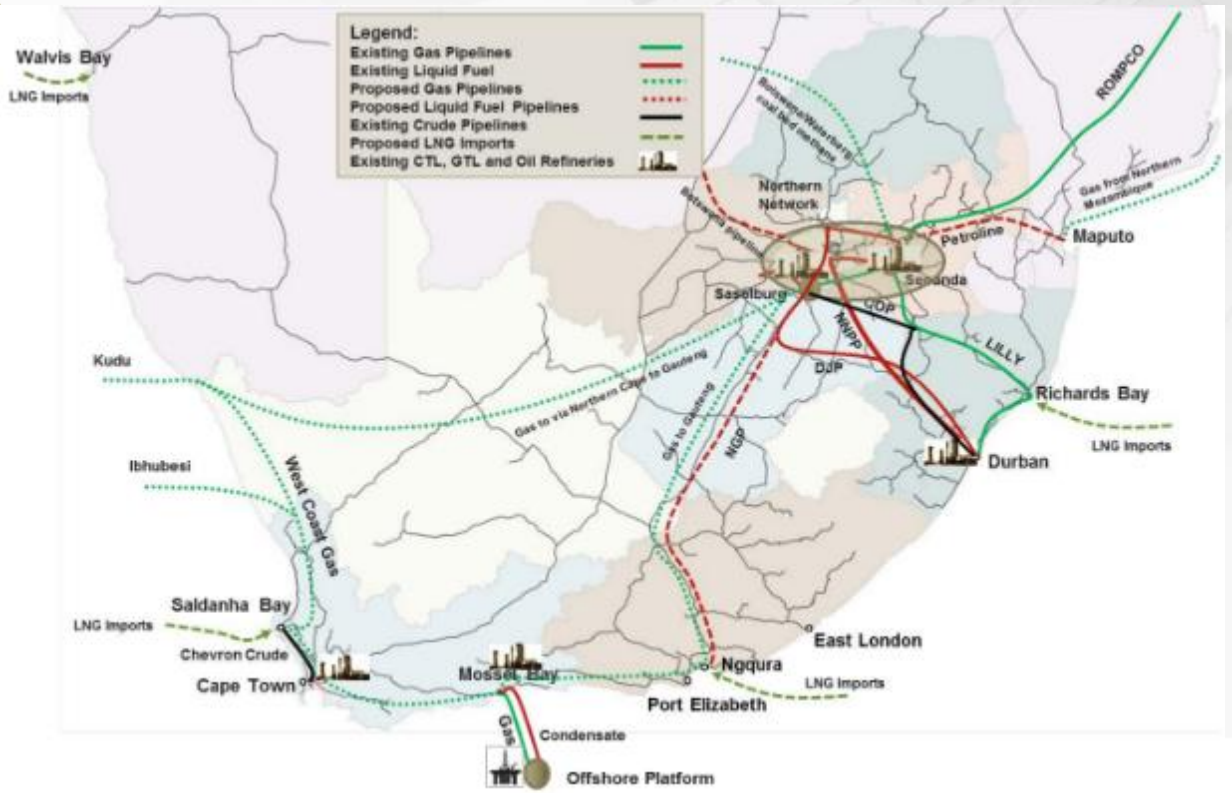
Dr Njabulo Siyakatshana

South Africa's freight rail and pipeline infrastructure

Freight rail



Pipelines



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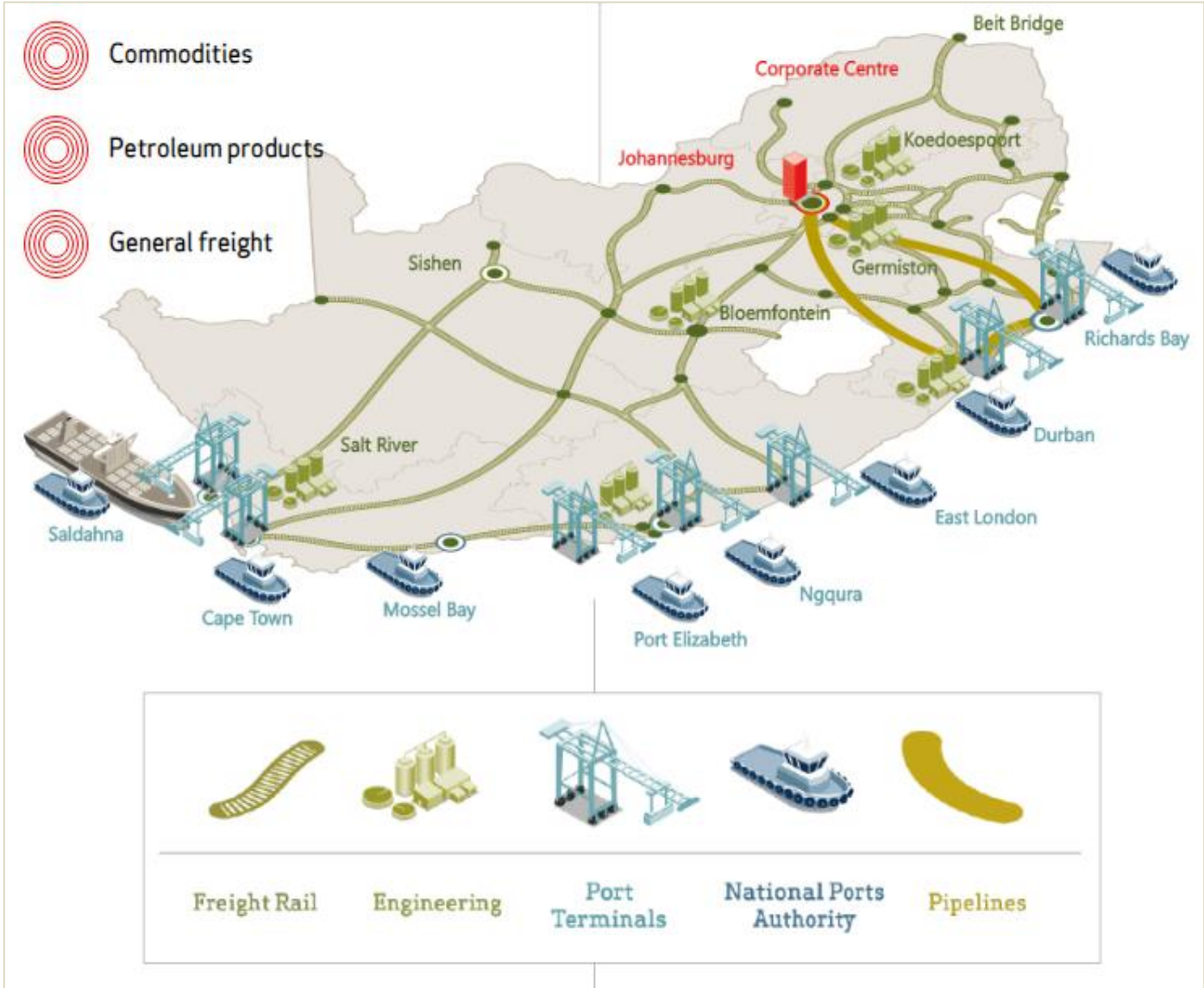
South Africa's port infrastructure



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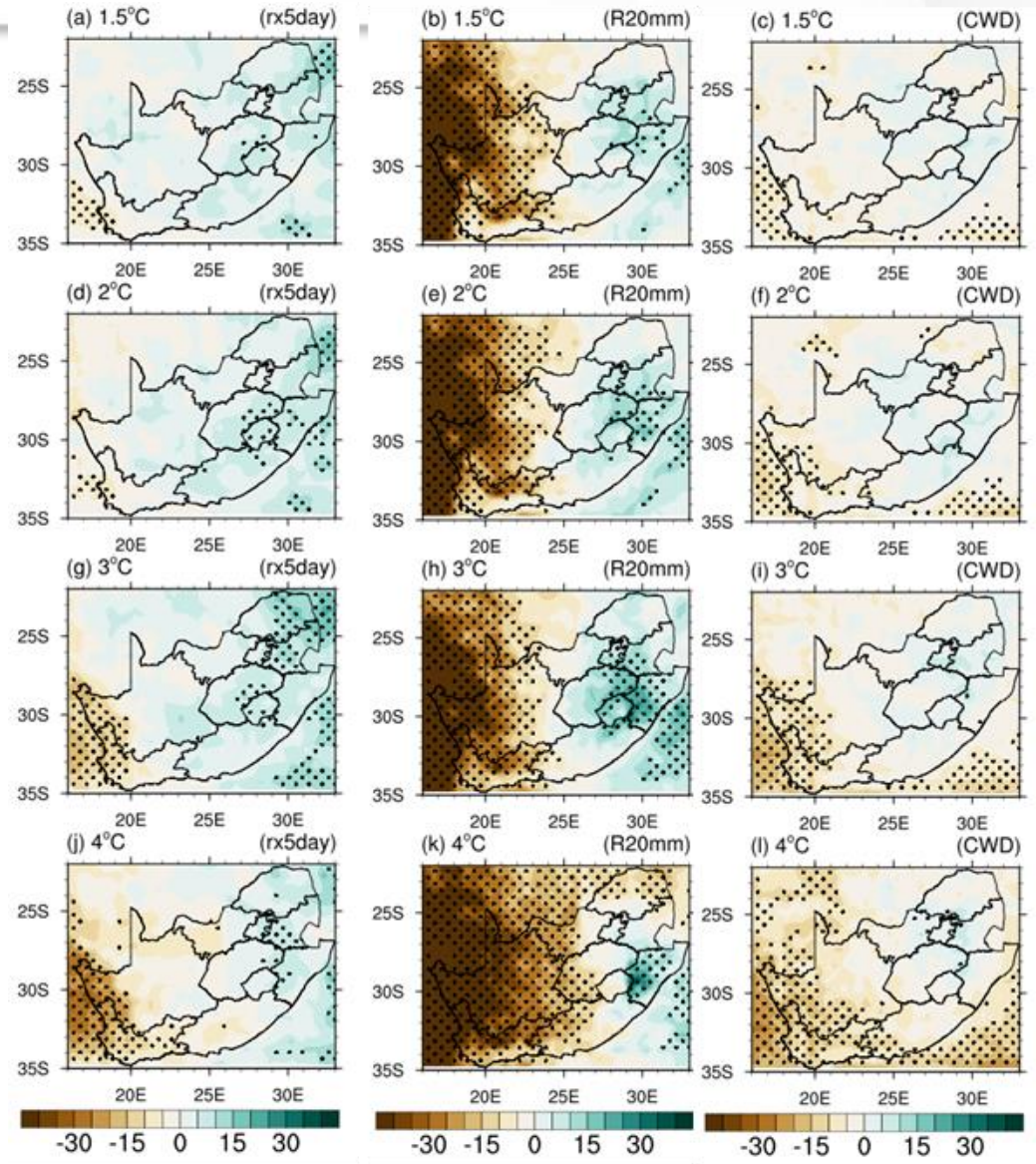
Examples of weather-related damage to rail network

Functional Location	Overview	Photo
Hammersdale	Multiple mud slides: washaway and line covered by sand; 4 x embankment failure; axle counter silos under water.	 
Delvillewood	Before and after wash away at Devillewood waterfall (TFR reopened a single line 13 June 2022, where operations had been suspended since11 April 2022).	 
	Substation damage.	
Kwandengezi	Bomvaas track covered by sand. Cutting collapsed; Kwandengezi tunnel and tracks covered by sand.	 

Examples of weather-related damage to port & road network

Functional Location	Overview	Photo
Bayhead Port	The debris in the Port was inclusive of heavy logs as well as plastic items which posed a risk to marine fleet. In less than 2 weeks, the debris at the Port was successfully removed.	 
Bayhead Road	Damaged Bayhead Road section.	 
Bayhead Park	Washed-away revetments within the area (three (3) revetments*).	  

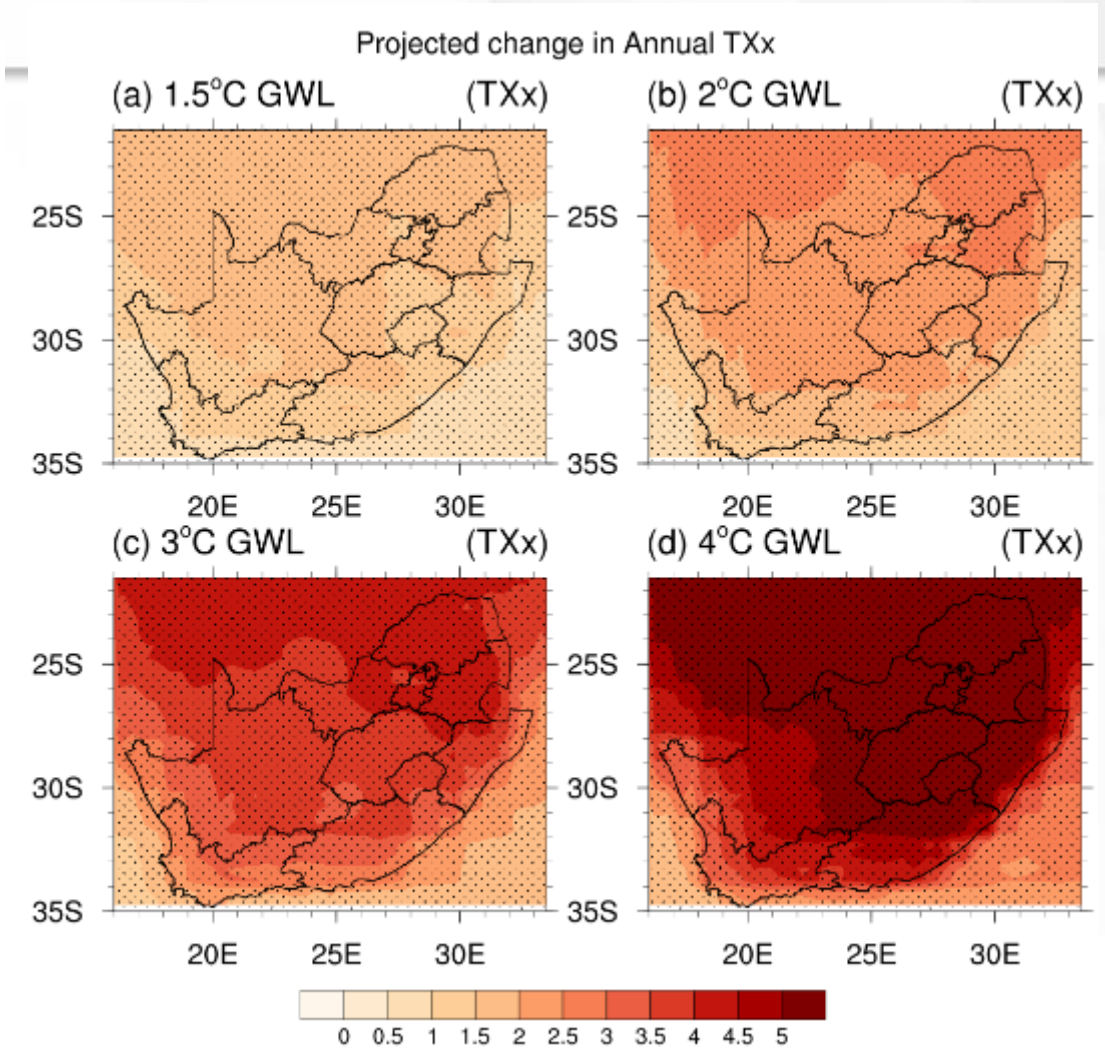
Projected changes in precipitation

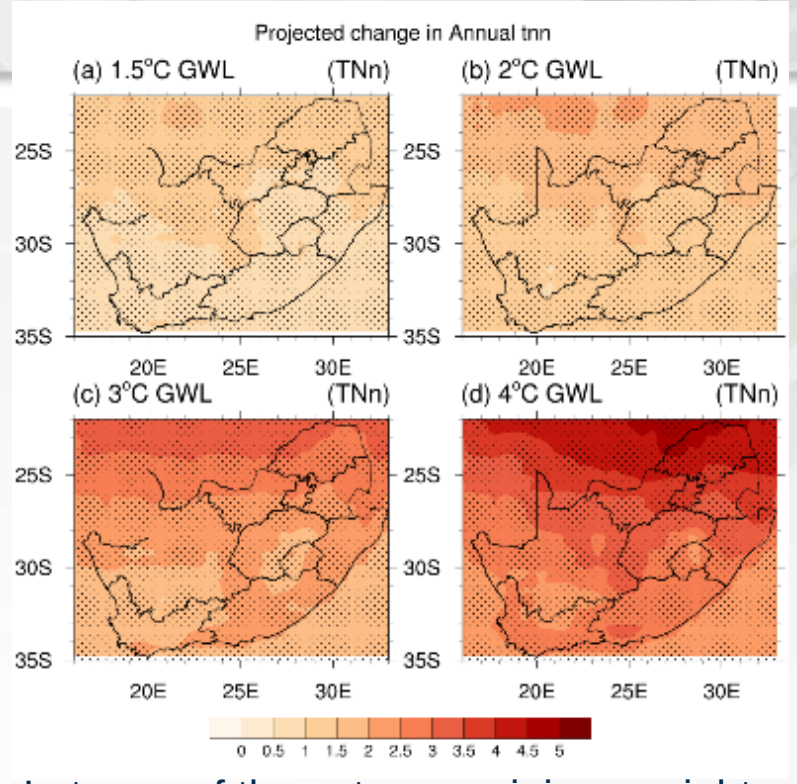


- The frequency and intensity of heavy precipitation over south Africa is projected based on the extreme precipitation indices below (i.e., Very heavy precipitation days with 20 mm or more precipitation (R20mm), Maximum 5-day precipitation (Rx5day) and Consecutive wet days (CWD)) across the four GWLs (1.5°C, 2°C, 3°C and 4°C).
- The models project effects that are likely to be more serious and damaging in areas that are already prone to the tropical cyclones and cut-off lows i.e. in the east.
- Thus, Transnet is increasingly exposed to the risk of revenue losses owing to the increased intensity and frequency of flood events in the east.
- Flood events lead to port downtime causing loss in productivity and increase in Transnet's operational expenditure.
- Transnet, through its Freight Rail division's rail network which is dense in the eastern part of the country can also be affected by these heavy rain events which lead to flooding.
- This also applies to the Transnet Properties division's widespread buildings concentrated in the provinces found in the eastern half of the country.

Projected changes in temperature extremes

- Extreme changes are projected in the eastern half of South Africa especially under 3°C and 4°C GWLs increasing the likelihood of heatwaves in both frequency and intensity.
- The changes in TXx is expected to get as high as over 5°C in some eastern parts of the country leading to significant impacts on Transport operations in those areas.

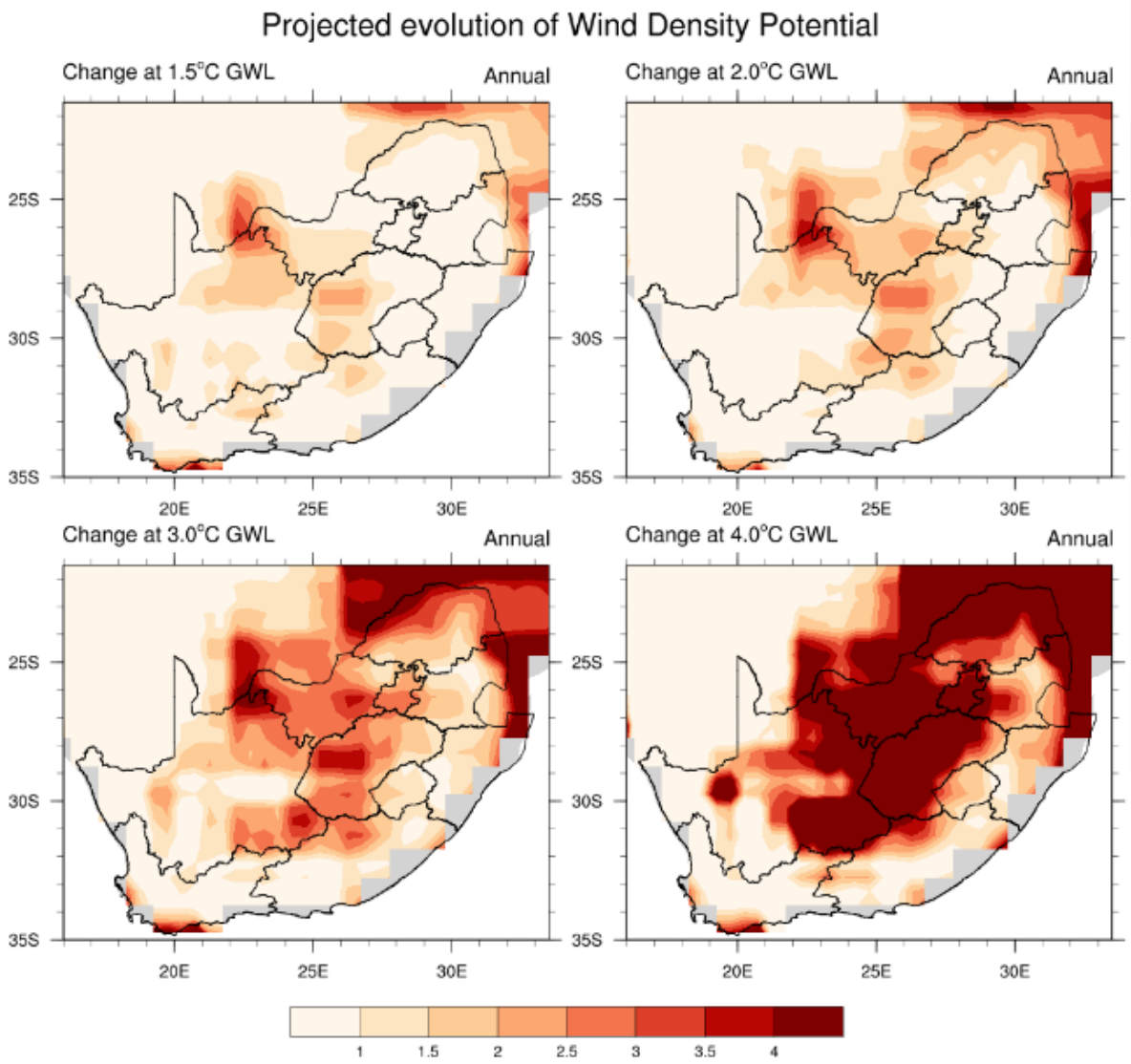




- In terms of the extreme minimum night temperatures represented here by TNn, defined as the minimum value of the daily minimum temperature in a year, the changes are modest as compared to the maximum temperatures
- The changes range between about 1°C to about 2.5°C across the four GWLs with higher values found in the east

- The projected changes in an extreme temperature index called TXx (Maximum value of daily maximum temperature in a year).
- TXx is expected to increase in magnitude as the GWLs increase across the country.

Projected changes in wind extremes



- Projected change in the wind density potential at 100m over South Africa.
- Under all the global warming worlds under study, the areas in the eastern half of South Africa are projected to experience a higher potential of wind speed at 100m.
- The power density becomes magnified with the increase in global warming hence the highest values are under the 4.0°C GWL.

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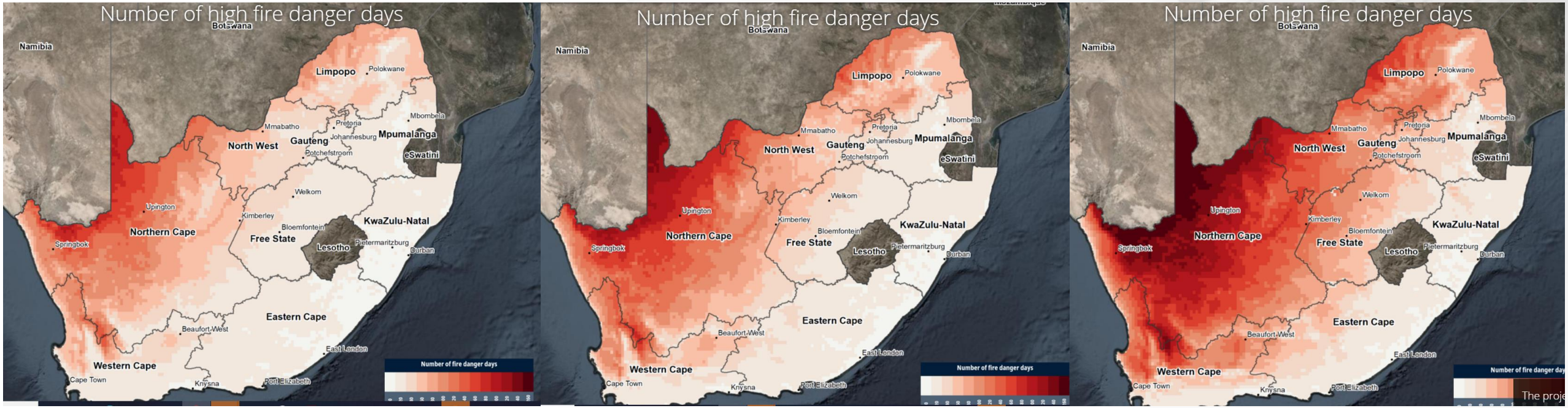
Projected changes in fire danger hazards

(a) (b) (c)



Number of fire danger days over South Africa's provinces under (a) baseline, (b) mid future, (c) far future

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Characteristics of the major infrastructure

Port location	Pipeline network	Property regions	Freight Railway corridors
Richards Bay, Durban, Saldanha, Cape Town, Port Elizabeth, East London, Mossel Bay, Ngqura (Coega	Gauteng, Mpumalanga, KZN, Free State	KwaZulu Natal, Eastern Cape, Western Cape, Northern and the Inland region.	Cape Corridor, Central Corridor, Container Corridor, North Corridor, North-East Corridor, Ore line
Port Components	**Pipeline components**	**Property components**	**Railway components**
Docks and berths	Gas pipeline	Commercial - offices, warehouses, retail buildings, land. Residential property - vacant stands, individual housing units and mass housing	Heavy haul coal, iron ore, manganese
Cranes	Liquid fuels pipeline		Catenary (overhead wires), Rails, Track, Contact wire, Tripping device
Utilities	Intake stations		
Access roads and rail	Tank farm (Tarlton)		

Climate risk summary for ports

Area	Current and expected stresses to the system	Projected CC impacts	Vulnerability of the system
`**Durban**	Current: •Already subject to coastal flooding, storm surges and coastal erosion. Expected: •Storms and floods will become more frequent and more intense. •In combination with sea level rise, the risk of storm surges and intense wave action increases. •More exposed to tropical storms and cyclones. •Increase in wind speed during spring and summer	Delays in loading and unloading of ship cargo + Congestion in and around port + Delay in transfer of cargo + Loss of operational hours + Loss of market opportunities + Unsafe working conditions +	High
Cape Town	Current: • Disrupting high wind speed •Subject to droughts Expected: •Decline in rainfall •Increase in wind speed during summer •Decline in wind speed during winter	Delays in loading and unloading of ship cargo + Congestion in and around port + Delay in transfer of cargo + Loss of operational hours + Loss of market opportunities + Unsafe working conditions + High wind speeds and swells impeding loading and docking of vessels	Medium

Climate risk summary for railways

Area	Current and expected stresses to the system	Projected CC impacts	Vulnerability of the system
North, Northeast and Natal corridor *North and North-east corridor makes the highest revenue combined (52%) contribution to Transnet and therefore more sensitive to weather delays.	Current: •Already subject to a number of flood events and extreme storms Expected: •Storms and floods will become more frequent and more intense. •More exposed to tropical storms and cyclones.	Major damages in infrastructure; coastal erosion affecting road and rail links to ports. Unsafe conditions for train operations Downed power lines; structural damage Track misalignment by fallen trees/wind-blown objects	High
Northeast and Iron ore corridor	Current: •Already subjected to heat waves and very hot days Expected: •Increase in frequency and intensity of heat waves. •Increase in wildfires.	Train delays, speed restrictions and equipment or infrastructure failures. More disruptions in ore transport to port due to heat impact on rail lines. Extreme temperatures in combination with drier conditions leading to more wildfires.	Moderate

Climate risk summary for property and pipelines

Property

Area	Current and expected stresses to the system	Projected CC impacts	Vulnerability of the system
Western Cape	Expected: • Contains large areas of coastal land with less than a 5.5 m elevation in South Africa which directly impact on coastal property in the event of sea level rising. •Increase in drought conditions	Increased damage to property from coastal erosion. Flood damage to infrastructure and property. Increased pressure on water sources, due to increased risk of water scarcity.	High

Pipelines

Area	Current and expected stresses to the system	Projected CC impacts	Vulnerability of the system
Main pipeline network in Gauteng, Mpumalanga, KZN, Free State	Predicted future increase in heavy rain and landslides	Flooding can lead to soil subsidence, particularly in variable, steep, and rugged terrain, which could cause pipes to bend and shift.	Moderate

EXTREME WIND EVENTS
&
CAPE TOWN PORT TERMINAL OPERATIONAL DISRUPTIONS

Vuyo Ndayi

Port System Resilience to Disruptive Events

Resilience of a port system

3 main objectives:

1. **Absorptive Capacity** – related to hazard awareness and reduction in vulnerability
2. **Adaptive Capacity** – related to temporary adaptation to maintain performance
3. **Recovery Capacity** – related to the restoration of performance after a disruptive event

(Hosseini & Barker, 2016)

Port of Rotterdam, “Daewoo and Port of Rotterdam work on smart port”, Maritime Business World, 21 July 2020

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Hosseini, S. and Barker, K., 2016. Modeling infrastructure resilience using Bayesian networks: A case study of inland waterway ports. *Computers & Industrial Engineering*, *93*, pp.252-266.

Adverse Winds in High Season Conditions

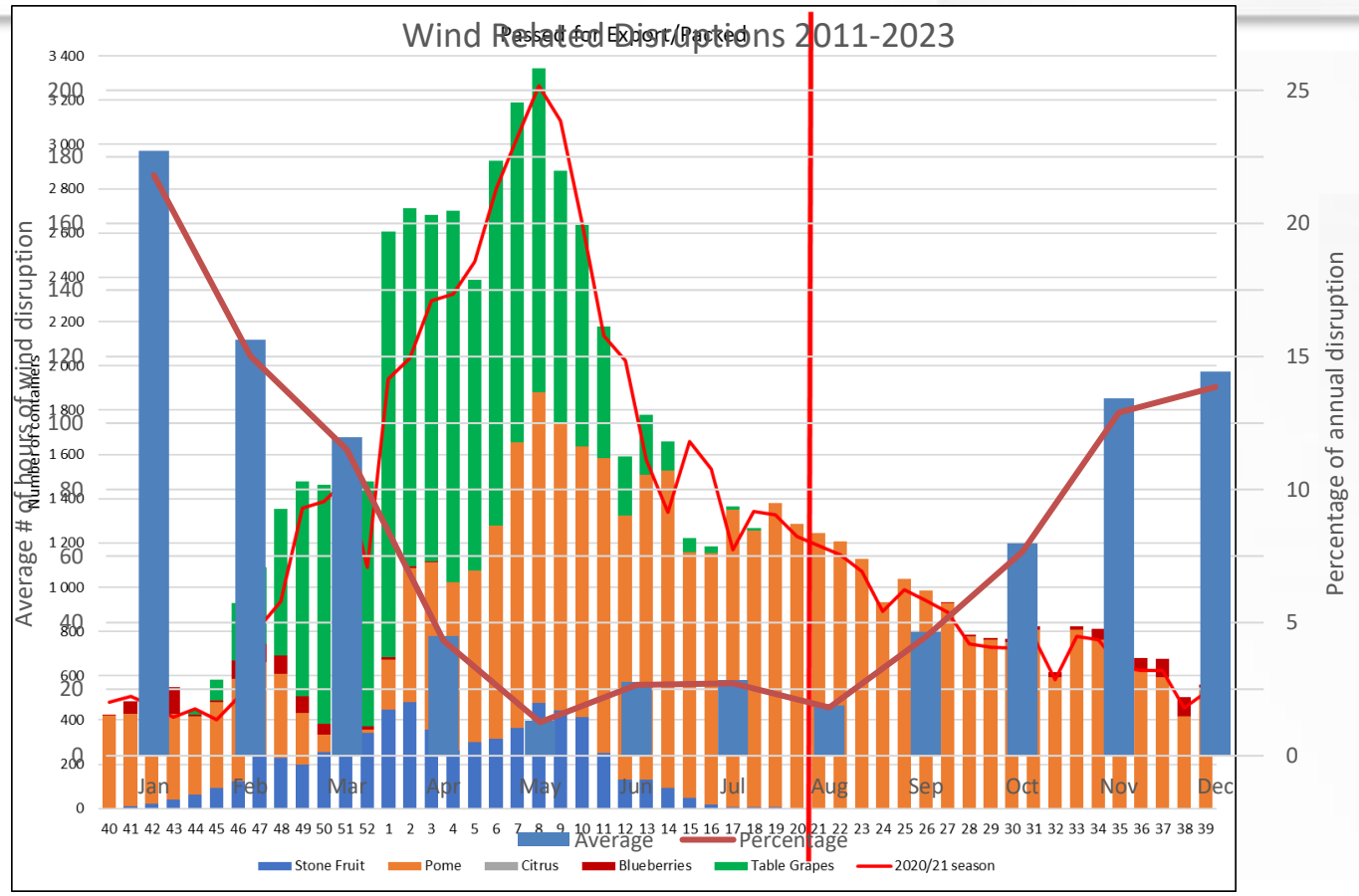
CTCT

Adverse wind… Extreme event?

How does adverse wind create an extreme event?

- “Africa’s Premium Fresh Produce Port”
- Peak export season coincides with “windy season” of the SE - late spring into summer and early autumn
- Increased volume of cargo (larger vessels, more containers etc.)
- Compounding effect = extreme event

Port Operational Risk Reduction



(Hortgro, 2021)

How to reduce the risk associated with an extreme event?

$$risk = \frac{hazard\ X\ vulnerability}{capacity}$$

Reduce the risk by reducing vulnerability and increasing capacity.

(Kruger et al., 2016)
(UNISDR, 2009)

C. Kruger, D. L. Pillay, and M. Van Staden, “Indicative hazard profile for strong winds in south africa,” South African Journal of Science, vol. 112, no. 1-2, pp. 01–11, 2016.
UNISDR, “Unisdr terminology on disaster risk reduction,” 2009, accessed: 2023-10-15. [Online]. Available: http://www.unisdr.org/files/7817 UNISDRTerminologyEnglish.pdf

Reducing Vulnerability & Increasing Capacity

Engineering & Optimization

- Improved and localized adverse wind prediction on the short, medium, and long-term scale
  - ➢ Terminal scheduling and operative planning

Climatology

- Assessment of the local, regional, and global climatological drivers of the extreme winds causing disruptions in the port and their potential impact in the future
  - ➢ Terminal infrastructural adaptative design

Economic and social impact modelling

- Assessment of the economic and social impacts of the port disruptions - to quantify losses and justify required investment
  - ➢ Infrastructure and system investment

CLIMATE CHANGE IMPACTS ON ROAD INFRASTRUCTURE

Refiloe Mokoena

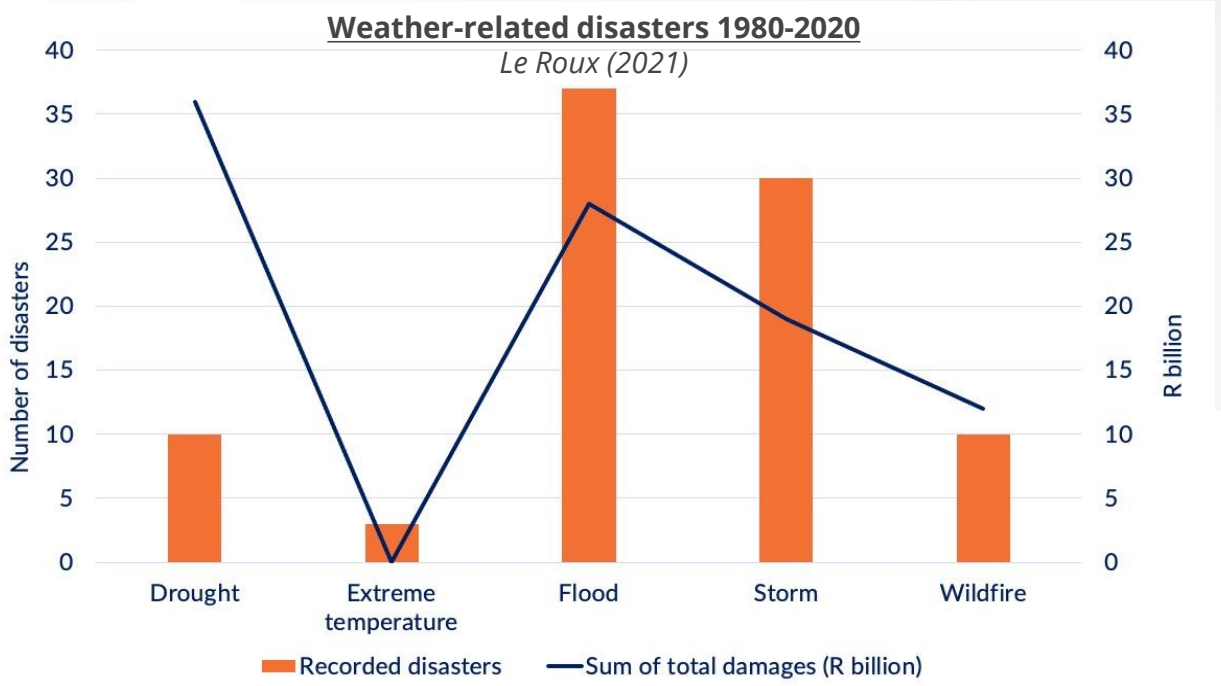
Introduction – Road impacts

The Problem *SA & Africa*

- International Disaster Database:
  - 90 noticeable weather-related disasters in South Africa in the past 20 years.
  - Estimated 95 billion rands in economic damages.
- Increasing Frequency:
  - 57% increase in recorded events in the past two decades.
- Impact on Mobility and Access:
  - Negative effects on emergency response services and access during disasters.
- African Road Repair Estimate:
  - United Nations estimate of up to US$183.6 billion for climate change-related road damage in Africa.
- South African Road Repair Estimate:
  - Between R 2.1 billion and R 4.2 billion annually in the 2050 decade if a reactive approach is taken.
- Growing Social and Economic Costs:
  - Expectations of rising costs without necessary adaptation measures.

Photo: eThekwini Municipality

Photo: City of Tshwane



Climate risks for road infrastructure

Climate risks for East Southern Africa

IPCC AR6 projections (ESAF)

- Decrease in mean rainfall
- Increase in heavy rainfall and pluvial flooding
- Increase in drought events
- Increase in fire weather conditions/wind speeds
- Increase in proportion of category 4-5 tropical cyclones

Damage to road infrastructure

- Pavements (paved and unpaved)
- Embankments
- Bridges
- Drainage structures

Climate parameter	Infrastructure damage
Extreme maximum temperature	• Premature deterioration of infrastructure. • Damage to roads from buckling and rutting. • Bridges subject to extra stresses through thermal expansion and increased movement.
Heavy rainfall (& shift in flood zones)	• Increased risk of landslides, slope failures, and floods from the runoff, causing road washouts, undercutting and road closures especially in and near flood zones and coastal areas • Increased need for road repair and reconstruction. • High soil moisture levels (compromised structural integrity of roads, bridges, and tunnels).
Drought	• Shrinkage of sub-surface soils
Sea-level rise	• Erosion of coastal road base and undermining of bridge supports • Temporary and permanent flooding of roads and tunnels • Encroachment of saltwater leading to accelerated degradation of tunnels (reduced service life, increased maintenance costs and potential for structural failure during extreme events). • Further coastal erosion due to the loss of coastal wetlands and barrier islands removing natural protection from wave action.
Cyclone events	• Increased infrastructure damage and failure

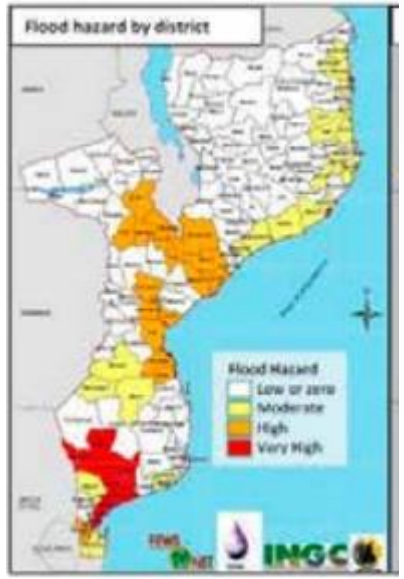
(Adapted from Meyer *et al*., 2014)

Response strategies: Low-volume gravel roads

CSIR ReCAP Climate Adaptation Regional Project (Paige-Green & Verhaeghe, 2019)


Loss of structural integrity


Erosion of embankments



Mozambique flood hazard (Le Roux et al., 2019)

Mozambique Case Study (Komba et al. (2021)

Mohambe-Maqueze road (Gaza province)

Climate risk

IPCC AR6 projections (ESAF)

- Increase in heavy rainfall and pluvial flooding
- Increase in proportion of category 4-5 tropical cyclones

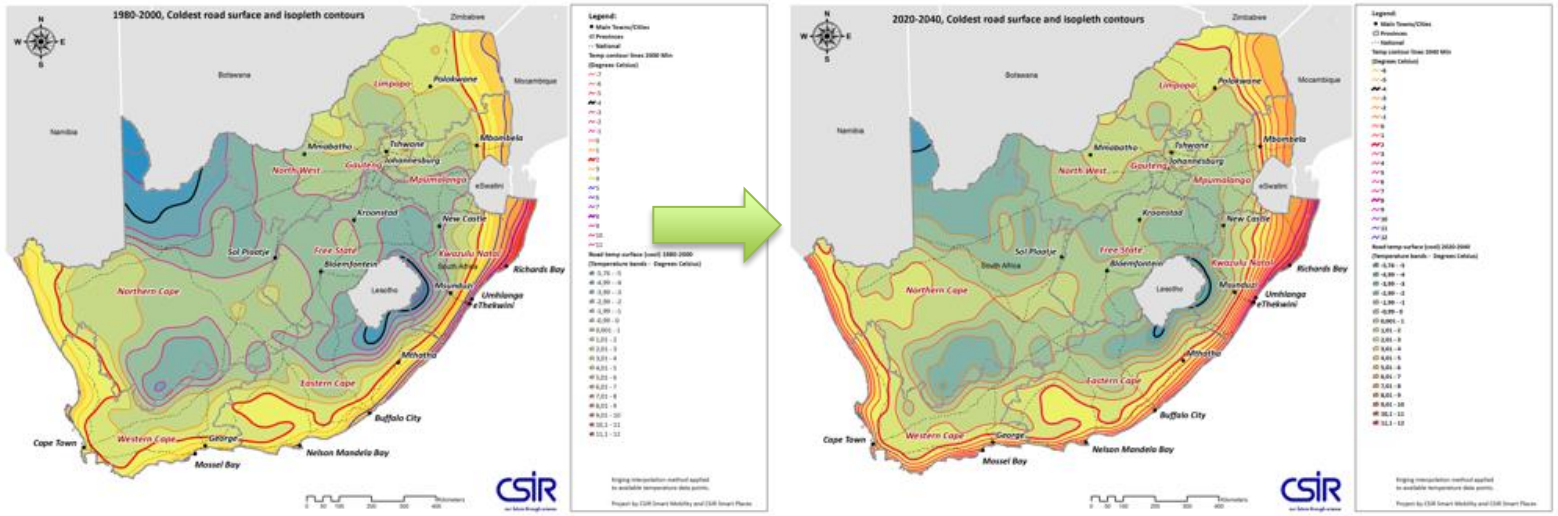
Vulnerabilities

- Geography
- Poor road condition
- Institutional capacity constraints
- Suffering economy
- High exposure and vulnerability contributes to increased dependency on external economic relief (Mondlane, 2004)

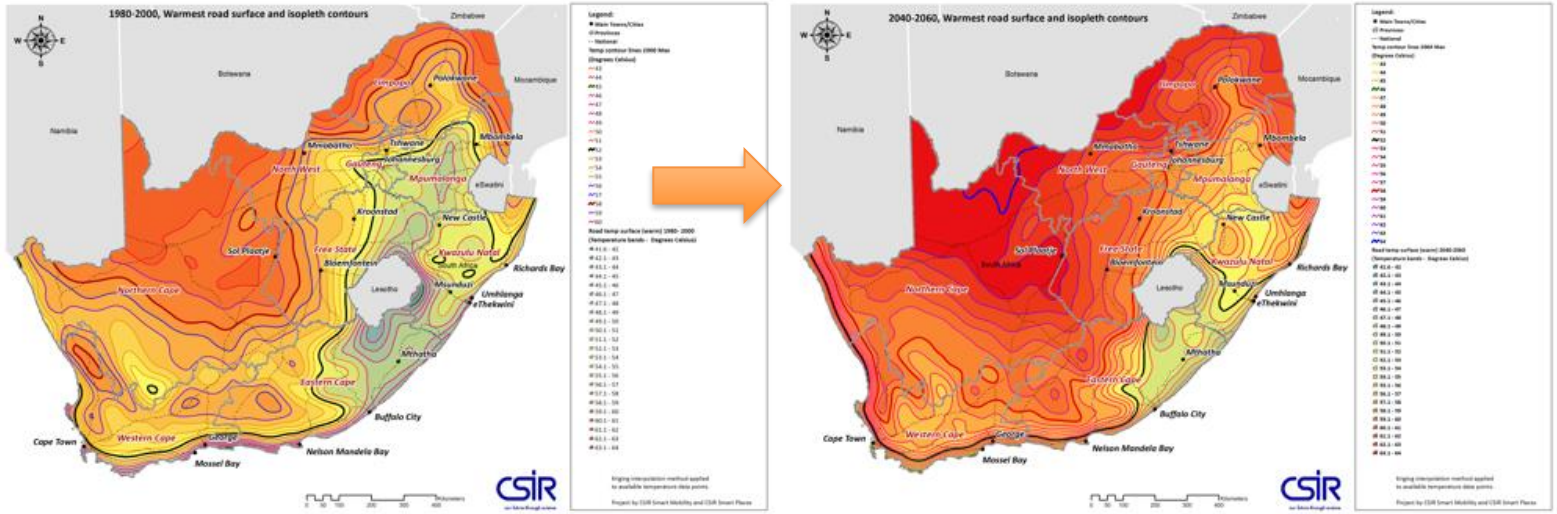
Adaptation planning and implementation

- Road assessment and identification of problems
  - Erosion and undercutting of concrete fords/crossings;
  - Damage to the road approaching the concrete fords;
  - Damage to culverts and erosion protection, and
  - Damage to the road surface
- Design of adaptation measures
- Construction of demonstration sections.

Temperature research: Asphalt pavements



Minimum pavement surface temperature progression between 1980 and 2060 (Mokoena et al., 2019)



7-day maximum pavement temperature progression between 1980 and 2060 (Mokoena et al., 2019)

ThermalPADS

Weather station data

- Measured temperatures
- Actual weather station readings
- Incomplete datasets
- Sparsely situated

Climate model data

- Projected temperatures
- Use of climate models
- Complete datasets
- High resolution

Need: Performance based material, design, maintenance specifications and criteria that incorporate climate variability

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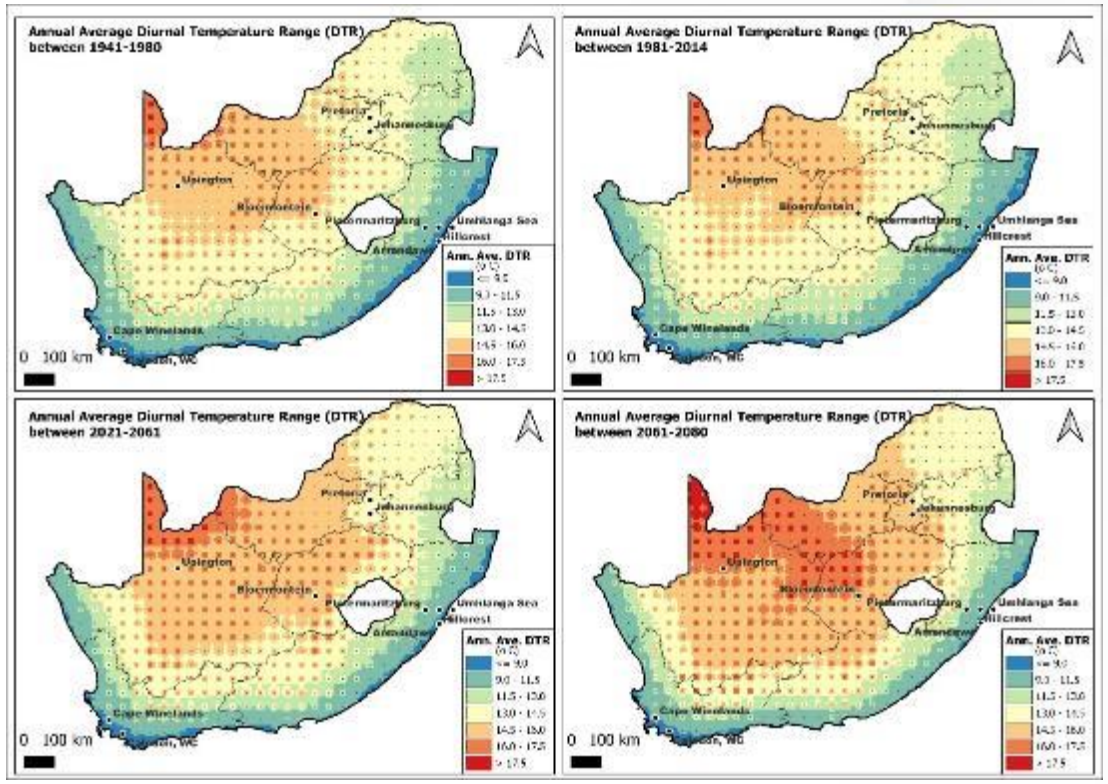
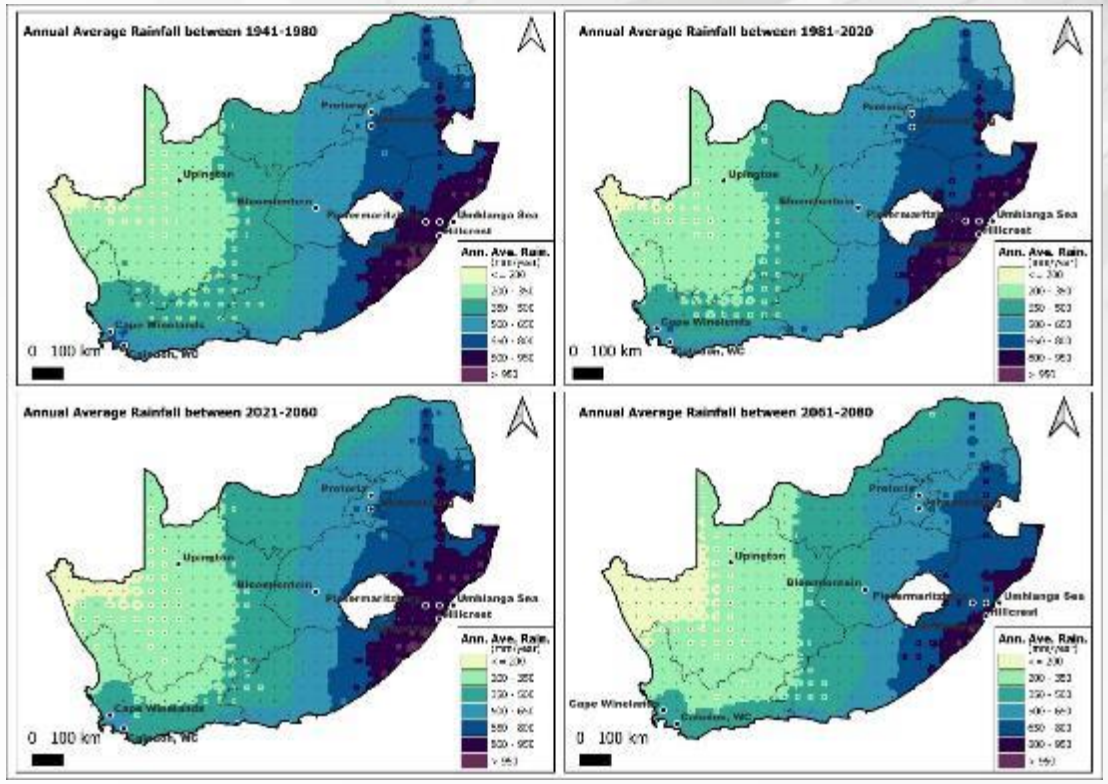
Climate research: Concrete pavements



Progression in average DTR between 1941 and 2080
(Mokoena et al., in press)



Progression in annual rainfall between 1941 and 2080
(Mokoena et al., in press)

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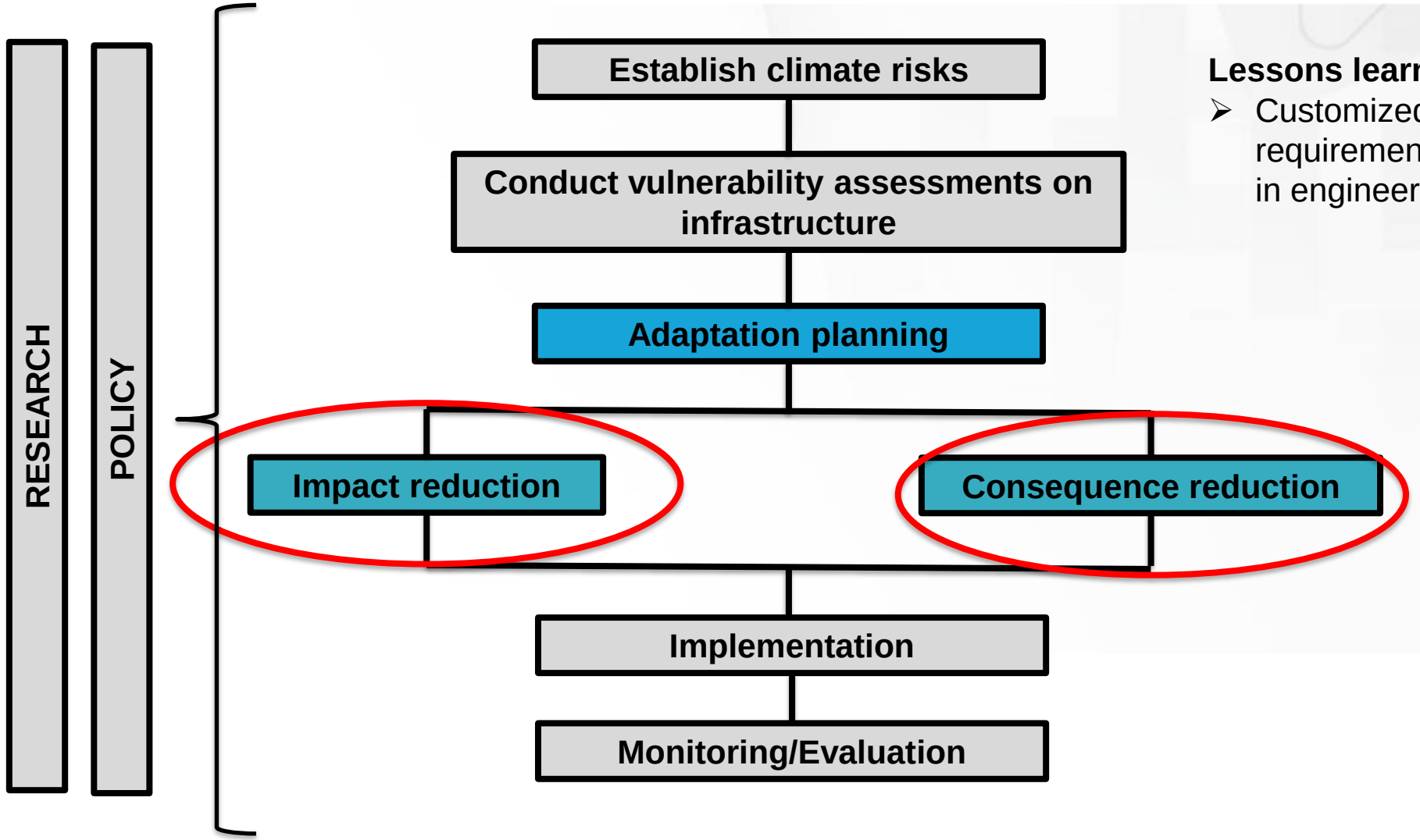
Response frameworks – Transport Infrastructure



Lessons learnt:

- Customized requirements for use in engineering design

Way forward:

- Incorporation to existing technical standards and maintenance systems

Way forward:

- Guidelines for infrastructure design, construction, monitoring and maintenance

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Adapting to a changing climate means reimagining our approach to engineering planning, design, construction and maintenance. As the climate evolves, so must our strategies, ensuring resilience and sustainability for the challenges ahead.

Thank you

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