Bridging climate data gaps with Frontier Technology

A report on technology options to bridge climate-related data gaps among BRICS central banks

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Abbreviations

4IR	fourth industrial revolution
5G	fifth-generation wireless technology
AI	artificial intelligence
ATM	automated teller machine
AWS	Amazon Web Services
BCB	Banco Central do Brasil (Central Bank of Brazil)
BIS	Bank for International Settlements
BRICS	Brazil, Russia, India, China and South Africa
CBAM	Carbon Border Adjustments Mechanism
CBDC	central bank digital currency
CO_2	carbon dioxide
DESA	Digital Earth South Africa
DGI	Data Gaps Initiative
DLT	distributed ledger technology
EO	earth observation
ESA	European Space Agency
ESAP	European single access point
ESG	environmental, social and governance
EU	European Union
FMCBG	Finance Ministers and Central Bank Governors
FoSDA	Future of Sustainable Data Alliance
FSB	Financial Stability Board
G20	Group of Twenty
GDP	gross domestic product
GFC	Green Fintech Classification
GFIN	Global Financial Innovation Network
GHG	greenhouse gas
ICBC	Industrial and Commercial Bank of China
IMF	International Monetary Fund
IoT	Internet of Things
IP	intellectual property
IPCC	Intergovernmental Panel on Climate Change
ISRO	Indian Space Research Organisation

IT	information technology
MAS	Monetary Authority of Singapore
ML	machine learning
NASA	National Aeronautics and Space Administration (US)
NGFS	Network for Greening the Financial System
NLP	natural language processing
OECD	Organisation for Economic Co-operation and Development
PBC	People's Bank of China
PRC	People's Republic of China
PV	photovoltaic
RBI	Reserve Bank of India
RFID	radio frequency identification
SAEOS	South African Earth Observation System
SAFBC	South African Financial Blockchain Consortium
SANSA	South African National Space Agency
SARB	South African Reserve Bank
SME	small- and medium-sized enterprise
TCFD	Task Force on Climate-related Financial Disclosures
UAV	unmanned aerial vehicles
UK	United Kingdom
UNCTAD	United Nations Conference on Trade and Development
US	United States

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The South African BRICS[1] Transition Finance Working Group consists of the researchers of Rabia Transitions, a South African non-profit research initiative, and members of the South African Reserve Bank (SARB).

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[1] A country grouping comprising Brazil, Russia, India, China and South Africa

Report summary

Climate data are essential to inform investment decisions, risk management and regulation as well as to monitor and understand the risks and opportunities associated with the green transition. Data needs are especially acute for the role of central banks, as gaps could hinder assessments of price and financial stability impacts associated with different physical and transition risks, thus increasing the probability of economic and financial crises. Therefore, climate risk management and monitoring of regulated entities such as banks and insurers is only effective to the extent that data sets exist, with sufficient granularity to support policymaking and monitoring.

New technological data advances such as artificial intelligence (AI), distributed ledger technologies (DLT) and earth observation (EO) satellites can bridge data gaps, thus strengthening financial institutions' capability to harness climate-related opportunities and build resilience to climate shocks. **This paper offers insights into the climate data needs of the BRICS central banks, and the role of emerging technologies to bridge climate data gaps.**

Across the central banks of Brazil, Russia, India, China and South Africa (BRICS), various methods are being used to analyse climate risk at both a macro and micro-prudential level, the most common being disclosures, stress testing and scenario analysis, taxonomies and stocktaking exercises. The application of these methods varies from country to country, as does the scope and depth of analysis. For example, the People's Bank of China (PBC) assesses climate risk at a macroprudential level through climate stress testing, whereas the Reserve Bank of India (RBI) contemplates to use these methods at a microprudential level.

Responses from the survey created for this paper highlight that the BRICS central banks face the same climate data gaps to those identified by the Network for Greening the Financial System (NGFS) in a 2022 report on bridging data gaps. They include:

- alack of historical data points for assessing physical and transition risks;
- the absence of detailed spatial and temporal data on exposure to climate risks;
- limited industry and asset-specific data on exposure to climate risks;

- an absence of granularity of data to assess climate risks;
- uncertainty on the level of financed emissions;
- limited generation and access to energy consumption data;
- no forward-looking data for projecting transition and physical risks; and
- limited data on the environmental, social and governance (ESG) application and impact on the financial system.

The climate data gaps identified are exacerbated by common challenges but in varying degrees across the BRICS central banks, which are:

- an inability to access existing climate data, with ownership, disclosure and data privacy being the main blockages;
- a lack of standardised climate data metrics;
- an inability to process and analyse existing climate data; and
- a lack of accurate, consistent and reliable climate data.

Frontier technologies which are defined as ‘new and rapidly developing technologies that take advantage of digitalisation and connectivity’, such as AI, the Internet of Things (IoT) and DLT (UNCTAD, 2023), hold significant potential to support central banks in collecting and analysing climate data. The most significant of these for the collection of climate data are IoT and drones, alongside EO satellites, while AI and big data analytics more broadly can enhance the analytical capacity of central banks, providing them with the capacity to analyse and process complex and large data sets. DLT and cloud computing also offer significant potential as they could enhance the capacity of central banks to verify, integrate and store data, though the use cases for these technologies are rather limited. Through their application and combination in various constellations, these technologies can:

- lower the cost and proliferation of sensing technologies;
- provide a greater spatiotemporal resolution of data;
- provide more complete data;
- lower technical barriers to emissions tracking;
- analyse complex and large data sets; and
- verify, integrate and store data in a cost-effective and easily accessible manner.

Use cases of how these technologies are being used to collect or analyse climate data within the BRICS countries are limited. A notable exception among the BRICS central banks is the Banco Central do Brasil (BCB) through its use of AI tools and broader big data analytics for climate risk analysis. The limited public information reflects the nature of frontier technologies and how they may be applied in bridging climate data gaps. However, the potential for their use at scale is immense.

The Technology and Innovation Report 2023 issued by the United Nations Conference on Trade and Development (UNCTAD) argues that the potential for frontier technologies in developing countries is significant, and changes in international trade rules will be necessary to realise such potential. Despite the challenges, some developing countries are building their potential and harnessing specific opportunities, such as AI in China and India[2] and DLT in Brazil.[3] Across BRICS, the ecosystem for these technologies to be advanced is relatively strong, with competitive local industries, research capacity and skill. This is reflected in UNCTAD's Readiness Index for frontier technologies in which the BRICS rank well among the 166 countries assessed.

A key concern, however, is that the development and ownership of intellectual property (IP) for most frontier technologies are still mainly located in the Global North, with China being the main outlier. This poses significant risks to the Global South including countries in BRICS. As they are dependent on imported data and technology, they are at risk of geopolitical changes which may inhibit access to various components or knowledge at various stages of the value chain, for example the European Union (EU) restricting the export of select radio equipment for satellite-earth applications to Russia (European Commission, 2023) and the United States (US) limiting AI chip exports to China (Fitch et al., 2023).

[2] Technology and Innovation Report 2023, issued by UNCTAD, https://unctad.org/tir2023; and also based on the authors' research and inputs from BRICS central bank surveys.
[3] Lift Challenge Digital Brazilian Real, https://liftchallenge.bcb.gov.br/site/liftchallenge/en; and also based on the authors' research and inputs from BRICS central bank surveys.

According to the survey conducted among the BRICS central banks, the following barriers exist in adopting frontier technologies:

- a lack of:
  - skills and capacity required to use and maintain the technology in question (a barrier that was raised multiple times in the survey);
  - funding available to explore and invest in the technologies in question; and
  - secure storage and an inability to verify collected data as barriers to the use of these technologies;
- limited capacity to process the data collected; and
- the need for appropriate regulatory compliance.

Areas for further work: Some data needs are nascent, such as monitoring the climate risks facing small- and medium-sized enterprises (SMEs). Emergent research suggests that AI and IoT can be applied to analyse and process various data including unstructured data from multiple sources, and geospatial data can help determine the potential risk exposure of businesses within a specific geographic area.

Recommendations: Collaboration and capacity building remain essential to unlock frontier technologies. Collaboration is also needed within countries, particularly where the national institutional capacity to collect and analyse data capacity exists.

1. Introduction

The green transition is driving a shift in global production and consumption to reduce global temperatures to below 1.5°C and build resilience to extreme weather events such as floods, droughts and fires. The pace and depth of the shifts in weather patterns have positive and negative side effects on economic and social systems, influencing how central banks and the financial sector more broadly may respond. The risks and opportunities of shifting systems are influenced by access to climate and green transition data that can be used to inform investment decisions, risk management and regulation. New technological advances such as AI, DLT and EO satellites can strengthen the capability of financial institutions to harness climate-related opportunities and build resilience to climate shocks.

The financial sector requires access to essential information (data) to inform the size and scale of required climate interventions and facilitate targeted investment. Data needs are especially acute for the role of central banks, as gaps hinder assessments of the price and financial stability impacts associated with the different physical and transition risks, thus increasing the probability of economic and financial crises. In addition, climate risk management and the monitoring of regulated entities, such as banks and insurers, are only effective to the extent that data sets exist, with sufficient granularity to support policymaking and monitoring. While the availability of relevant data are an important factor in addressing climate-related financial risks by regulated entities, other equally vital factors, such as effective governance structures and the enhancement of capacities for data collection, monitoring and assessment, also significantly contribute to this endeavour.

It is important to note that the financial sector is not regarded as a neutral respondent to climate crises, according to the principle of 'double materiality'. This principle acknowledges that while financial actors face climate risks (such as the risk of stranded assets) within their existing portfolios, they can also create new climate risks through their future actions or inactions. The implications of this principle for bridging climate data gaps are that data needs would have historical, forward-looking and anticipatory components, especially for applying tools such as scenario analysis and stress testing of the actions being taken. Further, to understand the impact of disclosures on climate risk by financial institutions, technology has an important contribution in instances where imperfect data and foresight analysis are necessary. However, human discernment is critical for making sense of the data outputs generated through technology.

Research by the International Monetary Fund (IMF), NGFS and Group of Twenty (G20) suggests that climate data gaps are obstacles to the green transition, citing paucity and a lack of granularity as the primary issue. As a result, climate change recommendations were added to the third phase of the Data Gaps Initiative[4] (DGI) in 2021.

Technological innovations and advances offer immense potential to support the DGI recommendations and bespoke data gaps experienced among financial actors, particularly central banks. Developments such as IoT[5] aid in climate data acquisition, data provenance, data for monitoring commitments and data for reporting. DLT, for example, builds confidence in the traceability of data. The ability of these technologies and others to fulfil the climate-related data needs of central banks and other financial entities relies on factors such as their accessibility, IP ownership and the feasibility of establishing collaborative models for their application and development.

Data on climate change and green transitions are an essential foundation for developing effective response strategies and contributions by the financial sector. Technology can be a useful aid for bridging data gaps to enhance the efficacy and impact of decisions and mandate execution among financial actors, and critical skills for data analysis and decision-making.

1.1 Objectives of the study

The report is guided by the following key deliverables:

a. Identification of data gaps impacting the financial sector in the BRICS countries within the four areas of data acquisition, data provenance (including timeliness of data), data for monitoring commitments and data for reporting.
b. Identification of possible technologies as well as how big data analytics can be used to address these data gaps, given developments in the policy space.

[4] DGI was first launched in 2009 by the G20 Finance Ministers and Central Bank Governors (FMCBG) to close the policy-relevant data gaps identified following the global financial crisis. For more information on DGI refer to: https://www.imf.org/en/News/Seminars/Conferences/g20-data-gaps-initiative

[5] Refers to the Internet of Things, being devices and sensors to measure carbon emissions, energy consumption, and pollution directly at the source.

c. Expression of the views of BRICS central banks on the data gaps in the financial sector in their respective financial sectors. When possible, offer case studies from the BRICS economies to illustrate the use of some of these technologies, for example how technologies are helping to identify the exposure of balance sheets to certain physical risks, or the use of ESG scores.
d. Identification of possible obstacles to technology adoption to address data gaps such as ownership, licensing, regulations or policies, or capabilities around technology adoption.

1.2 Definitions

The following definitions of 'data gaps' and 'technology' inform the analysis in this paper:

Data gaps and data holes. The Future of Sustainable Data Alliance[6] (FoSDA) distinguishes between data gaps and data holes in the context of ESG data in a 2022 report. 'Data gaps' are instances in which data exist and are reported but may not be collected in the needed level of granularity or format. 'Data holes' appear when there are "limited robust frameworks, guidance, or best practices for data, and where, at times, there are uncertainty about the exact data that would be needed or most useful" (FoSDA, 2022).

Data gaps. In our analysis, we define data gaps as "data that are missing from existing frameworks in the level of granularity or the format required, in the context of known data needs expressed by the central banks". Further research may be useful to identify potential data holes that the central banks and financial sector may face in relating their mandates to green transition and climate change. Such data holes would be relevant as the absence of appropriate frameworks or mechanisms for data collection, or knowledge of which data may be most useful to central banks, constitutes a transition risk.

Technology. Although the term is not particularly disputed, a variety of definitions and understandings exist (Mitcham and Schatzenberg, 2009). This paper, and the context in which it is used, defines technology as the "application (and advancement) of (automated) systems

[6] FoSDA is a standalone membership organisation that aims to "be the voice of the sustainability data and analytics ecosystem, bringing deep expertise, thought leadership and multi-stakeholder engagements" (FoSDA, n.d.). It was formed by the World Economic Forum and several other organisations after the 2020 Davos Summit. Some of the founding organisations include the Institute of International Finance, Asia Securities Industry & Financial Markets Association, Tsinghua University, the Official Monetary and Financial Institutions Forum, Global Financial Markets Association, Climate Bonds Initiative, FinTech4Good, Everledger, Oxford University, the Spatial Finance Initiative, Catapult, Finance for Biodiversity and GoImpact.

and devices that help to analyse and address problems and serve as a means to an end" (SI Network, 2023).

1.3 Research approach

The report offers a systematic analysis, starting with the climate risks faced by the respective BRICS countries (individually and collectively) and linking these to their central bank mandates to determine data needs. The report also considers the data availability and identifies gaps, matching these with technologies that can be used to address climate data gaps. The report concludes with considerations of technologies that can be readily applied by BRICS central banks to address their data needs and bridge emergent gaps.[7]

The report is informed by a desktop analysis and survey responses from the BRICS central banks. In addition, expert knowledge from the BRICS webinar series on climate data and technology as well as the 2023 Green Swan Conference co-hosted by the SARB offered useful insights.

2. Climate data gaps and challenges in BRICS

This section provides a summary of climate data developments among BRICS central banks, including the results from the BRICS central bank climate risk survey that was distributed in May 2023.

2.1 Global climate data gap workstream findings

In 2009, the G20 Finance Ministers and Central Bank Governors (FMCBG), in partnership with the IMF, launched the DGI to close data gaps following the global financial crisis. The first phase of the DGI concluded successfully in 2015 and led to the second phase which focused on creating mechanisms for regularly collecting and disseminating statistics. In 2021, the IMF, in collaboration with the Financial Stability Board (FSB) and the Inter-Agency Group

[7] This review will reference technology and its definitions broadly – a process that is driven by knowledge acquisition processes that develop at rapid speed and are destroyed or substituted at an even greater pace.

on Economic and Financial Statistics, developed a work plan for Phase 3 (DGI-3) (IMF, 2022a).

Adopted during the G20 Bali Leaders' Summit, DGI-3 included a climate change component and was accompanied by the following related recommendations (IMF, 2022b):

Recommendation 1	Monitor progress on greenhouse gas (GHG) accounts and natural carbon footprints
Recommendation 2	Prepare energy accounts to record the supply and use of energy
Recommendation 3	Determine the carbon footprint of foreign direct investment
Recommendation 4	Track sources and use of climate finance
Recommendation 5	Develop forward-looking physical and transition risk indicators
Recommendation 6	Examine the extent of government climate-impacting subsidies
Recommendation 7	Track climate change mitigation and adaptation in current and capital expenditure
Recommendation 13	Improve access to private and administrative data
Recommendation 14	Data sharing

In 2021, the Irving Fisher Committee on Central Bank Statistics surveyed its members to identify data gaps for sustainable finance from a central bank perspective.[8] Central banks from emerging market economies stated that their top sustainable finance policy priorities are increasing sustainability awareness, developing capital markets and financing sustainable objectives (Schmieder et al., 2021). The key findings from this study are as follows (Schmieder et al., 2021):

- There is a **growing demand for data** on sustainable finance from central banks as they seek to fulfil their core mandates which have broadened to adequately manage financial stability within the context of climate change and the development of green capital markets.
- There is a plethora of sustainable finance data needing assessment. However, many indicators in the areas of physical risk, emission trading and energy use pricing are

[8] Responses were received from 28 advanced economies and 31 emerging market economies. BRICS countries South Africa, Russia and India responded to the survey.

backward-looking. There is a new focus on generating forward-looking indicators that will enable a holistic assessment of risks; however, these indicators are still in development.

- There are substantial **differences in the availability of data** across different jurisdictions. These differences are particularly true for emerging market economies, where foundational work is still required to standardise definitions and taxonomies.
- Indicators related to **social and governance themes are limited**. Central banks identified financial inclusion, working conditions and human rights as the most important social indicators, whereas transparency, disclosure and board diversity were important from a governance perspective.

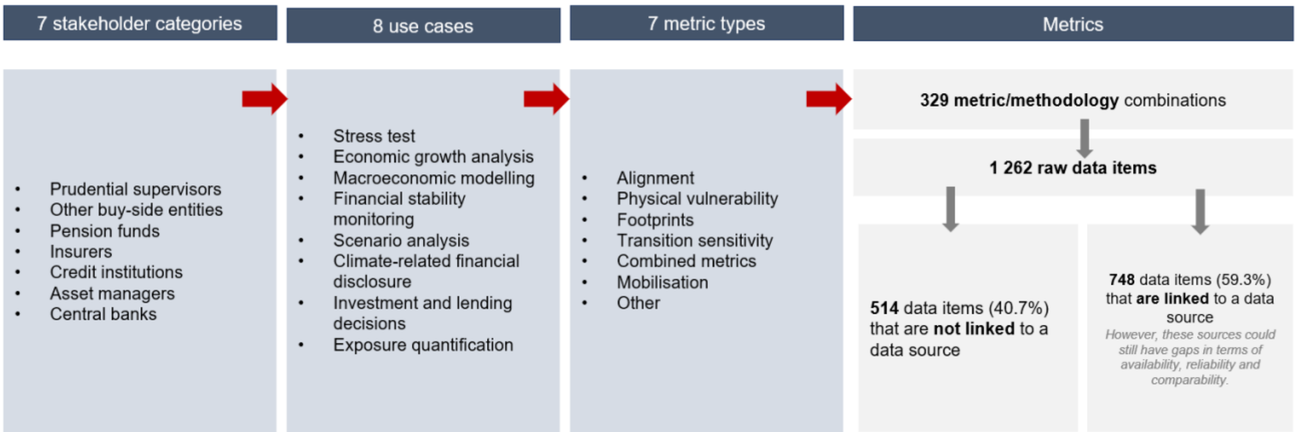
In July 2020, the NGFS established a workstream on bridging data gaps to start a dialogue with stakeholders in the financial sector to identify and address the gaps in climate-related data and advance their recommendations (NGFS, 2022a). This was documented in the 2021 progress report and the 2022 final report on data gaps. The NGFS (2022a) recognises that appropriate climate-related data are required to address climate risks and build resilient financial systems. Such data would need to be of high quality, reliable and comparable. As a foundation for addressing data gaps, three pillars were identified:

- Convergence towards global disclosure standards that are common and consistent across jurisdictions.
- Development of global taxonomy/shared principles for sustainable finance classifications.
- Development of well-defined metrics that enable decision-making, certification labels and methodological standards.

The NGFS compiled a directory mapping the data needs of financial sector stakeholders with data metrics and corresponding sources **(Figure 1)**. This exercise highlighted the areas with the most significant data gaps. Seven financial stakeholder categories were identified with eight data use cases and seven types of metrics, which cascade into 329 metric/methodology combinations and an additional 1 262 raw data items.

The study found that 40.7% (514 data items) of the raw data items required by financial stakeholders cannot be linked to an underlying data source. As for the 59.3% (748 data items) that can be linked to a source, there is no information about this data's availability, reliability and comparability (NGFS, 2022a).

Figure 1: Summary of the NGFS directory structure



Source: Adapted from NGFS (2022a)

An overview of the number of metric types within the directory shows that 'transition sensitivity' (37%) and 'physical vulnerability' (19%) are the two metric types for climate data. The report also found that forward-looking metrics are essential for financial stakeholders. This is particularly important for measuring 'physical risks', as 83% of these metrics rely on forward-looking indicators (NGFS, 2021a). The most significant data gaps impacting decision-making on investment and lending as well as the quantification of exposure (NGFS, 2022a) found in this exercise were:

- biophysical impact (such as floods, droughts, storms, biodiversity, forest depletion);
- emissions data; and
- geospatial data.

A similar study by the Bank for International Settlements (BIS) on climate risks and data gaps from the perspective of international reserve management for central bankers aligns with some of the key findings from the NGFS (BIS, 2022). The most significant data gaps the BIS study identified were:

- consistent and reliable emissions data;

- geographically specific data; and
- ESG data for issuing financial institutions.

In summary, research on climate data gaps is growing, particularly research on data gaps for physical and transition risks. Also emerging are new data needs which are required to facilitate the analysis of the interdependencies between environmental risks and social risks and their impact via transmission channels (NFGS, 2022a). Monnin and Robins (2022) have also highlighted new data gaps for central banks on 'just transition'. At present, precise recommendations on such data gaps are still nascent but are essential for understanding the impact of social consequences through climate risk transmission channels.

2.2 Data challenges

The findings described above are useful for scenario building and stress testing, for informing disclosure requirements and for climate risk management (especially for vulnerable economic sectors). However, for the financial sector to use such data there are certain prerequisites such as reliability, consistency and accessibility to facilitate investment, risk and policy decisions. These challenges are recognised in the NGFS studies (2022a and 2021a), which highlight the following climate data challenges:

- **Trust in the quality of the data:** auditability is required to ensure the quality of the data. This is particularly important to avoid greenwashing and to enhance the reliability of firm-level data.
- **Estimation/modelling:** many climate-related indicators rely on estimations derived through modelling techniques where underlying data points are often unknown. This requires the reliance on specific expertise and proprietary information, necessitating sufficiently capacitated stakeholders to understand the different modelling methodologies and their advantages and disadvantages.
- **Relevant benchmarks:** there is currently a lack of benchmarks from which to compare data. This limits the ability of stakeholders to assess their exposure to climate-related risks accurately.

- **Specific location information:** the directory currently lacks sufficient location information at the entity and asset level, making it challenging to measure the concentration of physical risks within a particular geographic location.
- **Cost of granular data:** there is a lack of granular data and where available, the data are not open source. Of the 65 organisations that provide emissions data, 58 require payment before granting access to their data, while only 7 of them offer open-source data.
- **Forward-looking transition risk:** the measurement of transition sensitivity and risk relies primarily on emissions data which are predominantly backward-looking. Transition plans use firm-level disclosures containing information on capital and operating expenditure which are backwards-looking indicators. Very few providers provide forward-looking capital and operating expenditure data, and those are also usually modelled instead of reported or audited.
- **Capacity building:** 13% of the raw data items are science-based data relating to biophysical impacts and climate changes. Also, about 20% of the raw data items that support the metrics for measuring physical vulnerability and transition sensitivity are science-based. This requires stakeholders and decision-makers to have a sufficient understanding of science-based metrics.
- **Lack of physical and transitional risk data:** there are not much data that record the physical and transition risks associated with climate change. Forward-looking metrics continue to remain a challenge, although risks metrics, including physical vulnerability metrics, are significantly more forward-looking than the relatively more backward-looking transition risk metrics.

Box 1: European single access point

In 2027, the EU is expected to introduce a European single access point (ESAP) that will act as a common data space and SAP for “public financial and sustainability-related information on EU companies and EU investment products”, including small companies, increasing the visibility and transparency of companies for potential investors (Spinaci, 2023, 1).

2.3 Climate risks identified among BRICS countries

Assessing climate risks requires close inspection of a number of factors, for example in the case of physical risks deconstructing unpredictable events, hazards and chronic exposures which will inform the aggregate physical vulnerabilities. This section provides an overview of physical and transition risks as well as projected biophysical impacts and related health vulnerabilities the BRICS countries face. The section does not intend to be an exhaustive understanding of climate risks and additional work would be essential to further deconstruct the specific risks each BRICS country is facing.

Physical risks

According to an Intergovernmental Panel on Climate Change (IPCC) report (IPCC, 2023), common physical risks among the BRICS countries are droughts, floods, heatwaves and vector-borne diseases.[9] **Table 1** presents projections of climate risk indicators by 2030.

Table 1: 2030 biophysical and health vulnerabilities projections in BRICS

Indicator	Brazil	China	India	Russia	South Africa
Biophysical indicators					
Mean surface temperature					
Precipitation					
Water discharge					
Drought index					
Surface winds					
Soil moisture					
Winter wheat yield					
Spring wheat yield					
Health indicators					
Exposure of vulnerable populations to heatwave					
Loss of labour productivity					
Heat-related mortality					
Wildfire risk					

Low risk within country

High risk within country

Source: Climate Vulnerability Forum and V20, 2022

[9] Illnesses generally caused by viruses, bacteria and parasites that are transmitted by vectors such as mosquitos and ticks.

There is a medium to high biophysical vulnerability in China, India and Russia, including indicators of a high-water discharge in 2030, which implies flooding for those countries, thereby affecting agriculture yields. The levels of soil moisture are also expected to be low across all the BRICS countries, with expectations of low precipitation in Brazil (implying drought). Health indicators such as the relatively high risk of heat-related mortalities show that the social consequences of biophysical impacts may negatively influence economic activity.

Transition risks

Based on the survey responses from BRICS central banks, there are common sector-related vulnerabilities in the bloc in which transition risks may manifest (i.e. agriculture, oil and gas, coal, iron and steel, and transportation). This may be due to shifts in production and consumption patterns and in finance flows as well as differing paces for the transition set between nations. Policy inaction may also exacerbate transition risk, which may delay the transition or cause a failed transition (NGFS, 2022b). In addition, where no policy action exists to combat transition risks, physical risks will only intensify and cause major economic losses (Zandi et al., 2022).

A growing focus by corporations and nations around setting net-zero targets will influence trading relations between countries, given the different time-based goals ranging from 2030 to 2060. Most Global North countries have set 2050 as the year for achieving net-zero emissions and are introducing climate-related policies both domestically and in their trade relations to achieve their goals, while also commercialising emerging mitigation technologies. Among the BRICS, the timing for achieving net-zero emissions is also varied – India (2070), China (2060), Russia (2060), Brazil (2050) and South Africa (2050).

These shifts may, depending on the materiality of exposures to certain trading partners, imply significant trading costs as the production base shifts, trade patterns change and comparative advantage gets redrawn to favour low-carbon supply chains for goods and services (Naidoo et al., 2023). In turn, changes in the revenue derived from trade may have complex fiscal implications for countries' public spending if diminished because of these structural economic changes. For example, the EU's Carbon Border Adjustment Mechanism (CBAM) which aims to preserve the competitiveness of EU exports and prevent carbon leakage, will begin its transitional phase in October 2023. Other countries such as the US, Canada and Japan are also considering the implementation of carbon border adjustment measures (Merven et al., 2023).

Both physical and transition risks are likely to have particular social consequences such as displacement and hence migration, health impacts, food and water security, and loss of jobs at the sector level. For example, storms, floods and droughts were among the highest causes of displacements in 2022, according to reports by the Internal Displacement Monitoring Centre (IDMC, n.d.). Approximately 5.9 million people globally were internally displaced, with China (0.94 million people) and India (2.5 million people) being among the most affected countries (out of 84 assessed).

During 2022, BRICS countries also experienced significant climate-related disasters which caused economic and social vulnerabilities and losses, such as floods in Brazil, South Africa and China. In particular, drought in Brazil caused an 8% drop in agricultural gross domestic product (GDP) in the first quarter of 2022 (Hanbury, 2022). South Africa's floods affected the supply chain of primary industries across the African continent (Cele and Naidoo, 2022) and prolonged flooding in China caused similar disruptions to that economy (Patton, 2021).

2.4 Data gaps identified by BRICS central banks

According to the survey results, the primary data challenges expressed among BRICS align with those identified by NGFS:

- **Difficulties due to lack of quality and consistency:** it is difficult to compare and rely on data from different sources as there is no consistency in the data or consistency in the reporting style.
- **No standardisation of metrics:** the lack of internationally agreed taxonomies creates difficulty in aggregating and comparing data. The data are also being reported in a qualitative or non-financial context, which makes the collection and analysis of the data challenging. It is also difficult to differentiate between activities that should be considered 'green' or otherwise.

- **Accessibility of data:** though data may be available, it is not always publicly available and require payment to access. There is also a lack of coordination and mobilisation of data sources.

Relative to the climate risks experienced, the following data needs and gaps in **Table 2** were identified in the survey completed by the BRICS central banks:

Table 2: Data needs per country

Countries	Physical risks	Transition risks	Other
Brazil	Emissions data, energy consumption and geospatial data	Company-level climate data, company-level climate targets and strategies, asset boundaries	
Russia	Emission data	Data on exposed sectors such as oil, gas and coal	
India		Data on exposed sectors such as electricity, steel, automotive, aviation and cement	Green/non-green activities
China	Emission data	Data on exposed sectors such as electricity and coal	
South Africa	Emission data, exposures per geographic area and sector (in granular detail), data pertaining to extreme weather events, GHG emissions vs intensity vs concentration, national carbon footprints, energy account data	Data on exposed sectors such as coal, electricity, agriculture, iron and steel mining and transportation	Climate finance investment, climate and environmental revenue, ESG data and climate change mitigation, and the adaption of current and capital expenditures

Source: Authors' own

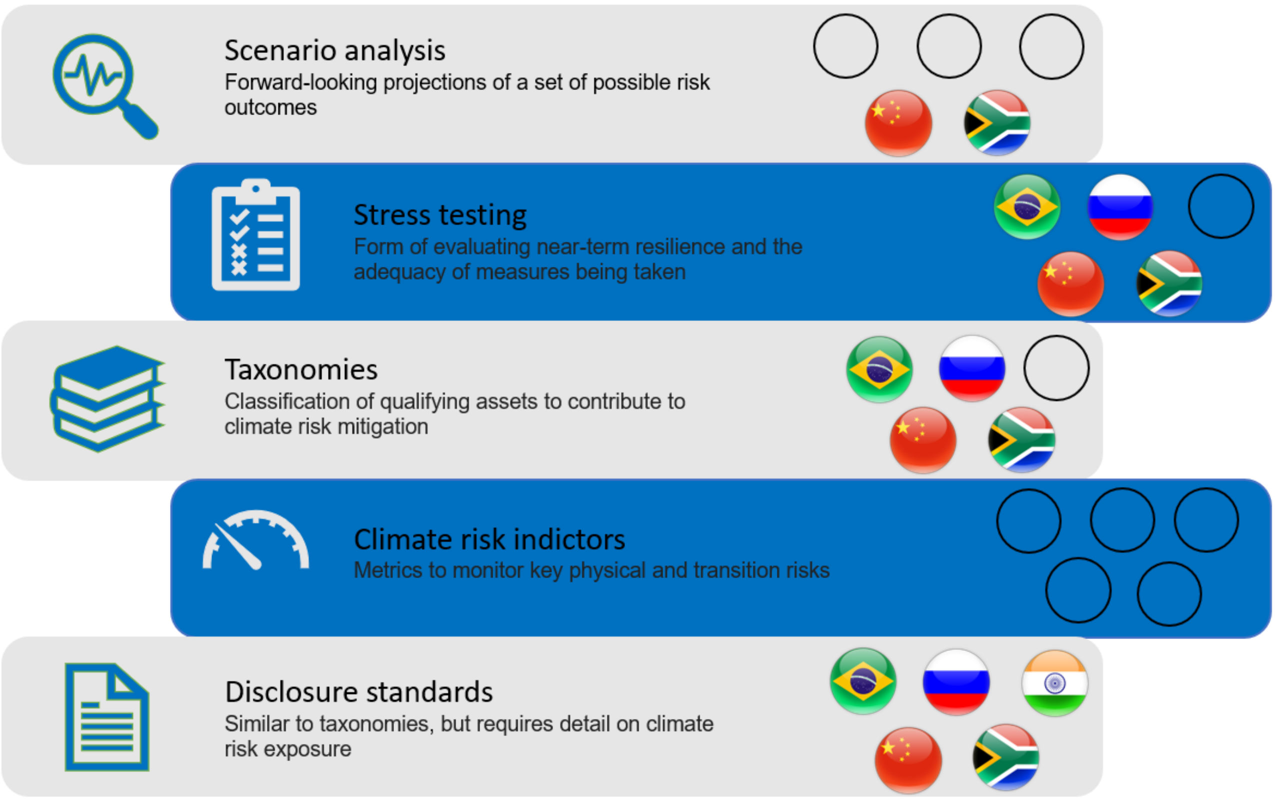
The summary shows the physical and transition risks and associated data needs and gaps of the BRICS central banks. The 'other' data suggest a qualitative review of the data gaps necessary for understanding how finances are spent (public and private) on mitigating and adapting to climate change.

The survey also considered the BRICS central banks' views on data gaps for social impacts in the context of climate risk being monitored. Climate change is regarded as an indirect contributor to conflict, given that climate-related events can lead to displacement, loss of pastoral lands, inaccessibility to water, migration and related vulnerabilities such as food and energy insecurities.

2.5 Methods employed by BRICS to engage in climate-related data strategies

A brief description of tools and processes used by BRICS central banks in climate risk analysis can be found in **Figure 2.**

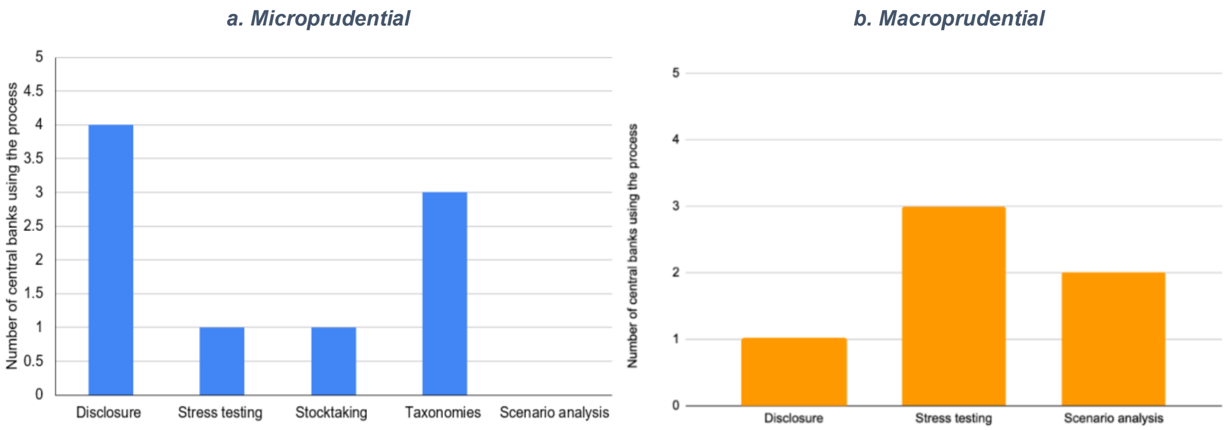
Figure 2: Processes utilised by central banks in climate risk analysis



Source: Authors' own

The survey results illustrated in **Figure 3** highlight that in BRICS countries, climate-related tools and processes are being used in differing degrees and intensities and for different purposes. For example, the PBC is currently assessing climate risk and impacts at the macroprudential level through stress testing and scenario analysis, whereas the RBI is contemplating the use of these methods at a microprudential level.

Figure 3: Climate-related processes adopted by BRICS central banks



Source: Authors' own

Figures 3 illustrates the following takeaways:

- **Disclosure requirements:** Brazil is currently the only central bank with mandatory disclosure requirements and includes aspects related to social, environmental and climate-related risks. In contrast, China has disclosure guidelines, but they are voluntary and related to institutions' environmental information to determine the risk and exposure to climate and environmental changes. Furthermore, South Africa, India and Russia have no existing climate-related disclosure requirements. However, this is under development and/or consideration. India has issued a framework for acceptance of green deposits for its regulated entities; South Africa's work around climate risk indicators is aiming to identify and monitor the climate risks the South African economy is facing; and Russia is using climate-related taxonomies.

- **Stress testing:** Only Russia and China have conducted specific climate-related stress tests. Brazil and Russia have taken a wider focus on the overall financial system, while South Africa is focusing only on financial institutions for now. Russia, Brazil and China focused on the impact on capital adequacy ratios of lending. In Brazil, these stress tests are done regularly, but not in climate-specific exercises. India focused on the level of preparedness among its regulated entities and South Africa on raising awareness around climate-related risks.

- **Scenario analysis**: The common climate risk scenario related to assessing transition risks was used by three BRICS central banks (Russia, Brazil and China) and climate-related financial risks by one BRICS central bank (South Africa), while Brazil focused on physical risks only.

Each BRICS country has among them opportunities for exchanging experiences and identifying potential areas of collaboration across the methods being used.

3. Climate data technology developments and prospects

This chapter considers the broad landscape of known technologies that are currently being used or under development that have the potential to reduce the data gaps in climate change. Research shows that advances are predominantly focused on the biophysical data needs across the data processing cycle. However, the data needs associated with transition-related economic shifts may constitute a ‘data hole’ (i.e. existing frameworks for data collection and analysis may not exist, or it is unclear what data needs to be collected and how).

3.1 Frontier technologies

Over the past decade, a new wave of technological innovation has changed the nature of knowledge, especially in the domain of technology innovation and application. UNCTAD has termed these technologies ‘frontier technologies’, which include but are not limited to AI, big data analytics, unmanned aerial vehicles (UAVs), 5G, DLT and IoT (UNCTAD, 2023). Table 3 summarises key frontier technologies that are relevant for gathering, processing and storing data to manage climate-related risks.

Table 3: Summary of frontier technologies and applications

<table>
<tr><th>Technologies</th><th>Application</th></tr>
<tr><td>Big data analytics</td><td>Big data analytics does not refer to one technology, but rather “the use of advanced analytic techniques against very large, diverse big data sets that include structured, semi-structured and unstructured data, from different sources and in different sizes from terabytes to zettabytes” (IBM, n.d-a).</td></tr>
<tr><td>Artificial intelligence</td><td>AI is often defined as “the capability of a machine to engage in cognitive activities typically performed by the human brain” (UNCTAD, 2023). Applications of AI include expert systems, natural language processing, speech recognition and machine vision (IBM, n.d-b).</td></tr>
<tr><td>Cloud computing</td><td>Cloud computing is the on-demand delivery of computing services using the internet, including servers, storage, databases, networking, software and analytics. Compared to the on-site provision of information technology (IT) services, cloud computing enables lower IT-related costs, improves agility and enables upscaling and downscaling as required (IBM, n.d-c).</td></tr>
<tr><td>Machine learning</td><td>Machine learning (ML) is a branch of AI that uses data and algorithms to imitate the way that humans learn, which gradually improves its accuracy (IBM, n.d-d)</td></tr>
<tr><td>Internet of Things</td><td>IoT describes physical objects that are embedded with sensors and actuators that communicate with computing systems via wired or wireless networks. This enables the digital monitoring of the physical world (McKinsey, 2022).</td></tr>
<tr><td>Distributed ledger technology</td><td>DLT refers to the protocols and supporting infrastructure that enables synchronisation between computers in different locations to propose and validate transactions as well as update records (BIS, 2017).</td></tr>
<tr><td>Unmanned aerial vehicles/drones</td><td>UAVs also referred to as drones are “flying robot[s] that can be remotely controlled or fly autonomously using software with sensors and GPS” (UNCTAD, 2023).</td></tr>
<tr><td>Earth observation satellites</td><td>EO is the use of remote-sensing technologies to gather information about Earth’s physical, chemical and biological systems. This typically involves the use of satellites carrying image devices (European Commission, n.d.). There are four main types of EO satellites:
Polar-orbiting satellites orbit the Earth from pole to pole about 14 times a day, providing medium to high-resolution images of the whole Earth. They can be applied for weather analysis and forecasting, climate research and prediction, global sea surface temperature monitoring, vegetation monitoring and environmental monitoring. (NOAA Satellite Information System, 2023).
Geostationary-orbit satellites are placed directly over the equator and revolve in the same direction as the Earth’s rotation. Geostationary orbit allows the high altitude, continual, uninterrupted monitoring of a specific region, providing high temporal resolution data (Carbon Brief, 2023).
Medium to low Earth orbit satellites operate at an altitude of less than 20 000km and have an orbital period ranging from 12 hours to 90 minutes, meaning a frequent temporal resolution of about 16 times a day. They provide high-resolution environmental monitoring, disaster response and forestry and agri-sector data (EOS Data Analytics, n.d.).
CubeSats are very small satellites that are inexpensive to build and launch. They could revolutionise the use of EO and environmental monitoring, particularly given their affordability.</td></tr>
</table>

The key innovations of these frontier technologies can be divided into several categories:

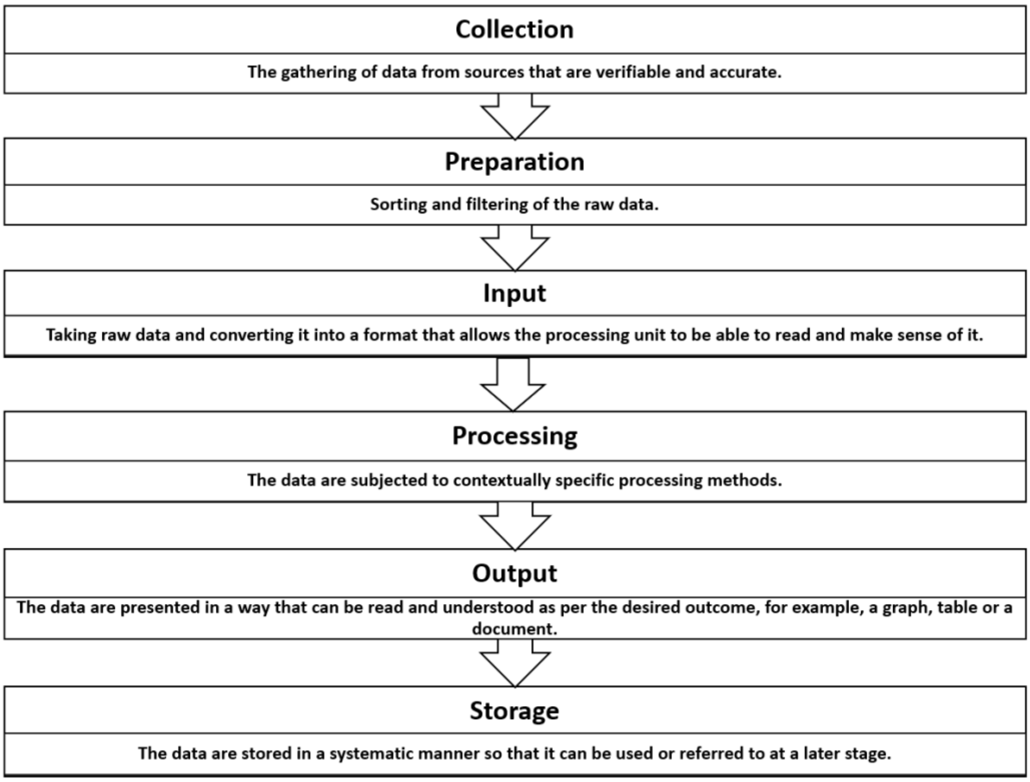
- The wave of technologies driving the fourth industrial revolution (4IR) include tools such as AL, ML, advancements in quantum computing, virtual reality, biotechnology and new materials.
- Devices equipped with sensors that are interlinked and can be used to collect large amounts of data such as IoT, UAVs and EO satellites.
- Cloud-based networks have resulted in a plethora of application software being developed and made available globally, increasing both storage and processing capacity.
- Online databases that provide easy access to data.

Frontier technologies are predominately developed and supplied by the US and the People's Republic of China (PRC) which constitute 30% of global research papers and close to 70% of patents. France, Germany, India, Japan, the Republic of Korea (South Korea) and the United Kingdom (UK) are also notable contributors to specific technologies such as AI and UAVs (UNCTAD, 2023). With the exception of the PRC, much of the IP for frontier technologies is held by organisations in developed countries (UNCTAD, 2023). These frontier technologies can help address tough global environmental challenges by allowing for the collection, storage and analysis of climate data. In turn, enabling policymakers may develop new insights into ways to avert climate and biodiversity destruction and drive economic and social development.

3.2 Technology and climate data processing cycles

When examining climate data technologies, the research has considered technologies across all the stages of the data processing cycle. Traditionally, the data processing cycle consists of six steps **(Figure 4)**, starting with the collection of raw data, followed by data preparation, inputting, processing, outputting and the storage of data. During this cycle, data are transformed into information, and finally, knowledge on which can be acted. Various technologies can be used within the data processing cycle and are applicable at multiple stages.

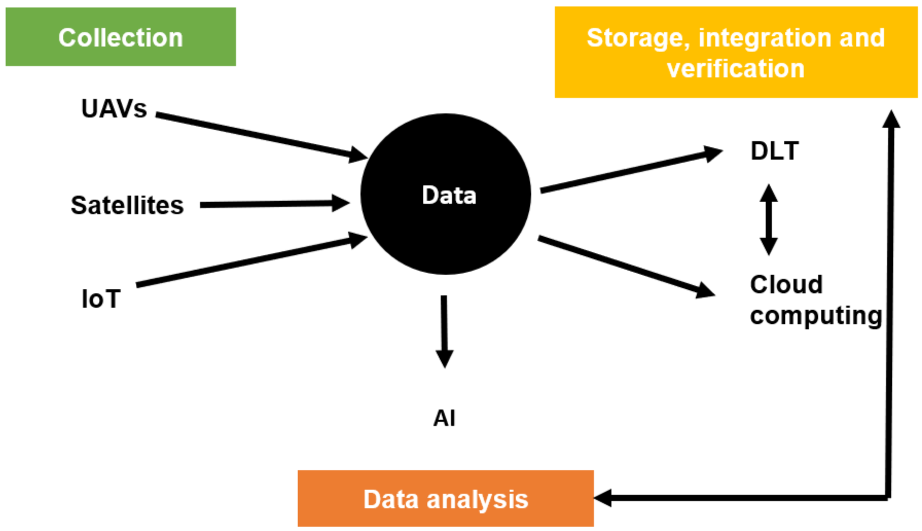
Figure 4: Data processing cycle



Source: Talend, n.d.

Within the (climate) data processing cycle, which includes collection and preparation dimensions, the key technologies described in Table 3 fulfil different roles (see Figure 5). IoT, drones and satellites can collect data; DLT can be used to integrate and verify data; cloud computing provides the necessary capacity for storage and computing capacity; and big data analytics, and more specifically AI, can analyse and process large data sets. Though AI can also be used to collect data, in the context of this paper its analytical abilities are of primary concern, hence the emphasis on its analytical capacity in **Figure 5**. Used in various combinations these technologies have the potential to enhance the quality and quantity of climate data available to decision-makers.

Figure 5: Relationship between frontier technologies in the data processing cycle



Source: Authors' own

3.3 Climate data technology developments

Together with the acceleration of technology development, the rise of data collection technologies has resulted in new opportunities for tracking progress towards global climate responses and understanding the risks associated with climate change (see Table 4). EO satellites and UAVs, combined with IoT devices and networks together solve important technical challenges and have the potential to introduce a new level of large-scale data availability, transparency and standardisation for assessing progress towards climate change mitigation and adaption.

Table 4: Data collection technologies with examples

Biophysical data	Technology for data collection	Expert views
Fires	Drones/UAVs	(Anderson, 2021)
	IoT	(Anderson, 2021)
	Satellites/EO	(Sharma, 2020)
Drought[10]	Drones/UAVs	(Moyer et al., 2022)
	IoT	(Dahir et al., 2023)
	Satellites/EO	(Crocetti et al., 2022)
Floods	Drones/UAVs	(Iqbal et al., 2023)
	IoT	(Arshad et al., 2019)
	Satellites/EO	(Więcławska, 2022)
Water-level rises	Drones/UAVs	(Varela et al., 2018)
	IoT	(Moreno et al., 2019)
	Satellites/EO	(ESA, 2020)
Temperature, climate and atmospheric conditions	Drones/UAVs	(Barfuss et al., 2022)
	IoT	(Srivastava and Das, 2022; Tziortzioti et al., 2019)
	Satellites/EO	(China Daily, 2023)
Greenhouse gas emissions	Drones/UAVs	(Xuefeng, 2015)
	IoT	(Xuefeng, 2015)
	Satellites/EO	(GHGSat, 2023)

Source: Authors' own

The inclusion of DLT in the digital data ecosystem can enable the integration of different data streams, from self-reported data and legacy databases to EO/IoT digital data collection technologies and could amplify the amount of data available to develop a more complete picture of global climate data.

To realise the potential benefits of an integrated digital climate data ecosystem, many challenges will need to be addressed. Some challenges relate to EO and IoT technologies themselves, while others relate more generally to the challenge of processing and analysing the anticipated massive volume of data that will be generated because of these technologies

[10] The probability and extent of droughts based on temperature, humidity and soil moisture data.

(Hsu, et al., 2020). Issues of storage, processing and new analytical approaches will be required to fully leverage the large-scale data generation of EO and IoT technologies. Emerging technologies such as DLT and file storage systems, such as InterPlanetary File System, provide the further potential to link together EO and IoT data streams with existing databases and to introduce a range of other mechanisms to ensure transparency, privacy and governance that can support next-generation tracking of climate change mitigation.

Over the past decade, the emergence of big data analytics, coupled with advancements in EO and IoT technologies, has paved the way for innovative research and practical applications focused on database mining and knowledge discovery (Hsu et al., 2020). In the context of EO and other developments, methodologies of spatial data mining and knowledge discovery have been further developed to extract and analyse large and complex sets of information (Mennis and Guo, 2009).

The forthcoming digital landscape will encompass more than just enhancing the intelligence of 'things' and expanding internet infrastructure to accommodate the surge in connected devices (IoT). It will also entail the seamless integration of data mining techniques to enhance services by introducing novel functionalities, including association analysis, classification, clustering, outlier analysis and time-series analysis. (Chen et al., 2015).

Frontier technologies have the potential to lower the cost and proliferation of sensing technologies; provide greater spatiotemporal resolution of data; provide more complete data; lower technical barriers for emissions tracking; and improve the quality and scale of data analysis. These are discussed in further detail below:

a. **Lowering the cost and proliferation of sensing technologies:** Advances in sensor and satellite technology, driven mainly by start-up entrepreneurs and private sector companies, have introduced low-cost, small-scale satellites that have the potential to lower the cost of EO for climate monitoring. There are now more working satellites deployed by fledgling space start-ups than by established government space agencies, with anticipated costs even lower for ChipSATs, smaller, postage-stamp versions of CubeSATs (Abate, 2019). The affordability of satellites, UAVs and other sensing technologies opens up new avenues for data collection, particularly in areas where conventional satellites might fail to capture daily or highly detailed measurements (Hsu, et al., 2020).

Small and inexpensive drones, for example, can be used for community-based forest monitoring to enable more effective forest management and conservation, which would be useful for tracking climate change adaptation progress (Paneque-Galvez et al., 2014). The ongoing trend of cost reduction implies an increased global scope in monitoring the Earth's physical, chemical and biological conditions, potentially offering a solution to the issue of inadequate climate data. (Hsu et al., 2020).

b. **Providing greater spatiotemporal resolution of data:** IoT devices can provide climate mitigation and adaptation monitoring with precise, high-resolution temporal and spatial data. In Norfolk, Virginia, ultrasonic sensors are deployed to detect subtle shifts in the gap between water levels and the ground, enabling real-time flood analysis (Carlson et al., 2019). In the electricity sector, networks and sensors can be easily implemented to collect energy readings from solar photovoltaic (PV) or wind power systems, sending that data to remote IoT gateways for pre-processing, storage and transmission to the cloud for monitoring and analysis. Open IoT platforms like Raspberry Pi and LoRa have the potential to significantly boost the effectiveness of renewable energy monitoring systems (Choi et al., 2018). UAVs provide high spatial semi-grid resolution environmental data which has better resolution than that provided by EO satellites. Drones have the flexibility and ability to capture detailed, more precise and frequent information (Li et al., 2022).

c. **Providing more complete data:** The low cost and ease of deployment of IoT devices and networks significantly reduce the barriers to data collection. For example, “the rise of cost-effective water quality sensing nodes and probes using commercially available off-the-shelf parts could pave the way for the large-scale implementation and robust environmental data collection and monitoring for assessing urban water quality targets in national and sub-national adaptation plans” (Hsu, et al., 2020). IoT can also be used for energy tracking and optimisation in the manufacturing sector. Wang et al. (2018) introduce a real-time energy efficiency optimisation method that uses radio frequency identification (RFID) and smart meters to monitor the flow of materials as well as the consumption patterns of machines. IoT devices then send information to a central server for analysis. These energy monitoring systems allow for energy-aware process scheduling and reduced resource wastage and are also able to continuously collect data without network or supply chain interruption.

Other notable systems for energy monitoring include OpenEnergyMonitor and ACme. OpenEnergyMonitor uses open-source Arduino boards in a three-phase power metering system that measures apparent and real power as well as root mean square voltage and current, while ACme measures active, reactive and apparent power, using wireless sensors and actuator networks (Jiang et al., 2009; Pease et al., 2018). These different monitoring systems could help to push the boundaries of indirect emissions accounting in a multitude of sectors. In smart city initiatives, connected wearables, sensors and actuators can help improve urban governance, environmental monitoring and sustainable living. The IoT European Large-Scale Pilots Programme was launched in 2016 to test the scalability of IoT applications and the interoperability of EU-based IoT platforms, such as Open-IoT and FIWARE (Meiling et al., 2018). The programme includes pilot projects which have been deployed in various European cities and focuses on using end-to-end sensor applications for collecting measurements on issues of ageing, food security and autonomous vehicles.

d. **Lowering technical barriers to emissions tracking**: IoT technology is capable of obtaining technically challenging data in both adaptation and mitigation domains. Low-power and long-range IoT devices can be installed at various industrial sites to capture GHG emissions in real time or near-real time (Hsu, et al., 2020), with probes and sensors that are interconnected with IoT control centres through communication protocols to oversee emissions (Hsu et al., 2020). To understand the land carbon cycle, sensors combined with AI modelling and satellite data are used. Flux towers can be used to measure the effect of different land use practices on the carbon cycle. This information helps researchers to more accurately predict the rate of CO_2 build-up that could lead to high-risk and costly climate change and to test the effectiveness of mitigation strategies. Also, location greenhouse emissions data can be used for ESG scoring by companies to estimate the environmental damage caused by carbon emissions from a company.

In smart city initiatives, open-source, long-range, low-latency and low-power wireless network standards can be integrated with IoT devices to collect information on temperature, light, humidity and pressure for the monitoring of green infrastructure (Le et al., 2019). These devices could also be employed in the adaptation domain, where sensors measuring water level, water speed, temperature, humidity and turbidity can generate warnings for flood detection systems. In the construction sector, specifically, an IoT-based system could make use of a distributed sensor network (e.g. RFID) to collect real-time emissions data to improve carbon emissions monitoring at different stages of the construction process (Mao et al., 2018).

e. **Analysing and understanding climate risks**: In addition to data collection, frontier technologies such as AI and big data analytics have also enabled more precise, detailed and comprehensive analysis of climate data, enabling the analysis of large and diverse data. In Brazil, the BCB is using data from the National Institute of Space Research on drought in the municipalities, cross-referenced with its own Credit Information System, to analyse and assess climate risk to monitor the sensitivity of the credit portfolio to extreme drought in each municipality (Sharan, 2023). In China, both state-owned and commercial banks are using big data analytics to analyse risk including climate risk. The Industrial and Commercial Bank of China (ICBC, 2022) is planning to develop a big data platform for environmental risk information which can be continuously analysed to improve ESG risk management by improving the speed and scale at which the data are assessed. The Bank of Huzhou in China analyses big data to extract environmental risk information and monitors various environmental performance indicators, which are then used by the municipal government for its Green Credit Management System (Choi and Li, 2021).

Perhaps the most prominent and significant technology when it comes to big data analysis for climate risks is AI. One of the most developed use cases for AI in assessing climate risk at a central bank level is NovA! of the Monetary Authority of Singapore (MAS). NovA! is an AI utility designed to assist financial institutions in their ESG risk assessment of the real estate sector, focusing on the origination, underwriting and servicing of loans (MAS, 2022). NovA! uses a natural language processing (NLP) technique to analyse information from documents, thereby reducing the time and cost of operations for financial institutions (MAS, 2022). A notable consortium partner within the NovA! project is the Bank of China

Limited; however, its role in the project or the extent to which it has been using NovA! is unclear.

Researchers at the Oxford Sustainable Finance Group and the Department of Banking and Finance at the University of Zurich have launched the Natural Language Processing for Sustainable Finance Programme. The project seeks to develop AI-based NLP to analyse large amounts of unstructured data that can then be used to monitor and assess sustainability risks in the financial sector, including climate risks. Already the project has developed an AI NLP tool 'Climate Chat' which is available online[11].

3.4 Broader technological developments

This section highlights additional developments in green fintech and data aggregator technologies which are relevant to this study.

3.4.1 Green fintech

Green fintech solutions are technology-enabled innovations applied to processes and products in the financial sector to support the reduction of climate-related risks (Green Finance Platform, 2023). The Green Fintech Classification (GFC) provides a standardised categorisation of the green fintech market. The GFC identified eight green fintech categories (Green Digital Finance Alliance and Swiss Green Fintech Network, 2022):

- green digital payment and account solutions;
- green digital investment solutions;
- digital ESG-data and -analytics solutions;
- green digital crowdfunding and syndication platforms;
- green digital risk analysis and insurtech[12] solutions;
- green digital deposit and lending solutions;
- green digital asset solutions; and
- green fintech solutions.

[11] The AI NLP tool "Climate chat" is a chatbot that was created based on the latest IPCC reports. The chatbot is named ChatClimate.ai. For more information: https://sustainablefinance.ox.ac.uk/nlp4sf-home/nlp4sf-resources/

[12] Refers to "technological innovations that are created and implemented to improve the efficiency of the insurance industry" (TIBCO, n.d.).

Fintech can be an important enabler to manage climate-related risks within the financial sector, but also in managing data integrity. For example, the RBI in collaboration with the Global Financial Innovation Network (GFIN) have organised a TechSprint which invited firms to develop a tool or solution that can help regulators and the market effectively tackle the risks of greenwashing in the financial services sector. Annexure A contains several examples of these technologies along with their use cases.

3.4.2 Data aggregator technologies

Data aggregator technologies have become important systems for aggregating and processing data. Some of the more popular aggregators of climate data are:

- Climate Data Tool (Dinku et al., 2022);
- Net Zero Tracker; and
- the World Bank Climate Warehouse programme.

Some of the applications are open source which means the data are publicly accessible and publicly available. Besides the aggregation of climate data, the functionality delivered by these applications also includes:

- data organisation;
- quality control;
- combining data sets from multiple sources;
- evaluating merged and inputs datasets;
- performing data analysis, including reanalysis and visualisation;
- downloading ancillary data (e.g. digital elevation models of country administrative boundaries); and
- multiple levels of granular data by country, city, state, region, province and company.

Prototyping and testing of the digital infrastructure to support measurement, reporting and verification of applications are used for national carbon registries, tokenisation instruments and knowledge-sharing and capacity-building resources.

4. Technology to bridge climate data gaps in BRICS

There are evident climate data gaps within BRICS that emerging frontier technologies can bridge for the respective central banks, a fact that is acknowledged by some of the central banks themselves. This includes emissions data, spatial-specific data, more granular data and more comprehensive data, among other data sets. However, despite the evident needs these technologies can provide, the extent to which they can be applied varies, and are dependent on several factors. This includes affordability, availability and the capacity to use the technology in question. For this study, the latter two have been given particular attention and have been determined by using survey results and a desktop analysis of the BRICS countries.

To best understand the extent to which frontier technologies can be deployed by the BRICS central banks for the collection and analysis of climate data, the following elements have been analysed across the BRICS countries:

- the extent to which the technology in question is being used to bridge climate data gaps in general;
- the extent to which the technology in question is being used or considered to bridge climate data gaps by financial institutions and the central bank; and
- the broader strengths, productive capacity and features of the local industry.

With this as a basis, potential blockages to the adoption and localisation of the technologies in question have been detailed, alongside commonalities, differences, risks and potential areas of collaboration between the BRICS countries. However, it is important to note that as many of these technologies have only recently emerged, use cases for their application are limited, particularly their application by central banks. Therefore, there are sections of this chapter where limited information is available.

4.1 Data collection

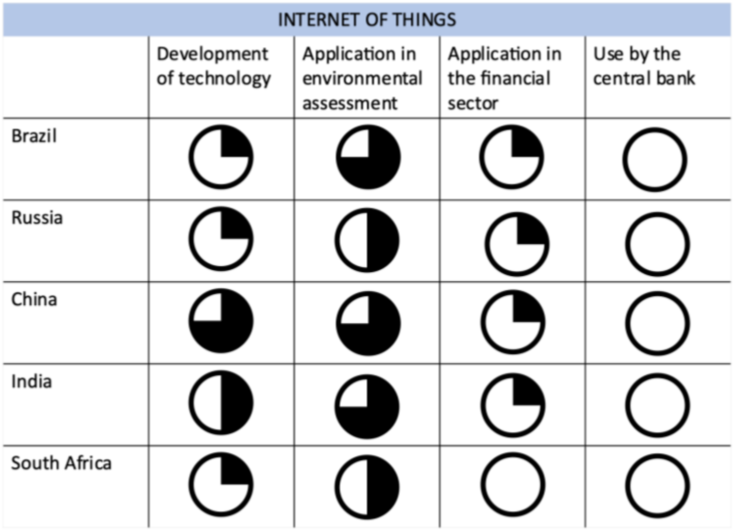
Three main frontier technologies can be used to collect more granular, spatially specific, comprehensive and detailed climate data; these are IoT, drones/UAVs and satellites/EO technology. The following tables (Figures 6–10) show the relative developments measured by four categories (i.e. development of technology, application in environmental assessment, application in the financial sector and use by the central bank) of frontier technologies. These developments are measured and graded according to the following key, and informed by desktop research and responses to surveys:

Key				
Fully developed	Strong but room for growth	Significant but still emerging	Nascent	Non-existent
●	◕	◑	◔	○

4.1.1 Internet of Things

One of the key technologies that can be used to address climate data gaps through the collection of large and diverse sets of data, is IoT. Within the BRICS, IoT is being used for a variety of purposes, including the collection of climate data (**Figure 6**). In Brazil and India, IoT has been used in combination with AI to predict fires (Pletsch et al., 2022) and monitor the level of pollution in water bodies (Balanchandran, 2021); in China, IoT is employed to collect environmental data relating to water quality (You et al., 2023) and the environmental impact of firms (Ding et al., 2023); in Russia Sberbank piloted a project in 2021 which uses IoT for precipitation monitoring (Tadviser, 2021) and MegaFon, a mobile phone operator, uses IoT to collect various environmental data (MegaFon, 2020). In South Africa, IoT has been used in the agricultural sector to monitor crops, forests, water, soil and weather conditions (Soeker et al., 2021). South Africa also uses IoT to collect carbon cycle data for climate change monitoring (Majozi et al., 2017).

Figure 6: Internet of Things within BRICS



Source: Authors' own

Despite the various examples of IoT being used to collect climate data in BRICS, instances of IoT use by financial institutions or central banks to collect climate data are limited, with the Sberbank example being an exception. In the case of BRICS central banks, there is no evidence of IoT being used to collect climate data. Nevertheless, there are numerous examples of how IoT is used by financial institutions for a variety of purposes. This includes banks in Brazil using IoT to gain insights into customer behaviour, preferences and usage patterns, while financial institutions in China are using IoT for credit evaluation, to collect data for risk analysis and to provide early warning signals for credit risks (Wen et al., 2021). In India, banks use IoT for several purposes, including improving the efficiency of automated teller machines (ATMs) (Vaitheesvaran, 2015).

In the actual development of the IoT industry within BRICS, the growth of the local industry has often been prioritised as part of their broader development strategies. The Brazilian government has taken several steps to promote IoT adoption. In 2017, it launched the National IoT Plan, which aims to foster the development of IoT applications across different sectors, such as agriculture, healthcare, transportation and smart cities (FUNAG, 2017). As a result, the development and adoption of IoT technology in Brazil has increased significantly. In China, the sector is also receiving financial and regulatory support from the state (Smid, 2023). In Russia, the government has introduced regulations that require particular institutions and consumers to purchase only locally produced IoT technology (Tadviser, 2023).

This is informed by its strategy to help develop the local industry as part of a broader information economy development strategy (Voronova and Dianova, 2022). This support of the local IoT industry is also taking place at the level of central banks, with the BCB currently supporting the development of several IoT technologies (Banco Central Do Brasil, 2022), as it has shown a keen interest in applying IoT for a variety of purposes.

As a result of these efforts to develop local IoT industries, growth in the innovation and production capacity of local companies has been significant. In China, dominant local companies have emerged, such as Quectel and Fibocom Wireless (Blackman, 2023) which hold a significant share of the local and global market. This is supported by the growing use of IoT in China, as there is already an adoption rate of more than 50% for IoT condition-based maintenance of equipment and remote asset monitoring (IoT Analytics, 2021). Of the BRICS countries China has the most advanced IoT industry and is often considered a global leader; however, India, Brazil and Russia have emerging industries, with India's being the most established of the three. In South Africa, there is also an emerging IoT industry (Brandusescu et al., 2017), however, its strength and size relative to other BRICS countries are minimal.

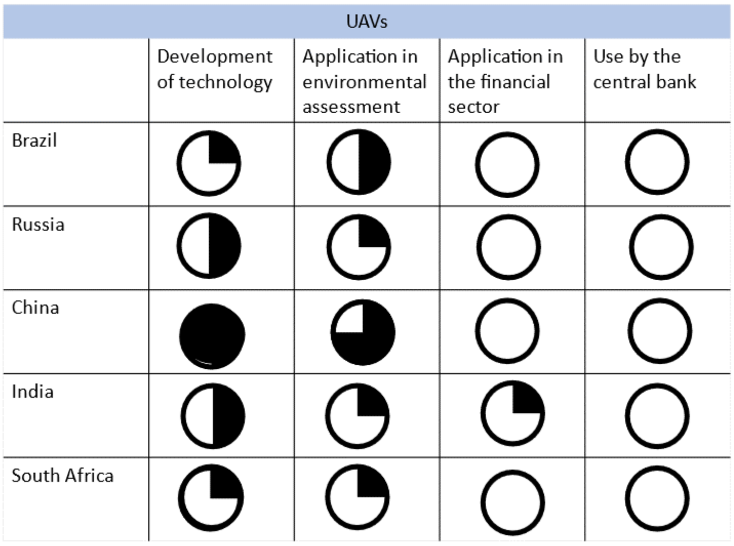
Within BRICS, the capacity to both provide and apply IoT for the collection of climate data, particularly relating to physical risks such as fires, droughts, flooding and water levels is available. Figure 6 reflects the relative developments of IoT technologies across the BRICS. Furthermore, BRICS-based IoT companies are strong global players, have the requisite infrastructure in place and have the capacity to innovate and design new products. This suggests that the basis exists for IoT to be used by central banks to collect climate data and thereby bridge some of the climate gaps BRICS countries are currently facing.

4.1.2 UAVs (Drones)

In the past decade drones/UAVs equipped with remote sensing technology have emerged as a viable means by which climate data can be captured, including in BRICS (**Figure 7**). In China, drones equipped with remote sensors were being used as early as 2012 to observe ice jams on the Yangtze River which historically have caused flooding (Lin et al., 2012). Drones have also been used by researchers to monitor pollution in water bodies (Qun'ou et al., 2021) and by local authorities to monitor pollution produced by industry (Xuefeng, 2015).

In other BRICS countries, drones are also used for similar purposes such as monitoring forest growth in Brazil (De Oliveira Andrade, 2019) and air quality in India (Hemamalini, et al., 2022), while in Russia it is used by the Russian Institute of Atmospheric Physics to conduct meteorological research (Forum Arctic, 2022). In South Africa, drones are mainly used in water-related applications, agriculture, disaster assessment, biodiversity mapping and land cover monitoring (Matthews, 2018; Refaai et al., 2022). However, their use in the financial sector has not yet been established.

Figure 7: UAVs within BRICS



Source: Authors' own

Despite the proliferation of drone use in the collection of climate data by various actors and institutions within the BRICS countries, there is little evidence that either financial institutions or central banks are using drones for this purpose or other purposes.

The state of the local drone industries across BRICS varies. China has a strong local industry second only to the US (He et al., 2022), and is home to the globe's largest drone maker DJI

(ARC Group, 2021). Russia, Brazil and India also have fast-emerging drone industries. In Russia the military industry is leading a lot of drone development within the country, and that drone systems in Russia are being developed to be combined with digital technologies such as IoT and AI (Edmonds et al., 2021). Brazil already has several well-established drone manufacturers (Plaza, 2022), with Akaer being one of the most prominent (MENAFN, 2023; Zawwya, 2023). In India, the industry is also being supported by the state as part of its efforts to achieve a US$1 billion drone industry by 2025 (Rawell, 2023). One of the largest local drone manufacturers is ideaForge (Gupta, 2023). In South Africa, there is also a significant military drone industry (Military Africa, 2022), and a small but growing commercial drone industry (Wesgro, 2022).

Drones equipped with remote-sensing technology can collect climate data, particularly data related to biophysical risk, as there are use cases of how this is being done across BRICS. Furthermore, the BRICS countries have relatively well-established drone industries, with China being the leader. There thus exists both use case examples of how drones can be used to collect climate data and the capacity to produce the drones that would be needed for this. However, drones are not being used by BRICS central banks or financial institutions to collect climate data. There is no indication in the literature or the survey results as to why this may be. However, drones combined with remote-sensing technology can be a useful means for central banks to address some of the climate data gaps outlined in Chapter 3.

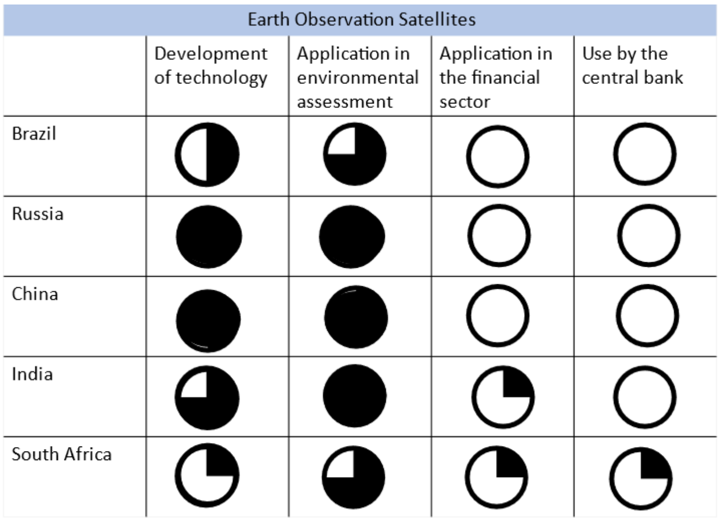
Box 2: Geocoding - Banco Central do Brasil (Central Bank of Brazil)

The BCB has implemented a plan to convert borrower addresses into geospatial coordinates. This initiative aims to enhance the BCB's capacity to assess the potential physical risks associated with borrowers: through the process of geocoding, the BCB can identify the precise geographical positions of the borrowers' addresses, thus enabling a more precise evaluation of climate-related physical risks, and furthermore facilitating the integration of relevant climate data into its analytical models.

4.1.3 Satellites and EO technology

Satellites and EO technology have been used to monitor climate and environmental changes for decades. This is as true in the BRICS countries as in other parts of the world, and in each of the BRICS countries satellites are being used for this purpose **(Figure 8)**. In China, satellites are used to collect spatial data on carbon emissions, droughts, atmospheric conditions, and carbon sinks to name a few examples (Zhong et al., 2019; CGTN, 2022; China Daily, 2023). In Russia, satellites are used to monitor ocean temperatures, storm systems, snow coverage, and general atmospheric and weather conditions (Reuters, 2021; Spaceflight Now, 2023).

Figure 8: EO satellites within BRICS



Source: Authors' own

India's space programme, which is led by the Indian Space Research Organisation (ISRO), has a National Information System for Climate and Environment Studies. Under this programme, and others such as the Earth Observation Application Sciences programme, the ISRO is monitoring and studying environmental and climate changes using EO technology (ISRO, 2023). This information is used by the ISRO and various institutes in India, including the Indian Meteorological Society to better understand climate risks, particularly physical risks. Satellite data are also used by financial institutions in India such as the ICICI Bank to conduct credit assessments of farms (ICICI Bank, 2020).

Brazilian institutions are also using satellites to collect climate and environmental data, including data on rainfall and droughts (Brito et al., 2021; Brasil Neto et al., 2021). In South Africa, the SARB uses climate models derived from EO data (Anvari et al., 2022). The South African Earth Observation System (SAEOS) data centre co-ordinates EO data from various platforms (SANSA, n.d.), and links them to complementary capabilities in neighbouring countries and the Global Earth Observation System of Systems. The South African National Space Agency (SANSA), a key contributor to the SAEOS, has a Digital Earth South Africa (DESA) technology platform which offers a vast collection of satellite imagery, spanning over 30 years, that covers South Africa and other African nations (DESA, n.d.). This imagery includes both archived and newly acquired data and is processed into useful information that can be used to observe, monitor, develop climate projections, and forecast climate change risks for key economic sectors. The satellite data in DESA's portfolio is diverse, with varying spectral, spatial, and temporal resolutions that are tailored to meet specific needs. Despite many EO satellites being owned and operated by the BRICS countries, those that can be used for GHG data collection are limited. The most well-known satellites used to monitor GHG emissions are the Orbiting Carbon Observatory series of satellites, the Greenhouse Gases Observing Satellite, and the European Space Agency (ESA) Sentinel-5P satellite, which are operated by the ESA, National Aeronautics and Space Administration (NASA), the Netherlands Space Office, and Japanese Aerospace Exploration Agency. The only BRICS-owned GHG monitoring satellites are in China and are not as effective as those in the global north (GEO, Climate TRACE, WGIC, 2021).

Though use of satellites and EO technology across the BRICS countries is extensive, not all of the data collected via these mediums is done with technology from the country in question. South Africa and Brazil collaborate with external partners to produce and launch their satellites or have to use the information generated by foreign institutions, as is the case for most of the satellite data South Africa uses. Brazil collaborates closely with China in its EO technology developments. India, China, and Russia by contrast have well-established satellite and EO industries, as well as the capacity to launch them, with the latter two having particularly strong capabilities.

In 2022 China had 541 satellites and 216 EO satellites in orbit, while Russia had 172 (Statista, 2023). This includes satellites used to collect data on the climate, ecology, and environment. These efforts are largely led by state institutions such as the Russian State Space Corporation Roscosmos (IAF, n.d.), the China Aerospace Science and Technology Corporation, and in India the ISRO. This information illustrates the extent to which each of the BRICS countries (and by association the central banks) have the foundation to use EO satellites to collect climate data.

An analysis of EO satellite use for the collection of climate data in BRICS shows that these technologies are being used by institutions in general, and by both central banks and financial institutions to collect climate data. Furthermore, BRICS countries can produce, launch and manage EO satellites. However, BRICS countries do face significant limitations when using EO satellites for the monitoring of GHG emissions. China is the only BRICS country with satellites that can monitor GHG emissions, and these satellites themselves are not as effective as those from the EU and North America.

4.2 Data analysis, verification, integration and storage

The collection of climate data is only the first step in the data processing cycle. Storage, verification, integration, and analysis of data are as crucial in the cycle and allow for the transformation of raw data into information and knowledge. Analysis of climate data (particularly big data) can provide the necessary detail, granularity, and nuance associated with the physical, transition, and socio-economic risks of climate change. In BRICS, the central banks and their subsidiaries are using various approaches to assess big data. The Russian National Reinsurance Company, which is a subsidiary of the CBR is developing a geoinformation system which will allow it to assess exposure to earthquakes and floods in a single web-mapping interface. The BCB is also using big data analytics tools in climate stress testing.[13] Of the frontier technologies, AI appears to hold significant promise for big data analytics and is the analytical technology detailed in this section.

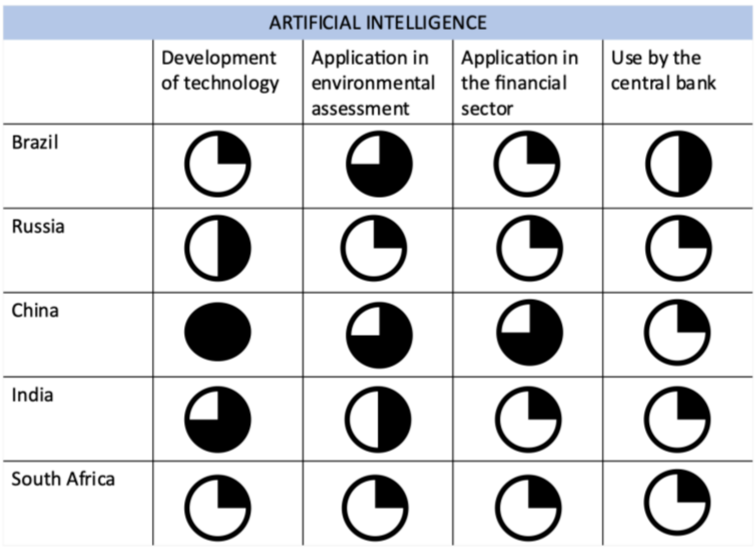
[13] Details on the tools have not been provided, nor are they publicly available.

Concerning storage, integration, and verification of data, DLT has emerged as a technology that can verify, integrate, and store data, while cloud computing is a means by which big data can be stored, while also providing the computing power needed to process and analyse data.

4.2.1 AI

Within BRICS, AI including ML technologies are being used to analyse climate data and assess climate risk **(Figure 9)**. This is or is planned to take place at various levels, including within central banks and financial institutions. In Brazil, ML tools have been used to assess the environmental impact of hydroelectric dams (Bortoluzzi et al., 2022), and AI has been used to analyse satellite imagery to map flooding in Brumadinho (Syifa et al., 2019). In the latter case, satellite imagery was analysed using an artificial neural network and a support vector machine (an ML algorithm). This made it possible to determine the possible dimensions of a mud flood following the collapse of a dam in Brumadinho, Brazil (Syifa et al., 2019). ML models are also being applied to satellite imagery data to monitor wildfires in national parks (World Bank, 2022). More importantly, the BCB has begun using AI to develop tools that it plans to use for climate stress tests and to monitor climate-related risk exposures within financial institutions.

Figure 9: Artificial intelligence within BRICS



Source: Authors' own

India has a few cases of AI being used to analyse climate data, including the use of AI to analyse data collected with IoT-connected sensors to monitor water quality in Lake Sembakkam (Balachandran, 2021). The system uses a variety of indicators and data points to measure the water quality, while also providing actionable insights (Balachandran, 2021). Within the Indian financial sector, there is considerable use of AI (Singh, 2022), however, there is no evidence that the RBI or financial institutions in the country are using AI to collect climate data.

Ping An, one of the largest financial institutions in China uses an AI system to assess extreme weather events. The system uses data from satellite images, drones and IoT devices as well as internal underwriting and claims data to provide a risk assessment designed to mitigate financial losses (Wall Street Journal, 2020). Research conducted by Ping An Research Centre in collaboration with the Brevan Howard Centre for Financial Analysis at Imperial College London has also found that AI-based climate disclosure indicators constructed using NLP technology perform better than certain ESG ratings in determining climate-risk exposure of various institutions (Biffis et al., 2020). In 2019, the Bank of Huzhou introduced a Green Credit management system to support the municipality in identifying green projects (Choi and Li, 2021). The AI ML system uses big data to determine whether projects meet national or local green standards.

Box 3: AI and satellite imagery for climate risk analysis in Morocco and Tunisia

The World Bank Group's Crisis and Disaster Risk Finance team is developing near real-time risk monitoring systems and risk financing products for Morocco and Tunisia using AI-training algorithms based on satellite imagery data. The technology is being designed with the intention of mapping the risk exposure of public infrastructure and property both prior, during and after climate-related disasters (Bavandi, 2021).

Beyond the financial sector, the FengWu AI system designed in China can predict atmospheric conditions 14 days in advance with a high degree of accuracy (Chen et al., 2023), using a deep-learning architecture with a multi-modal and multi-task perspective. Researchers at the Northeast Forestry University in Harbin Province developed an AI model to estimate the probability of forest fires within a particular region in China with an accuracy rate of over 80% (Wu et al., 2021), while a collection of researchers from various institutions developed an AI system to monitor ground-level nitrogen dioxide levels across China for a set period (Wei et al., 2022). The use of satellite data paired with AI computing systems is also evident at the state level with the state-owned China Aerospace Science and Technology Corporation using AI to monitor, analyse and evaluate ecological satellite-generated data (China Daily, 2023).

Despite the use of AI by a variety of institutions in China to analyse climate data, there is no evidence that the PBC is using AI to this end. However, the Central Bank of Russia is developing a real-time tracker of climate disasters using NLP technology. The idea is that the tracker will provide accurate data on the number of climate-related disasters taking place. In South Africa, banks are using ML algorithms to predict the likelihood and severity of climate-related events. By analysing historical data, these algorithms can identify patterns and make predictions that help banks prepare for potential climate risks (Anvari et al., 2022). The SARB also uses ML in its assessment of physical climate vulnerability (Anvari et al., 2022). This is primarily used for crop simulation models, climate envelope models, hydrological and hydraulic models, risk exposure approaches, impact assessment and econometric frameworks (Anvari et al., 2022).

Looking at the state of the local AI industries within BRICS, the overall strength of the industry differs from country to country. China has the strongest AI industry out of the BRICS countries (Figure 9) and ranks among the top three countries when it comes to AI advancements globally (Shen et al., 2022). By the end of 2019, there were over 1 000 AI companies in China (Wu, 2022). In 2021 alone, China accounted for one-fifth of total private global investment, with AI start-ups attracting US$17 billion worth of investment (Shen et al., 2022). By 2025, the industry is expected to be worth US$61 billion (Wu, 2022), and in 2021, China produced 27.6% of all AI conference publications, accounting for the largest national share (Global X, 2023). Though China has more than 1 000 AI companies, much of the research and development is led by national champions, such as Tencent Holdings, Alibaba Group Holdings, and Huawei Technologies (Fukuoka et al., 2023).

India is also considered one of the global leaders for AI skills and innovation, and it has a growing local industry. According to McKinsey (2021), India is one of the leading adopters of

AI among emerging economies and has the necessary skills base to become a global leader (Maslej et al., 2023). In 2022, Indian AI start-ups received US$3.24 billion worth of investment (Maslej et al., 2023).

The AI industry in Russia is in its early stages, lagging countries it considers its peers and competitors. However, it is expected to grow in the coming years, as the government has prioritised the development of the sector (Bendett, 2019). This has resulted in large investments by the state through state-owned entities and the military (Petrella et al., 2021), with the establishment of incubators, funds and initiatives aimed at developing an AI industry within the country. There has been comparably less private investment as a proportion of overall investment in the industry compared to other countries (Edmonds et al., 2021). Despite this, as of April 2023, Russia has 384 AI start-ups (Traxcn, 2023a).

Brazil has one of, if not the most advanced AI industry in Latin America. A study conducted by the SAS Institute found that 63% of companies in Brazil that work with big data use AI for analysis (BNAmericas, 2022). The local industry, as of April 2023, had a total of 535 AI start-ups (Traxcn, 2023b). These start-ups offer a wide variety of services, with several offering services to banks and financial institutions to analyse big data. Brazil has also shown an interest in developing the local AI industry and in 2021, launched a national AI strategy to support the development of the local industry (MCTI, 2021).

In South Africa, a nascent AI industry is also emerging, with several AI start-ups having been launched in the last five years (Tracxn, 2023c). However, the ecosystem needed for these companies to develop is relatively weak, so it is unclear whether the industry will have the capacity to provide the financial sector and SARB with the necessary technology it would require to analyse climate data.

AI in the BRICS countries can be used to analyse big climate data in various forms, so that it can be understood and used to inform both physical and transition risk analysis and mitigation efforts by a variety of actors. Furthermore, within BRICS as a collective, it appears that the necessary technical knowledge, skills and engineering capacity to produce AI systems exist, and that these could be used by central banks and their regulated entities to analyse climate risks. This illustrates that the foundation exists for central banks in BRICS to use AI to analyse climate data.

4.2.2 DLT

Within BRICS, examples of DLT being used to verify, integrate and store climate data at any level (**Figure 10**) are limited. In 2021, Huzhou City in Zhejiang began using blockchain technology to track and record carbon emissions (Qin, 2021). In the same year, a representative of the Shanghai Environment Energy Exchange stated that blockchain can play an important role in how carbon emission data are verified and traded (Qin, 2021). Other than that, no credible examples were identified.

Box 4: ESGpedia – the Greenprint ESG Registry

In May 2022, MAS in partnership with the Singapore FinTech Association and STACS launched ESGpedia as part of MAS's Project Greenprint. ESGpedia is an ESG registry that uses blockchain technology to record and maintain the provenance of ESG certifications and data of various companies covering multiple sectors. The blockchain technology enables the secure storage and ease of access for users on a single registry (STACS, 2022).

Despite the limited use cases of DLT in the verification and storage of climate data, the development of DLT has been prioritised within many of the BRICS countries and there have been advancements as a result. The Brazilian government has shown significant interest in exploring the potential of DLT. It has initiated various projects and partnerships to leverage blockchain technology in sectors such as public administration and finance. The BCB has shown particular interest in the technology and has developed several pilot projects, including the development of digital currency, and has encouraged the development of DLT technologies (BCB, 2020; Lift Challenge, 2021). DLT has also been employed in other sectors within the economy, with the technology often being locally developed. One example is the use of blockchain for a land registry system (Keirns, 2017).

As with other high-tech information technologies, DLT has been prioritised by the Chinese state. In 2020, the National Blockchain and Distributed Accounting Technology

Standardization Technical Committee was launched to help standardise the industry. This followed the patenting of more than 50 000 DLT technologies in China in 2019 (Hsu and Green, 2021). The PBC published the Financial DLT security specification in 2020.

There is an established DLT ecosystem in Russia that has gained support from the state in recent years, and it is viewed by some as a technology that would allow Russian institutions to bypass sanctions (Fintech News, 2022). Aside from cryptocurrencies and speculation as to how they can be used as an alternative international payments system, DLT technologies have also been developed and used by Russian companies for storing and verification of data. This includes use by financial institutions such as banks and insurance companies (Popkova et al., 2020; Novoselova and Grin, 2020). There is the possibility that, in the coming years, the use of DLT in Russia proliferates and that it will be used in combination with other digital technologies for a variety of commercial and financial purposes, as this is being explored by researchers (Mironov et al., 2019; Novoselova and Grin, 2020).

Figure 10: Distributed ledger technologies within BRICS

DIGITAL LEDGER TECHNOLOGIES				
	Development of technology	Application in environmental assessment	Application in the financial sector	Use by the central bank
Brazil	◑	○	◔	◔
Russia	◑	○	◔	○
China	◑	◔	◔	◔
India	◔	○	◔	○
South Africa	◔	○	◔	○

Source: Authors' own

In India, the government is using DLT technology for several purposes including for land registries and digital certificates. Furthermore, the RBI is exploring the use of a central bank digital currency (CBDC) using DLT and has an enabling framework for a regulatory sandbox, under which innovative products/services/technology including DLT may be tested (Bhuvana and Aital, 2020). The State Bank of India has also begun using DLT to resolve cross-border payments-related inquiries (Das and Manikandan, 2021).

In South Africa, some attention has been given to DLT. In 2018, the SARB also launched a trial DLT project called Project Khokha (SARB, 2018). Since 2016, South African banks have been collaborating around blockchain, resulting in the creation of the South African Financial Blockchain Consortium (SAFBC) (SARB, 2018).

Though there are limited use cases of DLT to store and verify climate data, there is evidence that it can be used for this purpose given the use of DLT by MAS under Project Greenprint. Though the DLT sectors within the BRICS countries are still growing, significant resources and efforts are being invested to develop the sector. This would potentially put some of the BRICS central banks in a position to use locally developed DLT to verify and store climate data.

4.2.3 Cloud computing

As with DLT, there are limited examples of the use of cloud computing to store climate data. The only example is from China where cloud computing has been combined with other technologies to store and analyse climate and environmental data, such as urban water hazards (Liu et al., 2014) and to track sustainability goals (Wu et al., 2020).

Despite these limited use cases, the local cloud computing industry in the BRICS countries is in a relatively good position. Nevertheless, in all the BRICS countries aside from China and Russia the market is dominated by foreign companies, although this is slowly changing in Brazil and India.

In South Africa, cloud computing services are widely used including by institutions in the financial sector (AWS, n.d.). However, the market is dominated by foreign companies, with Amazon Web Services (AWS) holding the most significant market share (Labuschagne, 2023).

In Brazil, the government has actively promoted the adoption of cloud computing and encouraged the use of cloud services through initiatives such as the digital government strategy, which aims to enhance public services by leveraging cloud technologies (MCTI, 2018). Though international cloud providers like AWS, Microsoft Azure and Google Cloud have a significant presence in Brazil, a small number of local companies exist. The most notable of these are TOTVS, Locaweb, UOL Diveo and Mandic Cloud Solutions (BNAmericas, 2021; Back4App, 2023).

Brazil and India have a growing cloud computing industry. The market is mainly dominated by international companies such as AWS and Google Cloud (Back4App, 2023), although there are emerging local players such as Tata Consultancy Services and Infosys (Dickinson, 2022). As with much of the tech sector in India, there is also a pool of skills that can be drawn on to further develop the local industry and support its growth.

Box 5: Cloud-based AI – weather forecasting systems in China

A growing number of AI tools are being provided on cloud platforms. Cloud computing provides the capacity to both store data as well as the computing power needed for analysis on demand, including AI tools (Hinge, 2019). As a result, cloud computing is used for climate data collection and analysis. Several AI tools are cloud-based or being developed by cloud companies. Examples of this include an AI-based weather forecasting system used in China that was developed by Huawei Cloud (Bi et al., 2023).

Cloud computing services in Russia are dominated by local companies such as Yandex and SberCloud (Balashova and Musin, 2022). Russia also has the necessary skills and infrastructure to expand local capacity and development (Balashova and Musin, 2022).

Over the past five years, China has seen rapid growth in the adoption of cloud technology and the development of the local industry. By 2025, China's cloud computing market is expected to be worth US$90 billion (Shen et al., 2022). The industry leaders in China and the largest providers of cloud computing services are Alibaba Cloud, Huawei Cloud, Tencent Cloud and China Telcom (Shen et al., 2022). As mentioned, the PBC does not use cloud services to store or analyse climate data. However, other financial institutions in China are using cloud computing to manage data, including banks such as the Bank of China (Huawei, 2020; Cheng et al., 2022).

The number of use cases that could be identified where cloud computing is used to store climate data are limited. However, there are examples of cloud technology being used to support the storage and analysis of climate data by various institutions. Given the existence of local cloud computing capacity within the BRICS countries, and because the technology is widely used, it is possible for cloud computing to be used to store climate data collected by BRICS central banks.

4.3 Blockages, risks and opportunities

Across BRICS, there is the capacity to collect, analyse, verify, integrate and store climate data using frontier technologies. There are examples of how these technologies are being used by central banks for a variety of purposes. Furthermore, select BRICS countries appear to have the necessary local industries, IP, infrastructure and skills to produce the equipment that will be needed to collect climate data, including data on fires, droughts, flooding, heatwaves, water-level rises, emissions and atmospheric changes.

Nevertheless, blockages and barriers exist, hindering Brics central banks from using these technologies. First, if analysed at a country level, it is evident that certain BRICS central banks do not have access to the technology or lack the local capacity to develop the relevant technologies, as they do not have strong local industries. Access to data or technology may therefore become dependent on bilateral relations which may also result in dependency-related risks. The result is that either access is restricted, or the technology and data are imported. Due to the complex and global nature of technological value chains, sanctions can cause significant disruption to the use and development of technologies. Real-world examples of such disruptions are evident in the banning of the export of AI chips to China (Fitch et al., 2023) and potential limitations being placed on the country's access to cloud computing (Hayashi and McKinnon, 2023). Another example is the restriction on exports of particular radio equipment for satellite-earth applications to Russia (European Commission, 2023).

These risks could potentially be mitigated by collaboration among the BRICS countries at various levels. This could entail sharing of data collected, particularly data collected by EO satellites, as they often have a global reach. Given the shared geography of China, India and Russia, there is also scope for greater collaboration among these countries in deploying technologies and sharing data. This could potentially increase efficiency in how data are collected, the scope of the data that are collected, the comprehensiveness of datasets and the level of detail within the data.

Sharing of technology, expertise, capacity and products, depending on the needs in question and the level of development of the local industry in question, is also a viable option. This would enable those countries that do not have the necessary technology to begin deploying or developing it to analyse, verify, integrate and store climate data for central banks and financial institutions. Pooling of resources should also be considered for select projects, as this could reduce individual costs and improve economies of scale. This is already taking place. In 2022, Brazil, China, India and Russia agreed to jointly develop a constellation of six EO satellites. This has helped the countries to collect data on agriculture, water management, climate change and disaster management (Xiaoci and Anqi, 2022). A similar initiative could also be developed to improve the capacity of BRICS to collect GHG emissions data. Russia has also proposed collaboration with SANSA to jointly establish a facility designed for the reception, processing and storage of earth observation data. This would cater for satellite-based information originating not only from Russia but also from other countries and could be used by the SARB for climate risk analysis.

Collaboration is not only necessary at an intra-country level but also between institutions within countries. It has been shown that within the BRICS countries there is existing capacity within various state and private institutions to collect climate data with IoT, EO satellites and drones and analyse that data with AI. This suggests that if BRICS central banks were to collaborate with other national institutions, they could potentially improve the quality and quantity of data that they can collect and improve their analytical capabilities. The same holds for DLT and cloud computing in particular, as various institutions within the BRICS states and financial institutions have significant cloud computing capacity.

The second major blockage identified is the lack of skills and capacity at central bank level to use and maintain the technologies in question, an issue highlighted in the survey responses. BRICS central banks and their regulated entities must therefore begin to develop the necessary skills and capacity to use the technologies in question to collect, analyse and verify climate data, as this would reduce their dependence on both national and international counterparts.

BRICS central banks have also highlighted the lack of funding available to explore and invest in these technologies. Aside from increased funding, this could potentially be addressed with joint projects at an intra- and intercountry level as this allows for shared costs and improved economies of scale.

There are also several AI-specific risks and challenges. Bias within AI systems can inadvertently impact the quality of analysis and result in biased results. Dependency on AI can also result in over-reliance and a lack of human oversight that can lead to potential errors. Data security also remains a concern when it comes to AI and other data analysis methods, as protecting the vast amounts of data being analysed is difficult to achieve.

Finally, a lack of secure storage capacity, an inability to verify collected data and limited capacity to process collected data have all been identified as potential blockages to the collection of climate data and the use of the associated technologies. Linked to this is the need for regulatory compliance for the collection, storage and use of data, particularly as it relates to data protection and privacy. If not accounted for this can pose serious risks, yet simultaneously it can inhibit the extent to which data are collected and used if the regulations are not in sync with the latest technological developments.

5. Conclusion and areas for further BRICS central bank engagement

In closing, the report considers three key questions:

5.1 What are the key climate data gaps affecting the financial sector in BRICS?

- Climate change creates physical, transition and social risks which are associated with large economic, health and social costs. These risks have a significant impact on the financial sector and, as such, need macroeconomic, policy and regulatory changes to help mitigate these risks.

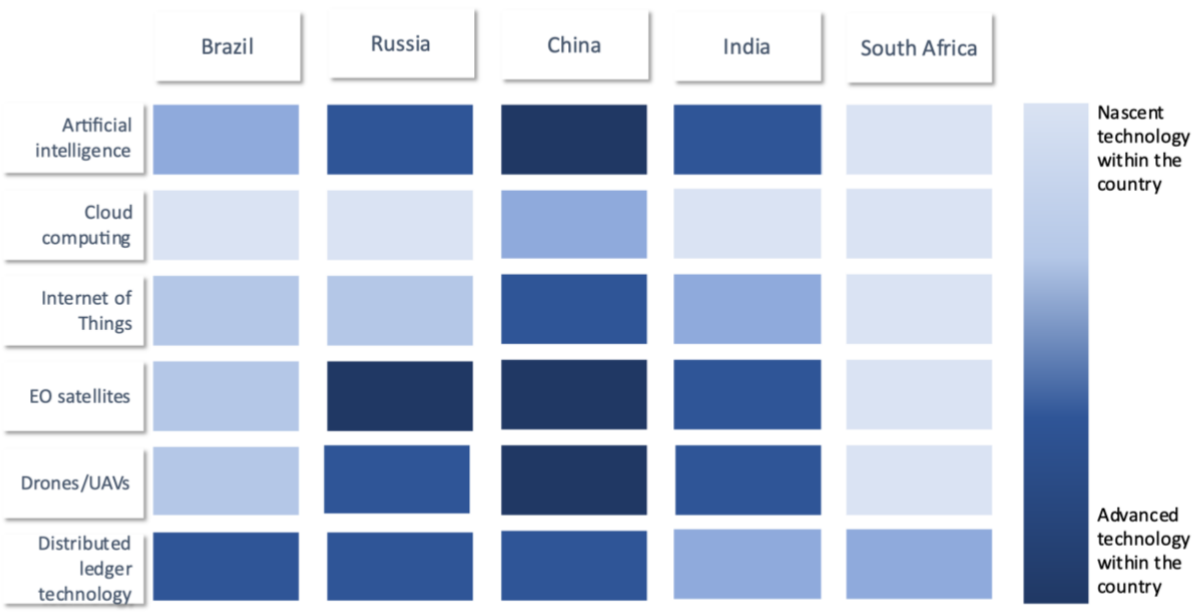
- Monitoring and engaging on climate risks within the financial sector depends on essential climate data sets that are not readily available due to the emergent nature of climate risk analysis in financial sector data. Data challenges can be classified as (i) 'data holes', data that are required but do not yet exist; and (ii) 'data gaps', where data are insufficient or incomplete.
- BRICS countries have common vulnerabilities relating to transition, physical and social risks. In aggregate, there is a strong demand for comprehensive data on emissions, carbon footprints, physical risks and transition risks associated with climate change. A new area of risk is emerging in the need to collect social risk data and health risk data.
- BRICS central banks are using certain tools and processes to consider climate-related risks in their processes. According to the survey results, the most common methods applied in the analysis of climate risk are disclosures, stress testing and scenario analysis. The application of these tools varies across the BRICS central banks in the level of prudential supervision, disclosure type, strategic focus, risk scenario and stress testing target, among other things.

5.2 How can technology help with addressing climate data gaps in BRICS?

- There has been significant innovation in recent years which has resulted in the development of so-called frontier technologies: AI, UAVs/IoT, big data analytics and DLT.
- These technologies offer new possibilities for how data can be collected and analysed and are most effective when used in unison in various constellations. Examples of how these technologies can bridge climate data gaps are:
  - lowering the cost and proliferation of sensing technologies;
  - providing greater spatiotemporal resolution of data;
  - providing more complete data;
  - lowering technical barriers to emissions tracking;
  - analysing complex and large data sets; and
  - verifying, integrating and storing of data.
- Except for China, the development and ownership of the IP of many of these technologies is dominated by the Global North. This poses significant risks to Global South countries, including those in BRICS, as it means a dependency on imported data and technology.

- The most significant technologies needed to collect data are IoT, satellites and drones. These technologies can enable and enhance the collection of climate data. Particularly data on physical risks such as fires, floods, droughts, heatwaves, water-level rises, emissions, sea-level rise and atmospheric changes.
- AI and big data analytics more broadly can enhance the analytical capacity of central banks, providing them the capacity to analyse and process complex and large data sets.
  - Limited use cases exist of how big data can be analysed by central banks using AI. The industry-leading example is Project Greenprint of the MAS. The BCB too is using AI to inform its climate stress testing, but there is limited public information on the precise methodologies of how the BCB is applying AI in this context.
  - Examples also exist in the private sector; Ping An, a leading financial institution in China, uses an AI system to assess big climate data to determine both physical and transition risks for its various investments and operating units (Ping An, 2023).
- DLT and cloud computing could enhance the capacity of central banks to analyse, verify, integrate and store data, though the use cases for these technologies are rather limited.

Figure 11: Strength of select frontier technologies (and EO satellites and cloud computing) in BRICS



Source: Authors' own[14]

[14] The strength of industries was determined using the data from the survey results, as well as a desktop analysis and informed by the Readiness Index in UNCTAD's Technology and Innovation Report 2023.

- Collectively, BRICS countries appear to have the necessary industrial base and capacity to advance data technology innovations required for the production and maintenance of frontier technologies that could bridge climate data gaps **(Figure 11)**.
  - For data collection technologies, the satellite and drone industries are particularly strong, led by China and Russia which have well-established satellite industries and in the case of China a well-established drone industry. China also has a growing and relatively strong IoT industry.
  - Across the BRICS countries, there is a strong AI industry, meaning the capacity to develop fit-for-purpose technology locally exists. However, the differences in the strength of the national industries are wide. China has by far the strongest industry (and is top three in the world). India is also developing an established industry while those of Russia, Brazil and South Africa are emerging (in this order) (Figure 11).
  - Despite the limited use cases of DLT in the verification, integration and storage of climate data, within many of the BRICS countries the development of DLT has been prioritised and there have been advancements as a result. The same largely holds for cloud computing.
  - China's industry is the most advanced, while Brazil, Russia and to a lesser degree India and South Africa have emerging industries. In the case of the latter two the industry is in its infancy.

5.3 What are the obstacles to the adoption of technology that can bridge climate data gaps for the BRICS central banks?

- Access to certain technologies and the data they produce is not universal, or is dependent on importing the technology and data, meaning many countries are at risk of geopolitical changes which may inhibit access to various components or knowledge at various stages of the value chain. Examples of this already exist with both Russia and China being restricted in their access to select technologies due to geopolitical dynamics.
- A significant barrier identified across the BRICS central banks is the lack of skills and capacity to use the technology in question.
- Limited investment in climate data technologies come from the public sector, with much of the existing investment coming from the private sector.

- Central banks have identified a lack of secure storage and an inability to verify collected data as barriers to the use of these technologies as well as limited capacity to process the volumes of data generated by the technologies.
- Regulatory compliance can also be a barrier and present potential risks to the collection and use of climate data by frontier technologies. Data protection and privacy concerns must be accounted for, as this can result in significant risks. Yet at the same time, regulations can also inhibit the extent to which data are collected and used if the regulations are not updated to reflect the strengths and limitations of frontier technologies.
- AI-specific algorithms may result in skewed results. Moreover, there are concerns about creating an over-dependence on AI which may lead to a lack of human oversight and associated errors.

5.4 Areas for potential collaboration among BRICS central banks

The BRICS central banks may benefit from exploring co-operation and collaboration to harness the potential of frontier technologies. The survey results in Figure 11 show the relative strength across the BRICS countries in how frontier technologies are being advanced, which could be the basis for strategic engagement relative to respective comparative advantages. Any such collaboration should be underpinned by sound data governance, technology development and data risk management (e.g., privacy rights). The Organisation for Economic Co-operation and Development (OECD) (OECE, n.d.) has developed extensive recommendations on these topics, which may be helpful in assisting the BRICS central banks in advancing collaboration efforts among themselves. Potential areas of collaboration among the BRICS central banks may include:

5.4.1 Addressing shared climate data gaps

An increase in the frequency of climate-related events was recorded globally, with 387 reported in 2022, which is higher than the average recorded in the period 2002 to 2021 combined. The catastrophic disasters affected 185 million people resulting in the mortality of 30 704, three times higher than the deaths recorded in 2021 (CRED EM-DAT, 2022). In the past decade alone, the BRICS countries have recorded 582 catastrophic climate-related disasters of which about 42 disasters were experienced in the year 2022 (CRED EM-DAT, 2022). Flooding, drought and extreme temperatures comprise most of these climate disasters. Table 1 in this working paper highlights some of these climate risks the BRICS countries face and which may manifest within the next 10 years according to the latest IPCC findings.

The emergent science in the latest IPCC report shows that the incidence and severity of climate events is intensifying and that the threshold of 1.5°C will be overshot by the early 2030s, creating economic and social hardship. Further, the climate response is becoming more systemic and time-based, impacting specific climate-sensitive industries such as energy, agriculture, automotive and certain manufacturing industries. The private sector in developing and developed countries is adopting net-zero targets and climate transition with different timelines ranging from 2030 to 2060, influencing trade and finance flows with socioeconomic implications.

The data gaps, such as biophysical impact, emissions, and geospatial data identified by the BRICS central banks are aligned to those identified by the NGFS and IMF. However, it is evident from the variations in responses and timing differences in implementing climate policies among countries that a sharper focus on national level data needs is critical, in addition to understanding the climate risk concerns specific to the BRICS. For example, collaborating on forward-looking data on transition and physical risks especially among countries with shared borders, may be one opportunity for data gap collaboration.

Though all BRICS central banks recognise the risk that social dimensions pose to economic and financial stability, the data needs for this dimension are nascent internationally. The survey results reflect recognition by the BRICS central banks of these systemic challenges, which suggests a shared concern for building economic and social resilience within the financial system. The BRICS central banks could therefore consider developing climate risk indicators across physical, transition and social dimensions that relate to their shared challenges to advance a collective resilience and mutual support.

5.4.2 Building technology skills and capabilities

While technology is a useful enabler to bridge climate data gaps, views vary on whether there is a paucity of data, or whether there is a lack of capabilities to analyse such data using technology as a tool. Inappropriate analysis without human discernment could lead to potentially misdirected and maladapted low-emission and climate-resilient development paths that are out of pace with the environmental, economic and social imperatives essential for an effective climate response.

The survey results among the BRICS central banks highlight concerns around the lack of appropriate skills, capacity and abilities to manage and utilise the emergent frontier technologies even if such were accessible. Thus, among the BRICS central banks, the following collaboration may be possible. The BRICS central banks may conduct a capabilities assessment around the existing and potential use of data technologies relative to the climate risks prioritised. Where skills deficits exist in the use of the technologies in question, BRICS central banks may explore joint programmes or workstreams to develop the skills needed, particularly around usage, adaptation, maintenance and integration of frontier technologies. The appropriate application of technologies will be unique for each BRICS central bank, but such collaboration offers scope to explore joint learnings and adaptations of these technologies.

5.4.3 Data sharing and co-operation protocols

Data sharing of such information among BRICS central banks would be helpful in tracking emissions, flooding, heat and fire risks. Further, the literature reviewed for this paper shows that data technologies are mainly under development and accessible through Global North countries, particularly the US and Europe.

- **Enhance data access**: Advancing the accessibility and ownership of climate data technology is essential if BRICS central banks are to apply such climate data in key decisions around climate risk. Such access may be through the sharing of existing climate data as well as identifying future climate data sets to co-develop to facilitate such data access.

- **BRICS central bank climate data portal**: Within secure platforms, a BRICS climate data open-source portal could be established where respective central banks share data covering various climate risks such as emissions, flooding, heat and fire risks. For example, among the BRICS countries, Russia and China have EO technological capabilities for collecting GHG data. Additional ideas may include data covering shared geographies that can be collectivised (Russia and China; India and China). This would most likely increase efficiency as well as the quality and quantity of the available data.
- **Developing sharing protocols**: To advance any co-operation among the BRICS central banks, there would need to be regulatory frameworks and protocols on how shared data are collected, stored and secured. This may require regulatory standardisation.
- **Strengthen national collaboration among institutions:** There may be existing capacity within various state and private institutions within the BRICS countries that currently collect climate data that may be leveraged and on which these institutions can draw. It may be useful, given the shared need for climate data across the financial sector, for BRICS central banks to partner with in-country institutions to support climate data.
- **Data aggregation sources:** The literature and survey results are not yet reflecting the climate data needs of large enterprises and SMEs. However, opportunities exist to partner with organisations that, for example, are monitoring deforestation and afforestation changes and utilising IoT and related technologies. Climate data sources of this nature address the need for granular data on physical and geospatial changes, while other technologies such as AI would be helpful in processing aggregated climate data into a usable form for BRICS central banks.

5.4.4 Advancing and partnering on data technology development

The limited use case of the climate data technologies explored in this paper suggests the need for further experimentation and innovation, to test how best these may be explored among BRICS central banks (individually and collectively), both at macroprudential and microprudential level.

- **New technology development**: Exploring key technologies on which to collaborate may be helpful for the BRICS central banks, particularly around EO satellites and IoT to support geospatial and biophysical data mapping. Examples of this could include using EO satellites, drones and IoT to collect data in geographies that are shared between countries (e.g. Russia and China/India and China), or the development of AI tools to process and analyse climate data and cloud storage facilities to store and develop datasets.
- **Sharing investment in climate data technology:** Those BRICS countries with existing IP and capacity should consider sharing select IP with other BRICS countries for technologies that can be used to collect and analyse climate data. Selling technology could be particularly advantageous (but is cost dependent), as it reduces dependence on countries outside BRICS and would boost the exporting country's industry. Given the relative strength of China across the technologies and in the case of EO satellites Russia, they are in a position to share their technologies with the other BRICS countries and help them develop their industries.

Annexure A: Green fintech examples

Below is a list of prominent green fintech products and services

No	Green fintech	Functional area	Provider	Fintech use cases
1	T-Risk	Transition risk scoring	Entelligent (US)	Transition risk (T-risk) scoring measures the short-term (two-year) price movements of corporate equities and fixed income of client portfolios. The scoring system is updated on a quarterly basis.
2	Climate financial impact edition	Financial impacts of climate events	Munich Re (Germany)	The solution quantifies the financial impact of physical climate risks for portfolios.
3	Climate credit analytics	Climate risk assessment/ Scenario analysis	Oliver Wyman/S&P Global (US)	The climate credit analytics tool offered by Oliver Wyman/S&P Global provides an extreme short-term scenario featuring a three-year carbon tax.
4	Planetrics	Climate risk assessment/ Scenario analysis	Planetrics (US)	Planetrics provides in-year impacts and can support on-custom, short-term scenario development.
5	Aladdin Climate	Climate risk assessment/ Scenario analysis	BlackRock – BlackRock's Aladdin platform (US)	Aladdin Climate was built to quantify climate risks and opportunities in financial terms, bridging climate science, policy scenarios, asset data and financial models to arrive at climate-adjusted valuations and risk metrics.
6	CLIMAFIN	Climate risk assessment/ Scenario analysis	CLIMAFIN (France)	The tool offers quantitative metrics and customised consulting services for climate risk for all asset classes and using all relevant climate scenarios.
7	ISS ESG Solutions	Climate risk assessment /Scenario analysis	ISS ESG (US)	ESG Solutions covers corporate and country ESG research and ratings, enabling its clients to identify material social and environmental risks and opportunities.
8	Risk Management Global Flood Model	Climate change flood model	JBA Risk Management (UK)	JBA's global flood modelling probabilistically assesses river (fluvial) and surface water (pluvial) flood risk for every country in the world.
9	Morningstar Sustainalytics	Climate risk assessment/ Scenario analysis	Morningstar Sustainalytics (Netherlands)	With Sustainalytics' physical climate risk metrics, carbon emissions data and carbon ratings and research, investors are able to identify, assess and manage climate-related investment risks and opportunities.

No	Green fintech	Functional area	Provider	Fintech use cases
10	Climate VaR	Climate risk assessment/ Scenario analysis	MSCI Inc. (US)	Climate Value-at-Risk (Climate VaR) is designed to provide a forward-looking and return-based valuation assessment to measure climate-related risks and opportunities in an investment portfolio. The quantitative model offers deep insights into how climate change could affect company valuations.
11	Location Risk Intelligence	Climate risk assessment/ Scenario analysis	Munich Re (Germany)	The solution accesses the world's largest natural catastrophe loss database, NatCatSERVICE, which contains more than 45 000 entries on natural hazards. This modular, powerful solution combines different complementary assessment models to generate detailed, meaningful data.
12	Ortec Finance	Climate risk assessment/ Scenario analysis	Ortec Finance (Netherlands)	Ortec Finance equips investors with climate-informed risk-return metrics, including in absolute dollar value, that quantify exposure to systemic climate risks and opportunities across asset classes, regions, sectors and holdings
13	Physical Climate Analytics	Climate risk assessment/ Scenario analysis	Pricewaterhous eCoopers (PwC) GmbH (UK)	This tool for climate scenario analyses supports investors and companies in making their portfolios fit for the risks and opportunities of climate change.
14	Climanomics	Climate risk assessment/ Scenario analysis	S&P (The Climate Service) (US)	Climanomics enables climate risk reporting and disclosure aligned with the TCFD framework. Subscribers use the outputs to measure and report their transition and physical risks and opportunities in financial terms under different climate scenarios
15	Sust Global	Climate risk assessment/ Scenario analysis	Sust Global (US)	This technology is used for physical risk assessment, including climate scenario modelling.
16	XDI	Quantify climate costs	XDI Systems – XDI Hub (Australia)	XDI quantifies the cost of extreme weather and climate change impacts to physical assets.
17	1in1000	Stress test	1in1000 Initiative (Germany)	The 1in1000 model allows users to assess the financial impact of transition, physical and litigation risk to counterparty loan, bond and equity portfolios.
18	Climate Excellence	Climate excellence	PwC (UK)	This climate scenario tool helps support investors and companies in making their portfolios risk averse by visualising financial impacts of climate change.

No	Green fintech	Functional area	Provider	Fintech use cases
19	NovA!	Climate risk assessment/ Scenario analysis	Monetary Authority of Singapore (Singapore)	NovA! is an AI technology that allows financial institutions to assess the environmental impact of real estate companies and any emerging environmental risks they may face in the future (MAS, 2022).
20	ESGpedia	Data registry (verification and storage)	Monetary Authority of Singapore (Singapore)	ESGpedia is a blockchain-based data platform used to record and verify sustainability data and certification, acting as a common and secure data access point.
21	Ping An AI system	Climate risk assessment/ Scenario analysis	Ping An (China)	Ping An has developed an AI system to assess big data to determine both physical and transition risks to investments and various operating units.
22	Green Credit Management System	Data verification and analysis	Bank of Huzhou (China)	This AI system uses big data to determine whether projects meet national or local 'green' standards.
23	Earth Science AI	Climate risk assessment/ Scenario analysis	Cervest (UK)	Earth Science AI is an on-demand climate intelligence tool that provides historical, current and predictive climate risk analysis of physical assets, enabling the monitoring and forecasting of risk for portfolios.
24	Climate Price	Climate risk assessment/ Scenario analysis	Climate Alpha (Singapore)	Climate Price is an AI-driven platform designed to provide location-based analytics to assist real estate investors in understanding the financial impact of climate volatility across climate change scenarios.

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