EASTERN AND
SOUTHERN AFRICA

KENYA CCDR

Digital sector background note

World Bank Group

COUNTRY CLIMATE AND DEVELOPMENT REPORT

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Acronyms and abbreviations

4R	4R Digital's Carbon Value Exchange
ACRE	Agriculture and Climate Risk Enterprise
app	application
CCDR	Climate Change Development Report
ENACTS	Enhancing National Climate Services
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
GHG	greenhouse gas
GIS	geographical information system
GSMA	Global System for Mobile Communications
ICPAC	IGAD Climate and Prediction Center
ICT	Information and Communications Technology
ICTA	Information and Communication Technology Authority
ID	identity card
IGAD	Intergovernmental Authority on Development in Eastern Africa
IoT	internet of things
IRI	International Research Institute for Climate and Society
KCERT	Kenya Carbon Emissions Reduction Tool
KEFRI	Kenya Forestry Research Institute
KFS	Kenya Forest Service
KMD	Kenyan Meteorological Department
KNBS	Kenyan National Bureau of Statistics
NAP	National Adaptation Plan
NCCAP	National Climate Change Action Plan
NDC	National Determined Contributions
PAYG	pay-as-you-go
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goal
telecom	telecommunications

All dollar ($) amounts are US dollars

Executive summary

In Kenya, climate hazards are not future risks but a reality that affects people, sectors, and the economy. Climate change is taking place alongside rapid digital development in Kenya. With a mature digital ecosystem and ambitious climate commitments, Kenya is well positioned to leverage digital technologies for climate adaptation and mitigation. In Kenya, as elsewhere, climate change disproportionally affects low-income populations threatening health and livelihoods. Digital technologies are boosting climate resilience in Kenya, for example by enabling safety net programs, information for farmers, and early warning systems. At a macro level digitalization is enabling economic diversification away from climate prone sectors such as agriculture. Due to high reliance on renewable energy Kenya has a limited climate footprint. The context for mitigation efforts is hence wider and interlinks with resource access and management. Data and digital technologies are emerging as important tools for forest and water management, as well as pay-as-you-go solar systems. Kenya boasts many novel climate solutions. But many platforms and applications have not scaled or are standalone solutions that lack cross integration. A more strategic approach is needed to ensure interoperability, ownership, and scale of effective solutions. In addition, continued investment in digital foundations are needed to ensure inclusive access to resilience related solutions and services.

1. The digital and climate change nexus in Kenya

This background note complements the World Bank Climate Change Development Report (CCDR) for Kenya. The purpose of the note is to assess the role of the digital sector in Kenya for climate change adaptation and mitigation. Chapter 1 lays out the digital context in Kenya, including how the digital climate nexus is reflected in policies, while chapter 2 focuses on digitally enabled adaptation measures as a response to Kenya's high climate vulnerability. Chapter 3 looks at climate hazards hampering the digital sector itself, and chapter 4 at the role of digital technologies for mitigation, with a focus on the energy sector. Chapter 5 considers emissions from the digital sector and the role of digital technologies in reducing emissions in energy-intensive sectors to avoid being locked to a carbon-intensive growth path. Chapter 6 looks at the crosscutting role of digital data to improve climate change monitoring, reporting, and decision-making, and Chapter 7 concludes the note with policy recommendations.

1.1. Kenya's digital landscape

Kenya is a digital leader earning an early reputation as an innovator in digital services and widespread digital access. Its role as a regional information and communications technology (ICT) hub for East Africa is evidenced by the presence of advanced broadband connectivity, innovative value-added services such as mobile money, a strong tech ecosystem, and digitally skilled talent. Kenya continues to benefit from early liberalization of the telecom sector, strategic public investments in the national fiber optic backbone infrastructure, and a vibrant private sector. The digital sector saw double-digit growth as it matured quickly but has plateaued in the last years. From 2017 to 2022, the average annual ICT share of gross domestic product (GDP) was 5.0 percent, with an average annual growth rate of 5.7 percent in the same period, similar in size to the average national growth in GDP.[1] Kenya boasts mobile broadband networks of 3G and higher for over 96 percent of its population. Unique mobile internet penetration rate stood at 34.2 percent of the total population at the start of 2023, compared to the East African average of 23 percent, with a fixed broadband penetration of only 1.5 percent.[2] Kenya is ahead of many of its peers in the region on 'e-government'[3] and is ranked third in Africa in the 'Networked Readiness Index' 2022 rankings.[4]

Kenya's digital agenda has been championed by its leaders. In its cross-sector *Vision 2030,* the digital sector plays a role helping the country achieve development goals, including reaching middle-income status. The *Digital Economy Blueprint* and the *National Digital Master Plan* lays out the blueprint for how this digital transformation will take place. The government has invested heavily in the digital sector, dedicating several institutions to drive this agenda, principally the Ministry of Information, Communications and Digital Economy, the Information and Communication Technology Authority (ICTA), and the Communications Authority. For FY2022/2023, the government has allocated $132 million towards digital initiatives, corresponding to 0.5 percent of the total government expenditures the same year,[5] among which 19 flagship projects listed in the Digital Master Plan are of high priority (box 1.1).[6]

Box 1.1. Flagship projects in Kenya's Digital Master Plan

The National Digital Master Plan's 19 flagship projects include:

- Installing 100,000 kilometers of high-speed fiber optic infrastructure
- Establishing 25,000 internet hotspots
- A digital one-stop-shop for all government services
- Digital literacy capacity building for 20 million Kenyans
- Establishing 1,450 digital hubs for digital literacy training.

Despite the impressive penetration, a digital divide remains in access to broadband, digital public services, and the skills needed to benefit from an increasingly digitized economy and society. The 2019

World Bank *Digital Economy Diagnostic* report identifies gaps in digital infrastructure and broadband availability, particularly in rural regions, as well as challenges related to integrating and using digital platforms and practices for service delivery.[7] Coverage of fiber and mobile network remains patchy in the less populated parts of the country. Kenya's *National Broadband Strategy 2018–23* notes that people often have to walk several kilometers to access a mobile cellular signal, and have no fixed line internet access.[8] Currently the existing fiber and mobile network coverage has the highest density in the southwest near the most populated regions. Many areas still lack long-distance connectivity to fiber optic networks, but expected to be connected once the planned networks are constructed over the coming years. Besides connectivity gaps, a major hindrance to the adoption of mobile internet is the cost of internet-capable devices and data plans. Limited literacy and proficiency in digital skills are also commonly cited barriers, as well as a lack of perceived importance in owning a mobile phone and accessing the internet.[9] COVID-19 lockdowns increased incentives for adopting the internet. At the same time, the crisis reduced the average household income, making internet access more unaffordable.

1.2 Digital climate policy linkages

In Kenya, climate change is taking place alongside rapid digitalization. While both climate action and digitalization are strategic priorities in the country, the agendas are often siloed. But examples of convergence are emerging in digital as well as climate related policies. For example:

- The **National ICT Policy** envisions ICT as a tool for adaptation, monitoring, and mitigation, stating that the government will "promote the use of ICT to mitigate the impact of climate change and broaden the use of technologies for natural disaster and emergency monitoring, prevention, mitigation and response".[10] This message is repeated in the **National Adaptation Plan (NAP),** which cites the need to climate-proof physical ICT infrastructure among priority actions.[11]
- Recognizing the environmental impacts of the telecom sector, the **ICT Policy** also states the intention to "ensure that ICT players and consumers minimize the effect of infrastructure, appliances, machines, devices and tools on the environment".[12] This receives further attention in Kenya's **Digital Economy Blueprint**, which emphasizes the need to reduce e-waste and increase efficiency of ICT equipment.[13]
- The **Government Enterprise Architecture Framework** defines the minimum standards for government data centers, network, and cloud computing, but provides limited guidance on disaster risk reduction and climate resilience.[14] The government's visions for a green state-of-the-art digital sector are being tested at Konza Technopolis outside Nairobi, with a national data center built in compliance with green standards.[15]
- Although Kenya's **National Determined Contributions** (NDC) does not mention digital technologies, the **National Climate Change Action Plan** (NCCAP)[16] and **NAP**[17] both highlight them as enablers for adaptation and mitigation actions. Kenya has also signed the **Sendai Framework for Disaster Risk Reduction**, which highlights the use of digital technologies and tools that support information platforms and dissemination, online monitoring and reporting tools, hazard data, risk assessments and data analytics, and facilitation of public participation and social inclusion.[18]
- Projects such as the **flagship** projects (box 1.1) should adhere to the provisions of the Environmental Management and Coordination Act (1999) by undertaking an environmental assessment including a climate change risk and vulnerability assessment (stipulated in the Climate Change Act. 2016).

These examples illustrate that climate is integrated into some sectoral policies in Kenya, which is forward-looking compared to many countries globally. However, it does not consistently integrate environmental and climate considerations and there is limited focus on implementation.

2. The role of digital technologies for adaptation

Kenya is vulnerable to both long-term climate risks and climate shocks. These effects of climate change are multidimensional and aggravate existing development challenges. In 2021, Kenya ranked as the 41st most vulnerable country to climate change and 152nd in terms of adaptive capacity among 185 countries.[19] As described in the Kenya CCDR,[20] climate variability and climate change are sources of significant risk for the country. More than 70 percent of natural disasters are attributable to climate shocks, the most common being floods and droughts, which have led to devastating social impacts and high economic costs. Droughts are increasing in frequency and have affected more people than floods, but normally have the most severe impacts in the highly arid zones of north and northeastern Kenya.[21] Seasonal inundation of low-lying areas (Lake Victoria and Tana River) are major sources of riverine flood hazard, while other parts of the country (Central Highlands, Western Nyanza, North Rift Valley) are more prone to flash floods and rainfall-triggered landslides.

Increasing levels of climate hazard have severe consequences for livelihoods, health risks, and poverty. For Kenya, adapting to climate shocks and longer-term climate risks are therefore key concerns. Digital technologies can be part of the solution to both sets of problems, as shown in table 2.1.

Table 2.1. Examples of the role of the digital sector for resilience

<table>
<tr><th></th><th>Impacts</th><th>Enablers</th></tr>
<tr><td rowspan="2">Long-term climate risks</td><td>Macro resilience: Digitalization to strengthen or diversify economies in response to climate change.
Household resilience: Digitalization to reduce poverty and strengthen socioeconomic resilience.</td><td rowspan="5">Digital infrastructure
Data
Digital skills
Applications (apps) and services
Regulation and safeguards</td></tr>
<tr><td>Sector adaptation: Digital solutions that help sectors adapt to climate change.</td></tr>
<tr><td rowspan="3">Climate shocks</td><td>Disaster preparedness: Digital solutions that build resilience to shocks or monitor weather.</td></tr>
<tr><td>Disaster management: Digitally enabled Disaster risk management and early warning systems. Digitalization to ensure continuity of business and services.</td></tr>
<tr><td>Disaster recovery: Digital identity card (ID), digital cash transfers after climate shocks that allows social protection.</td></tr>
</table>

The rest of this chapter looks at the impact of digital adoption and digital enablers on economic resilience at macro and household level, and how three climate-sensitive sectors—agriculture, forestry, and water—use digital solutions for climate adaptation.

2.1. Digitalization and financial resilience

There is growing evidence that digitalization can stimulate growth and macro-level economic resilience. One study, for example, shows that for low- and middle-income countries, like Kenya, an increase of 10 percent in mobile broadband penetration yields on average a 1.8–2.0 percent increase in GDP.[22] The growth returns are highest for countries like Kenya, with greater human capital and electricity access rates.[23] The Kenyan digital sector has shown steady growth, with its share of GDP averaging 5 percent over the last five years.

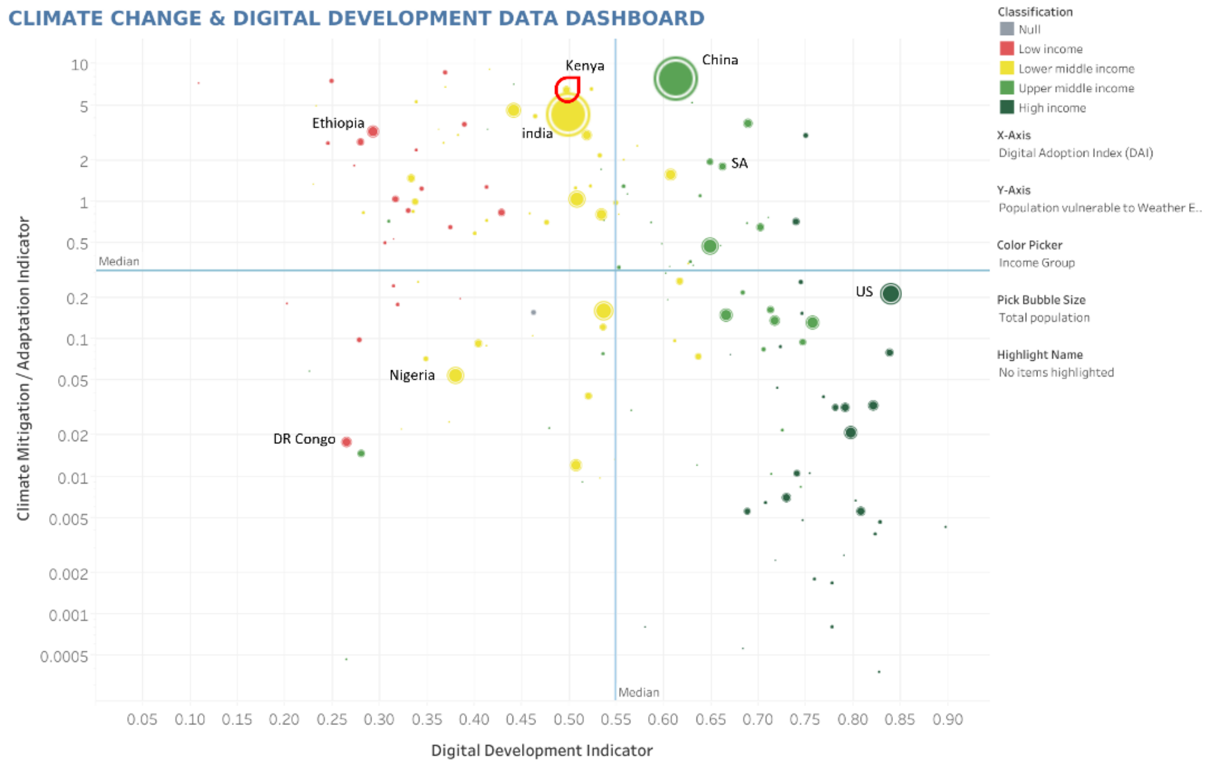
In Kenya, mobile money accounts are a crucial financial support, making it easier for individuals—particularly informal workers and small enterprises—to access credit, savings, and insurance.[24] Mobile money is widespread across Kenya, simple to adopt, and widely used by lower-income households and individuals, enterprises, and governments to make and receive payments. In 2022, the overall value of mobile money transactions reached Sh7.91 trillion, marking a 15 percent surge on reported 2021 figures.[25] The most prevalent app, M-Pesa, can be found in 97 percent of Kenyan households, and more than 30 million customers used the service every month in 2022.[26] Research shows access to mobile money services has reduced poverty rates and increased financial resilience, with significant increases in total savings.[27] This is significant from a climate perspective, as household-level poverty is a core risk factor increasing climate vulnerability.

Digitalization is a driver of economic diversification. As climate change continues to impact rural livelihoods, it is likely that population groups will migrate in search of opportunities and better lives. Climate change heavily impacts the agricultural sector, which contributes about one-fifth of the value added to GDP.[28] Digitization—particularly access to the internet and mobile money—can provide economic diversification. In Kenya, the longer-term impacts of M-Pesa include significant changes in occupation choice, largely among women. For example, between 2008 and 2014, 185,000 women moved away from agriculture as their main occupation to business and retail, which have higher earnings potential.[29] The availability of online marketing and mobile payment has also encouraged the growth of formal and informal businesses, leading to more sources of income.[30] But despite some advancements in diversification, the pace of development and movement of employment from climate-sensitive sectors has not matched the rapid population growth.

2.2. Digitalization and climate shocks

Digital infrastructure and apps can build adaptive capacity before, during, and after climate shocks. Kenya is highly exposed to many climate shocks, including repeated floods and drought, and climate change is expected to increase the risk of flooding events. Due to relatively high digital adoption, Kenya has good opportunities to manage climate hazards with digital tools (figure 2.1). Before and during climate shocks, weather forecasts and early warning systems can help protect vulnerable populations, while insurance services can provide a safety net against income loss. During and after climate shocks, digital ID systems, digital financial services, and geospatial analysis can allow rapid and targeted outreach to affected populations through cash transfers, emergency supplies, information, and rehabilitation efforts. Digital technologies can also help policy makers prepare better for disasters by providing tools and data that sharpen predictions and enhance decision-making.

Figure 2.1. Population vulnerability to climate shocks against digital adoption



Source: World Bank Climate Change & Digital Development Data Dashboard

Digital technologies—such as satellite imagery, weather forecasting, and internet of things (IoT) devices—can be used to create early warning systems, helping the government, aid organizations, and individuals prepare and respond more effectively before and during climate events. Effective quantitative and spatial visualization of data can improve decision-making quality and speed (box 2.1). In Kenya, weather forecasting relies on global and local data sources. Global data are provided through open data sources by the International Research Institute for Climate and Society (IRI), the Intergovernmental Authority on Development in Eastern Africa (IGAD) Climate and Prediction Center (ICPAC), and others. Although the Kenyan Meteorological Department (KMD) has some climate and meteorological data, granular data on climate risks and hazards is scarce. KMD provides weather forecasts via the digital platform KMD Map Room;[31] social media platforms, such as X (formerly Twitter), Facebook, and WhatsApp; radio and television broadcasts; and regular PDF bulletins. User-oriented platforms and apps are available, but mainly tailored to the agricultural sector, including the Big Data platform that provides monthly weather and agro-met forecasts through a mobile app available for farmers [32].The Regional Centre for Mapping of Resources for Development in Nairobi has worked with the United Nations Environmental Program and National Drought Management Authority to develop hazard maps for 13 counties, available in PDF format through their website.[33]

Box 2.1 Digital tools increasing flood-risk resilience

In 2019, a Kenya Red Cross Society-initiated project was launched in four counties to map out and create digital tools to identify areas that are prone to floods. This included Narok County, where flash floods, which used to occur only once every five years, have become a common occurrence during the rainy season.[34] These floods in and around Narok arrive with short notice, typically within two hours of heavy rainfalls in nearby mountain regions, making them incredibly dangerous.

A communication strategy developed to alert people of the potential danger involves the KMD sending a text message to the county focal person and director, who then instruct *boda-boda* (motorbike) riders to continuously honk their horns, indicating people to move to higher ground. KRC and Safaricom also created a map of the past two decades of flash floods and telecom towers, sending text alerts to people close to the towers. This strategy has been effective in reducing the number of casualties in Narok. Similar projects have subsequently been implemented in eight or nine counties, assessing the most efficient communication channels. These projects found that WhatsApp is the preferred method of communication in more urban areas, while text messages and other channels are used in rural areas.

Digital public services and safety nets can support effected households during and after climate shocks. For example, the Kenya National Safety Nets Program introduced digital technology-based payments in 2015, allowing over 930,000 beneficiary households to receive cash transfers electronically via a two-factor authentication system.[35] Likewise, the Hunger Safety Net Programme, a government cash transfer program that covers the Arid and Semi-Arid Lands region, uses digital payments (through a fully operational bank account with an ATM card) to expand coverage during times of drought or other emergency, such as flooding. Safety nets require digital tools that can facilitate the selection and enrolment of beneficiaries and targeted and transparent delivery of funds. Effective methods of verifying beneficiaries are essential to these processes.[36] To enable digital public services, it is necessary to invest in mutually enforcing digital layers—or *digital stacks*—which include digital ID, payment solutions, seamless data exchange, and other elements. There are plans in place to provide all Kenyans with digital ID by 2024.[37] Full implementation will require significant resources and coordination; but it would yield important gains for a range of public services that enhance climate resilience.

2.3. Leveraging digital technologies for sector adaptation

This section takes a closer look at how the climate-sensitive agriculture, forestry, and water sectors use digital solutions as enablers for climate adaptation.

2.3.1. Agriculture

Climate change is increasing the level of risk faced by Kenya's agricultural sector, and adaptation measures are lagging. The sector, which includes crop cultivation, livestock, and fisheries, provides livelihoods for the majority of the rural population in Kenya and over 70 percent of employment in rural areas. Its exposure to climate risks is high due to the combined effects of drought, floods, and extreme temperatures. Rising temperatures have led to increasingly erratic weather patterns and a general decline in rainfall during the main growing season. Considering that 98 percent of agriculture is rainfed, farmers are highly vulnerable to disruptions in rainfall patterns. Weather information and climate forecasting are essential for improved decision-making and risk mitigation for individual farmers and policy makers.

Kenya's agricultural sector has spearheaded the adoption of several digital platforms and tools. Technologies such as mobile apps, data analytics, and digital extension services have been trialed to support Kenyan farmers and enhance their climate resilience. These include data-driven agricultural services that draw on multiple data sources to support decision-making at both macro and grassroots level, such as weather and climate services, which provide the information farmers need to adapt their practices to anticipated conditions or respond to impending extreme weather events (box 2.2).

Box 2.2. Big data platform and digital apps

The Kenya Agriculture and Research Organization (KALRO) has developed a big data platform with support from the World Bank's Kenya Food Systems Resilience Program. The Kenya Agricultural Observatory Platform[38] contains a comprehensive database of more than 1 million farmers, complete with geographic information and personal details, through which KALRO can disseminate integrated agrometeorological and market advice to farmers and other interested parties. KALRO has also digitized 650 climate-smart agriculture practices across 19 value chains which are available to farmers via an app, Interactive Voice Response System, or through a website. It also mobilized agritech actors under the One Million-Farmer Disruptive Agriculture Technologies platform to help provide digital services relating to production, data analytics, and market and financial linkages. The platform has reached 450,000 farmers to date using digital tools, and efforts are still needed to systematize and expand the deployment of digital services across value chains. Phase 3 of the World Bank Kenya Food Systems Resilience Program plans to do this by improving and scaling up digital solutions and platforms.

Digital financial services are a key enabler, especially for private sector-driven solutions. Pay-as-you-go (PAYG) models, for example, give smallholder farmers access to agricultural assets they were previously unable to obtain. PAYG uses mobile money payments and remote locking technologies to make farm equipment, energy grids, and irrigation systems available. For example, Kenya-based agritech company SunCulture specializes in solar power irrigation systems,[39] which farmers can buy on credit through PAYG. SunCulture uses data collected from both before and while the farmers are using the pumps—such as application stage farm and farmer information, pump efficiency data, and solar battery storage information from remote sensors—to advise farmers on how to optimize their irrigation systems.

In Kenya, insurance could be one of the most transformative uses of digital financial services. This can be in the form of an insurance scheme that leverages different forms of technology to determine and deploy payouts in the event of loss of crops (weather index cover) or the death of livestock herds due to a drought. Nairobi-based Agriculture and Climate Risk Enterprise (ACRE) is the largest index insurance program in the developing world and the largest agricultural insurance program in Sub-Saharan Africa. Among its core products, ACRE offers weather index cover based on farm-level satellite monitoring. If the index is triggered, farmers are automatically paid via the M-Pesa mobile phone platform.[40] ACRE uses indexes based on several data sources, including solar-powered automated weather stations, satellite rainfall measurements, and government area yield statistics. ACRE has around 200,000 farmer clients in Kenya, Tanzania, and Rwanda.[41] The initial results from insurance schemes are promising, but more work is needed to understand the linkages with climate resilience. According to Financial Sector Deepening Kenya, the research and data on climate impact are not conclusive.[42] It appears that certain digital financial services can help vulnerable communities recover sources of livelihood after a climate shock, but if not appropriately designed to address environmental climate risks, insurance can have adverse impacts. For example, index-based livestock insurance promotes restocking of herds in drylands soon after a drought. This suppresses vegetation recovery, leading to habitat deterioration and increasing sensitivity to climate risks.

The digital agriculture ecosystem is growing rapidly and the current set of technologies available to the sector is broad, but sector wide adoption is yet to come. A range of private, nonprofit, and public institutions are developing and promoting tools, including the Ministry of Agriculture, which is leveraging digital solutions to deliver services and promote economic opportunities and climate resilience for farmers throughout the country. But much remains to be done to develop, mature, and mainstream the most effective solutions and services across the sector. High technology costs, low digital literacy, and digital infrastructure access are among the primary constraints to adopting digital agricultural solutions.

2.3.1. Forestry

Forest degradation is a significant contributor to land and water resource degradation and reduced climate resilience due to loss of important ecosystem services. The removal of forests and dense vegetation results in the loss of essential environmental functions, including retaining natural water, regulating water flow, and preventing soil erosion. This can intensify the effects of flooding on infrastructure, increase sediment buildup in water storage systems, and deplete organic matter in topsoil, which is crucial for agricultural success. Kenya's five major forested areas are also important watersheds that supply 75 percent of the country's renewable surface water. Between 1995 and 2015, Kenya lost around 20 percent of its tree cover, mostly in the water tower areas, reducing water availability by approximately 62 million cubic meters per year[43]—equivalent to a quarter of the water demand for Nairobi city—which impacts on irrigation and hydroelectric power.

Digital solutions can play a role improving forest preservation and restoring the ecosystem services Kenya's natural assets provide to the economy. WorldAgroforestry Kenya, for example, has launched several decision support tools to aid the selection of suitable tree species for different contexts. They include the Global Tree Knowledge Platform,[44] which links to various databases, maps, apps, manuals, and guidelines to help select which tree species to plant where (see also box 2.3). Featured resources include the *Climate Change Atlas for Africa,* which shows alterations in environmental conditions. Land-use planners and scientists can use this information to determine how to adapt to the climate crisis on the continent.

Box 2.3. Examples of knowledge and verification for forestry

The Kenya Forestry Research Institute (KEFRI) developed a mobile and web-based app, called KEFRIApp,[45] that seeks to establish a species site-matching guide for sustainable tree growing and supports the National Tree Growing and Land Restoration Campaign to attain a minimum 30 percent forest cover nationally by 2032.

KEFRIApp's main objective is to provide information that enhances science-based smart greening activities for stakeholders in forest-based enterprises and agroforestry, commercial forestry, and landscape restoration initiatives to achieve Vision 2030 goals. It also facilitates the collection of real-time data on tree planting activities, estimating the number of trees planted on public and private land. Its verification module monitors survival and mortality of trees planted in various sites.

Complimentary to the KefriApp, the Geospatial Forestry Platform[46] (developed by Gatsby Africa) provides farm and plantation forestry solutions through a geographical information systems (GIS) platform. There is also a portal, spearheaded by Kenya Forest Service (KFS), for voluntary registration of institutions and private tree nurseries in Kenya.[47]

While platforms and apps emerge, a more coordinated strategy and approach is needed to leverage digital tools for forestry and landscape restoration. Establishing a comprehensive national forest monitoring and data system would offer detailed insight into restoration measures and aid in the efficient coordination of restoration initiatives across sectors such as energy, agriculture, and tourism. There are clear links between forestry managements and other sectors, and the promotion of clean energy, efficient cooking, as well as innovations in agroforestry, can bring benefits in forestry as well as other sectors, where digital technologies also have promising apps.

2.3.3. Water

Kenya is classified as water-scarce with low and declining freshwater resources, which is a challenge in the face of fast-rising demand and increased precipitation variability. As described in the Kenya CCDR,[48] one-third of the country's households do not have access to a basic water supply and two-thirds have no access to basic sanitation. There is a need to improve water management practices and respond more effectively to adverse weather events. Adopting digital water management solutions and practices that improve water use efficiency could help reduce water loss, support the sustainability of water resources, and increase the economic profitability of water. Combined with mobile payments, IoT devices enable PAYG service models, and smart metering are evolving in Kenya, but advanced metering and network monitoring and control remain frontier tech for many utilities. Such technologies are being tested to address nonrevenue water losses but are still at the piloting stage.[49]

In Kenya, digital water solutions are transforming the way utilities and customers interact. Mobile money is a game-changer for revenue collection while IoT devices have created new ways to monitor water services and automate processes. The advancement of digital financial services has become crucial in the water sector, playing a significant role in facilitating tariff and incentive payments, and providing accessible credit for individuals and farms to invest in pumps, irrigation systems, and sanitation facilities. Digital platforms and enterprise resource planning apps are also supporting more effective utility management and providing a foundation for digitalization across utility operations. Table 2.2 summarizes existing and emerging digital solutions in Kenya's water sector.

Table 2.2. Digital urban water solutions in Kenya

Solutions	Details
Pay-as-you-go services	Mobile-enabled PAYG services allow customers to make micropayments in advance for water services, while also guaranteeing revenue collection for water service providers. Apps include business models for energy, water, sanitation, and clean cooking apps.
Smart metering	Automatic meter reading is essential for gaining efficiency in billing as it records consumption and key operational data, and eliminates the time, costs, and errors of manual meter reading. Other uses are post-paid models or water vending machines.
IoT/machine-to-machine connectivity and GIS tracking	Smart monitoring of system performance can improve operational efficiency and avoid the technical losses that contribute to nonrevenue water. This is essential for deploying real-time data systems—for example, to detect leaks, inaccurate meter readings, and fraud.
Big data, artificial intelligence, and machine learning	Using large datasets can improve decision-making, while implementing algorithmic automation can help optimize utility operations. For example, it is possible to program pumping to take place when grid energy prices are low.

Source: Adopted from GSMA 2022[50]

A crucial factor for water utility digitalization has been Kenya's digital maturity and prevalence of digital financial services. Kenya's position as a leading mobile money market enabled many utilities to adopt mobile payments early. Financing for digitalization has, however, been a constraint, and some utilities have responded to this by engaging in innovative, digitally-enabled financing models based around revenue sharing.

3. Resilience of digital infrastructure

As Kenya digitalizes public and private services, reliable digital infrastructure becomes increasingly important. Digital infrastructure in Kenya is susceptible to damage from extreme climate events (table 3.1), as floods, thunderstorms, and high temperatures present challenges, from damage to materials, cables, and cell towers to connectivity and data loss. Climate hazard risks are not confined to single sites, but extend to regional infrastructure, partners, and utilities. This chapter explores the costly effects of climate change on digital infrastructure in terms of increased operating costs, supply chain disruptions, and data center migrations or re-sitings, and the knock-on effects when damaged cables and other infrastructure cut off critical communication and emergency relief services.

Table 3.1. Climate hazard risks to digital (connectivity and data) infrastructure

Risk	Site impacts (primary)
Fluvial and flash/pluvial flooding	- All sites with ICT equipment are at risk of outage due to flooding of premises, and power backup becomes challenging if the power source is at ground level - Underground and aerial cable deployments are at risk from flooding as well as debris and surface damage from washout or uprooting of trees
Drought	- Restricted water for cooling (chilled, evaporative) - Subsidence
Sustained high temperature	- Heat stress due to insufficient cooling capacity - Utility power instability due to very high demand
Wind/storm	- Wireless communication antennas and related passive infrastructure (poles, towers, building fixtures) can be damaged in high wind and from debris - Aerially deployed linear infrastructure is at a greater risk of damage, particularly from falling objects, such as trees
Dry weather/wildfire	- Direct risk of fire damage to equipment, poles, and cables - Ash entering equipment and clogging fuel filters - Utilities turning off substations or telecommunications (telecom) towers - Restricted water use

The level of vulnerability varies greatly across the country and among different parts of the digital infrastructure. Kenya is one of the most connected countries on the eastern coast of Africa, with six submarine cables and close to 14,000 kilometers of long-distance government-owned backbone fiber optic network cutting across the country, and another 52.000 kilometers of planned fiber. Additionally, the private sector has installed over to 35,000 kilometers of fiber. But older parts of the network require an upgrade, with some segments out of service for months or even years (box 3.1). While mobile sites (towers and antennas) and fiber cables are spread across large areas with varying topography and climate risks, and have a high degree of exposure, data centers are usually located in less exposed areas and are at best designed to withstand most climate hazards.[51]

3.1 Current disruptions to digital infrastructure

Interviews with digital stakeholders indicate that several parts of Kenya have experienced flood-related disruptions in the last few years. In many cases, the disruption is relatively minor—for example, in the case of damaged cables that can be easily fixed or replaced. But adverse weather and bad road conditions can delay access to damaged areas, increasing disruption by several days. In more severe situations, damage to road and bridge infrastructure that fiber cables are connected to can be so extensive that it can take months or even years to fully restore and enhance the connection. Disruptions to the backbone fiber infrastructure can result in a widespread blackout in affected counties. This can have a major impact on end users, especially in areas with limited mobile broadband coverage.

Remote northern and northeastern regions such as Turkana, Wajir, and Marsabit counties have suffered from digital disruptions related to pluvial floods (box 3.1). Such disruptions are due to climatic[52] and environmental circumstances, remote geographic locations, bad or no energy grid-connections,[53] and limited coverage or poor maintenance of road and telecom infrastructure particularly for the last mile. Although other counties can be more prone to flooding and landslides, they appear to be less affected based on data collected for this report. This could be due to the safer location of mobile sites (towers and antennas) and fiber optic cables, the availability of alternative digital infrastructure (redundancy), and preventive maintenance applied to the network.

Box 3.1. Examples of climate disruptions in Kenya

Turkana (northwest): Part of the first phase of the national fiber optic backbone infrastructure, construction of the fiber link between Eldoret and Nadapal on the South Sudan border began in 2009. But from around 2013, the link became nonoperational, due to a combination of flash floods and vandalism. The area west of Lake Turkana has experienced extensive flash floods in river streams running into Lake Turkana. The fiber stretch was recently refurbished (and in parts fully reconstructed) with funds from the World Bank's regional roads and fiber lending program, EA-RTTDFP.

Wajir, Marsabit, and Mandera (northeast): In Wajir, weather-related disruptions, particularly flash floods, have led to network downtime and fiber cut outages as recently as July 2023, when flash floods once again exposed and cut fiber cables by creating heavy erosion in the soil where the cables are buried, or destroying protective measures along riverbanks and roads. The same types of disruption have occurred in Marsabit and Mandera. In these counties, it often takes a while before technicians get to inspect and repair the cables, especially when the weather and roads are in a bad condition.

Figure 3.2 shows examples of ducts and fiber cables that have been exposed or torn apart by seasonal pluvial flash floods that erode riverbanks and protective gabions, leading to fiber cuts.

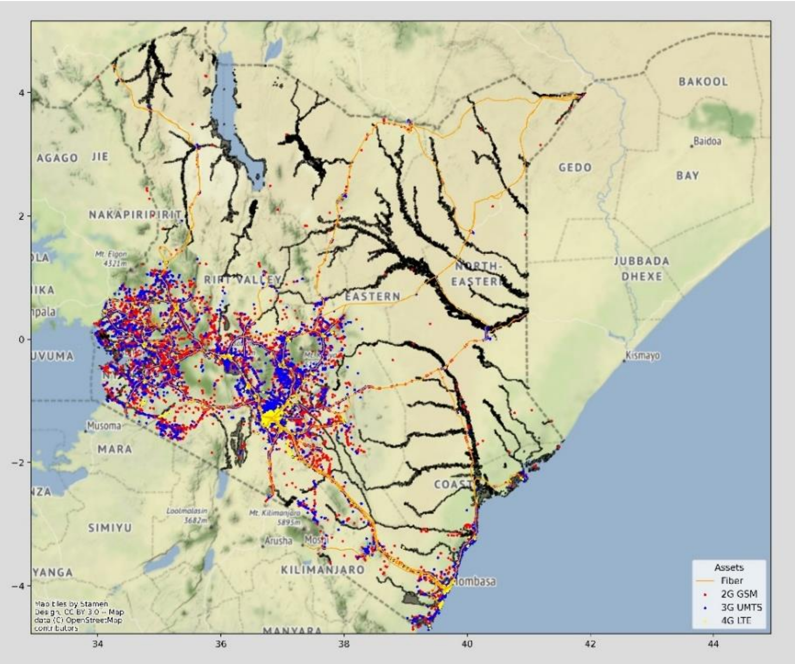
Figure 3.1. Fiber damage from seasonal pluvial flash floods

Source: Anonymous

3.2 Projected disruptions to digital infrastructure

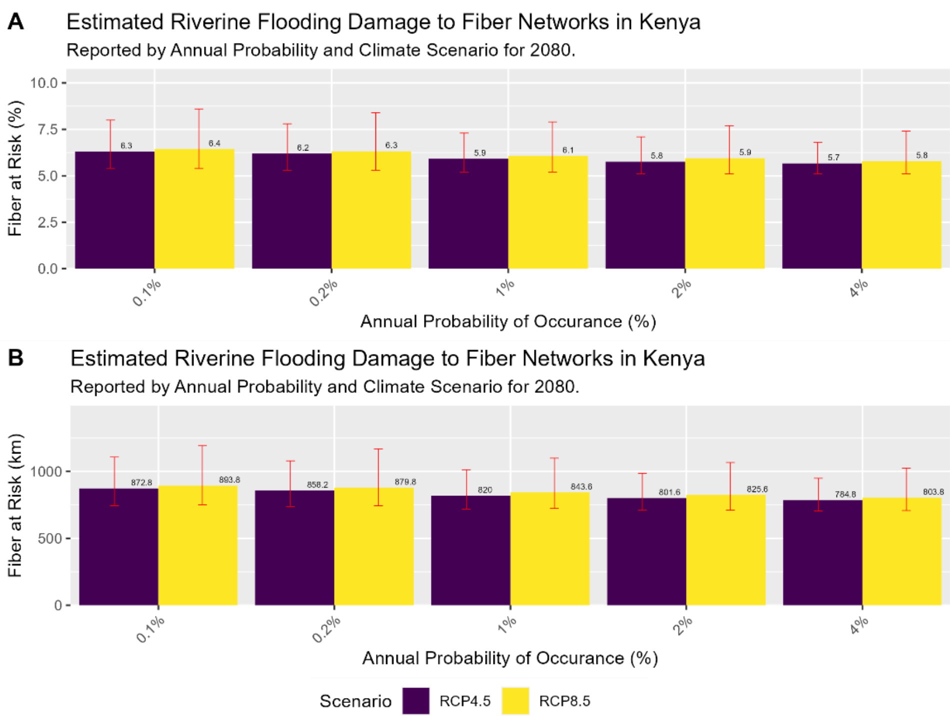
Given the changing weather patterns, digital infrastructure will continue to be at risk in Kenya. Assessing climate risk requires detailed information about the exact locations of digital infrastructure and local climate hazards now and in the future. Climate scenarios are used for this purpose called Representative Concentration Pathways (RCP). These define climate risks given different projected greenhouse gas concentrations. The estimates of digital infrastructure locations in this report use publicly available datasets, some of which are crowdsourced.[54] The findings therefore only provide an indication of vulnerabilities. Figure 3.3 shows flood risks to Kenya's fiber network and mobile cells[55] for a 1-in-1,000-year flood event in a moderate GHG emission climate scenario. Under these conditions, an estimated 6.3 percent (872.8 kilometers) of the fixed fiber optic network is vulnerable to riverine flooding (figure 3.4). Additionally, more than 6,500 mobile cells are at risk under the scenario and probability event, equating to more than 8 percent of total assets. Only marginal variability in fiber network exposure is present across the different RCP scenarios and probability events (fig 3.4), and the same applies to mobile cell exposure.

Figure 3.2. Flood risks to Kenya's fiber network and mobile cells in a 1-in-1,000-year flood event under the RCP4.5 scenario



Source: By the authors, based on data from Network Startup Resource Center (fiber network), OpenCelliD (cell locations), Global Aqueduct geospatial hazard datasets (riverine flooding).
Note: RCP = Representative Concentration Pathway; the RCP4.5 scenario is a moderate GHG concentration scenario

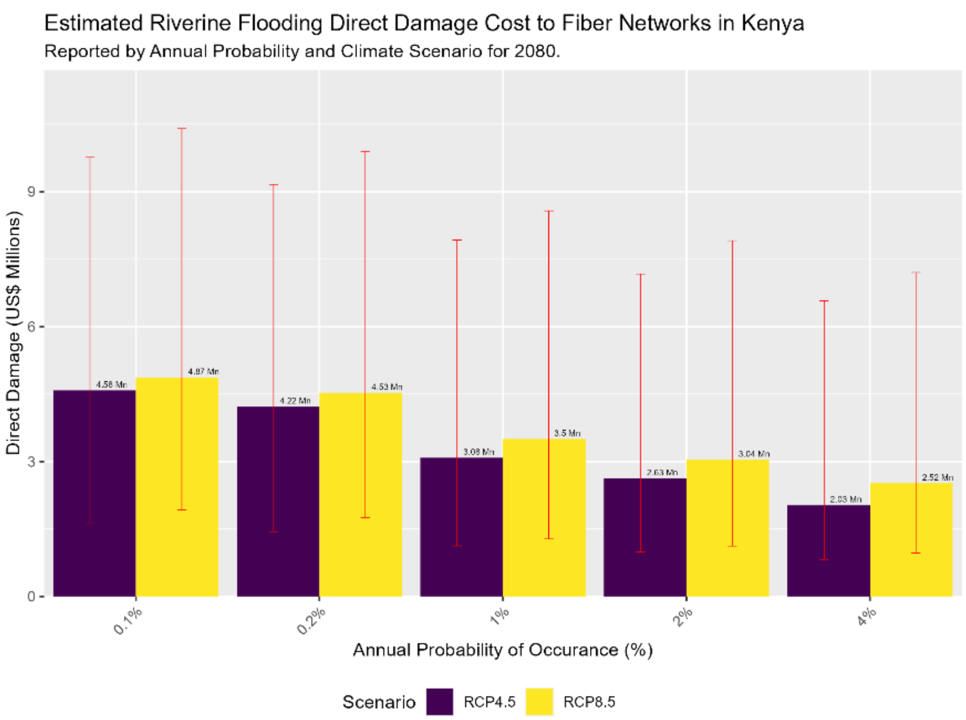
Figure 3.3. Estimated vulnerability of Kenya's fixed fiber optic network by 2080



Data that document the extent of weather-related disruptions are limited, as these are not collected or shared systematically by government authorities, telecom operators, or their subcontractors. The Communications Authority collects information from licensees on any incidents causing significant network downtime but has limited data available to share. The lack of proper data makes it difficult to determine the extent of climate impact on a national level, to validate the risk hotspots shown in figure 3.3 or to rank counties according to network exposure and real impacts. As a result, the suggested mitigation measures outlined here are derived from known and shared examples. To effectively address this for future infrastructure risk management, a more systematic and collaborative effort is needed.

It is not possible to quantify the exact economic impact of nationwide or local climate-triggered network disruptions in Kenya, but rough estimates are possible. Based on Deloitte's methodology,[56] a temporary nationwide internet shutdown would translate to total losses of an estimated $2-5 million per day, or 1–2 percent of the average daily GDP. Based on GIS analysis, figure 3.5 reports the estimated direct damage cost for the portion of the fixed fiber optic network that is vulnerable to riverine flooding. The figure shows that, as the severity of events increases (with a lower likelihood of occurrence), the costs of damage also increase, under both the RCP8.5 high-emission and the RCP4.5 low-emission scenarios. While a significant amount of the network may be at risk, it is fortunate that underground fiber optic cable is somewhat less susceptible to flooding as it is primarily vulnerable to kinetic damage rather than water exposure, which has a more limited impact (unless transmission electronics are affected). But this analysis is based on data for existing backbone infrastructure and does not account for all assets, including last-mile connectivity. As such, it is a conservative estimate of damage costs. As extreme weather events become more frequent, conducting risk assessments for infrastructure and preparing for high-consequence events is vital. This highlights the importance of investing in climate-resilient connectivity infrastructure.

Figure 3.4. Estimated direct damage cost of riverine flooding to Kenya's fiber networks



3.3 Measures to enhance resilience of digital infrastructure

Planning, building, and maintaining digital infrastructure with climate resilience in mind is crucial to avoid interruptions. Useful principles include planning for redundancy, using multiple technologies at key locations to improve resilience during and after a climate event, and ensuring the core network nodes have enough back-up power to sustain service during a loss of commercial power. Kenya's internet comes through six international submarine fiber optic connections, enhancing network redundancy and resilience. With multiple cables, the risk of extensive disruption of data traffic in and out of the country is relatively small, although the use of only one landing station in Mombasa could pose a risk in case of major coastal disaster.[57] The backbone and last-mile network are, in comparison, more exposed and vulnerable, so hazard risk mapping and response measures are essential to reduce the risk of damage costs and downtime. Data centers are also susceptible to climate hazards such as flooding and excessive heating, but no examples have been found in the public domain documenting incidents. Mitigation measures include site selection, choice of weather-resistant materials and design for facilities, and contingency planning.

Kenya has taken initial steps toward building a framework for more climate-resilient infrastructure. As previously stated, the country's NAP notes the need to 'climate-proof' infrastructure, ensuring investments are not compromised in the future. Although few comprehensive measures have been taken to date, the ICTA, Communications Authority, and private sector partners all recognize the importance of incorporating climate risks into digital infrastructure design, planning, and maintenance. The digital master plan prioritizes improving network redundancy, which also contributes to resilience. But additional measures are needed to protect infrastructure in the most vulnerable areas. While resilience measures have overhead costs, these are often relatively low if included in the initial design and should be assessed against the benefits of avoiding service interruptions, data loss, and maintenance costs due to disruptions. This is particularly relevant considering the government's plans to expand the fiber network and connect last-mile end users in rural underserved areas, which are often particularly susceptible to extreme climate events.

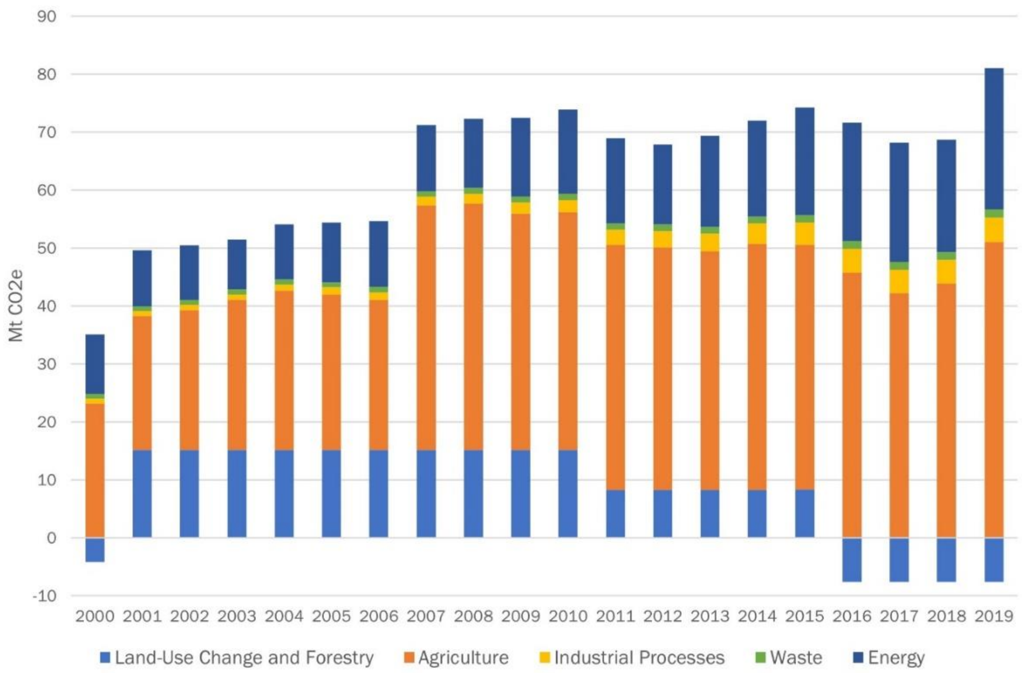
Building the resilience of telecom infrastructure and other critical infrastructure, such as power cables and roads, to climate risks is often intricately linked. The Kenyan government, its development partners, and private sector partners are increasingly coordinating their efforts across road, energy, and digital authorities, and stakeholders. This comes in recognition of the increasing interdependencies and evolving risks arising due to the increasing inter-reliance of different types of infrastructure, reflecting that disruptions in one sector can have immediate, and in some cases, long-lasting, cascading effects on operations in others. Collaboration between actors from different sectors and within the telecom sector—such as tower companies and telecom operators—can have various advantages, such as sharing infrastructure deployment and maintenance expenses, which allows the reallocation of budget toward resilience-building measures. In a move to better protect infrastructure assets from disruption by natural disaster and man-made threats, the government has designated public roads, energy, and digital infrastructure as *critical*, under the Critical Infrastructure Bill. Enforcing this legislation could significantly strengthen Kenya's ability to complete risk mapping, planning, deployment, and investment strategies for protecting both digital and other essential infrastructure.

4. Digital as a mitigation enabler

Although Kenya contributes less than 0.1 percent of global greenhouse gas (GHG) emissions annually, its economy could still be vulnerable to transition risks, especially if it becomes more carbon intensive as it develops, and global climate ambitions continue to grow. As such, it should aim to avoid a carbon-intensive growth path. Digital technologies can help sectors reduce their energy and carbon footprints. This chapter explores how platforms, apps, and other digital tools can contribute to service delivery and low-carbon development, with examples from the energy sector, where digital technologies play a key enabling role. Further examples from the agriculture, forestry, transport, and carbon trading sectors are in the appendix.

In the past five years, the energy sector has been Kenya's second-highest emitting sector, after agriculture (figure 4.1). Energy emissions are mainly driven by the transport sector, as electricity emissions have fallen due to the country's increased renewable energy capacity.[58] Kenya's updated NDC sets a 2030 goal of reducing emissions by 32 percent compared to the business-as-usual scenario, with plans to increase renewables, raise tree coverage, and improve efficient and sustainable energy, low-carbon transport, and climate-smart agriculture.

Figure 4.1. GHG emissions by sector, 2000–19



Source: Based on data from ClimateWatch[59]

4.1 Green energy supply and transition

Digital technologies play an important role in reducing transmission losses while improving the reliability and reach of electricity supply. Kenya has developed a well-diversified energy mix, and about 90 percent of its energy generation is renewable. With geothermal, hydro, and wind providing 48, 33, and 12 percent, the country has the potential to achieve a fully green grid in the near future.[60]

The costs for electricity grid access in Kenya are mediated by factors such as location, distance from urban centers, population density, and the nature of the terrain. Using geospatial tools, the Kenya National Electrification Strategy identified grid expansion and intensification, mini-grids, and standalone solar systems as the least-cost technology options for universal access to electricity.[61] Digital tools can help create better access to reliable and renewable on- and off-grid energy sources in underserved urban areas and remote rural settings of Kenya.

Off-grid solar solutions—such as the Safaricom and M-Kopa solutions—leverage mobile payments and control solar devices remotely.[62] From a meager 25 percent access to electricity in 2010, Kenya has achieved more than 70 percent access today both from grid and off-grid solutions. Off-grid solutions include solar home systems and solar lighting systems, mainly accessed through PAYG solar solutions. PAYG solar originates in Kenya and offers individuals and small businesses access to a range of clean and affordable energy systems. Solutions range from entry-level systems powering mobile phones, portable radios, and portable lights to high-end systems powering fans, refrigerators, water pumps, cookstoves and televisions. Payments are made easily through mobile payment apps. Kenya is one of the world's most attractive PAYG solar markets.[63]

Transition to clean cooking is another area where digital can accelerate adoption and GHG mitigation. In Kenya's NCCAP,[64] clean cooking is considered the next most impactful focus area after geothermal expansion. Despite the country's abundant renewable sources, more than half of all households still use wood fuel for cooking, and household cooking with firewood, charcoal, and kerosene is a major contributor to Kenya's GHG emissions, health challenges, and rapid deforestation. The country is leveraging digital payment technology to reduce entry costs for clean cookstoves and remove barriers to low-income families. This includes PAYG energy services to consumers who cannot afford the upfront cost of household energy products and clean cookstoves technologies with smart valves and smart meters, such as M-gas linked with M-Pesa.[65] Kenya targets an ambitious 100 percent access to clean cooking by 2028. But the 2022 World Bank *Energy Progress Report* indicates that adoption of clean cooking was at 20 percent in total, and just 5 percent in rural areas.[66]

Beyond helping consumers access energy, digital technologies also help utilities manage service delivery. Smart grids have been instrumental in ensuring a consistent power supply. The installation of smart meters allows real-time monitoring of the electricity grid, and allows companies to forecast demand, shape customer usage patterns, enhance energy efficiency, prevent outages and losses, and optimize unit pricing. Today, energy utilities in Kenya are moving to smart meters and grids as part of long-range plans to ensure a reliable energy supply, prevent severe energy and revenue losses, and give customers more control over their own power use.[67] For operators such as Kenya Power Company, smart meters could help reduce severe energy losses. Liquid Telecom and Safaricom are among the country's internet service providers that offer networking capability for smart meters.

5. Emissions from the digital sector

The digital sector plays a crucial role in catalyzing adaptation and mitigation in Kenya; but it is also a source of emissions. The sector is energy-intensive and competes for sometimes scarce energy resources. Reliable digital services hinge on stable and affordable energy supply. With the expansion of the backbone fiber network and increase in mobile users, the energy consumption demand on mobile networks will rise.[68] As 4G and 5G become more common[69] usage might also rise; they are generally more efficient per unit of data but can also increase consumption. Understanding and managing energy consumption in the digital sector is vital for ensuring reliability and reducing its carbon footprint in line with mitigation targets.

As in many countries, Kenya does not register ICT sector energy consumption and emissions separately in national statistics. According to World Bank approximations, excluding electricity used by mobile devices, the digital sector accounted for roughly 4 percent[70] of total electricity consumption and 0.5 percent of the country's total emissions in 2020 (table 5.1). ICT electricity consumption is notably higher than its emissions due to Kenya's relatively green electricity grid. Kenya's digital emissions are therefore relatively small compared with the global average. Nonetheless, rapid growth in the ICT sector is reflected in the sector's electricity demand, which will continue to grow as the country's digitalization increases.

Table 5.1. Estimated electricity consumption and emissions in Kenya's ICT sector, 2020

ICT industry	Emissions (tCO2e)	Electricity use (MWh)
Telecom	68,180	208,724
Data centers	*1,160*	*4,941*
Towers	*20,373*	*125,372*
TOTAL	***89,713***	***339,037***
Percent of Kenya	***0.5%***	***3.9%***

Sources: World Bank staff calculations, based on country CO2 emissions data from https://ourworldindata.org/ (percentage of total GHG emissions) and data from the KNBS 2022 Economic Survey (total electricity consumption)
Notes: tCO2e = tonnes of carbon dioxide equivalent; MWh = megawatt hours. Numbers in italic represent estimates of low confidence. Due to a lack of available quality data on direct GHG emissions for each segment, proxy indicators for the "size" of each segment have been used to approximate breakdowns of the sector's energy consumption. As such, the assessment of ICT sector operational energy consumption and emissions are based on data estimates of relatively low confidence, except for ***telecom***. *For* ***data centers:*** *If electricity consumption and efficiency could be obtained for the main data centers, it would be possible to calculate a better estimate of emissions and electricity consumption. For those that were found (e.g., Icolo), it is not clear whether the part-owner DRT is reporting a control boundary (i.e., all emissions) or equity (i.e., only its share of emissions). For* ***towers****: It is not clear whether the tower companies assigned all emissions for operator base stations or if the operators report them. Or towers belonging to ATK and American Towers Company, the only way to estimate electricity consumption is to divide the estimated emissions by the Kenyan grid emissions factor reported by bt, which is 0.1625.*

5.1. Harnessing a green digital sector

Greener digital transformation requires a pull from government and a push from industry. Although Kenya's digital policies increasingly include environmental and climate considerations, climate-informed regulation and green incentives have not been widely implemented, due to climate commitments and cost drivers. However, the private sector is still findings ways to enhance energy use and efficiency.

Safaricom is the only Kenyan ICT company with an explicit emissions reduction target. The company commits to net zero by 2050, with interim targets of reducing absolute Scope 1 and 2 GHG emissions[71] 43 and 74 percent by 2030 and 2050, respectively, from a 2017 base year. Safaricom emphasizes renewables and energy efficiency, reporting in its 2023 *Sustainability Business Report*[72] that it has reduced emissions through increased use of solar (1,432 sites) and modernizing energy equipment. This despite an increase in overall energy consumption and the continued use of generators as primary backup. As of early 2023, 99.3 percent of Safaricom's sites were either on the grid (75.9 percent) or powered by renewable energy (23.4 percent).[73] Safaricom also recently entered into a partnership agreement with the KFS to implement a tree growing and forest conservation program. These voluntary offsets complement other measures. Other operators and tower companies, such as Airtel and American Towers Company, are also exploring how solar energy and batteries can replace their reliance on diesel as a back-up, but it is unclear to what extent.[74]

To reduce emissions along the digital value chain, Kenya will ultimately have to make greater use of renewable energy and improve efficiency through new technologies and better processes. One of the challenges Kenyan telecom operators face is the lack of available electricity in rural areas and the reliability of the grid. As a result, they either resort to using generators as their primary or backup power source, or invest in converting the energy supply to solar with lithium batteries as backup. This appears to have great emission-reduction potential in Kenya, considering the high proportion of off-grid and bad-grid towers powered by diesel.[75]

Box 5.1. The cost of off-grid base station energy

A study[76] looking at the use of renewable generators for Safaricom's base stations finds that, although the initial installation cost of the renewable system is higher than installing a diesel generator, in the long run, the cost of operating a renewable system ($8.24/MWh) is more than twice as low as a pure diesel generator ($21.8/MWh). Excess energy generated from green sources can also be sold back to the grid.

If Kenya can strengthen its reliable clean energy supply, it would be well positioned to become a low-carbon hub for data storage and digital services. Africa represents a low share of global data center capacity, but the sector is growing and attracting both local and international investments. Globally, multinational digital firms are the largest consumers of renewable energy and as such, access to reliable, affordable, and clean energy is often among their investment criteria. During a trip to the United States in 2023, President Ruto visited tech companies promoting Kenya as an investment destination. Access to clean energy was among key selling points.[77] However, Kenya can still do more to ensure its energy and digital policies are conducive and its energy supply reliable. To position itself as a cloud hub, data localization policies and harmonization with neighbors on data protection and privacy regimes are important areas to consider.

6. Leveraging climate data in Kenya

Data volumes have increased in Kenya alongside digital adoption. In a climate context, data is the foundation for many crucial tasks—including weather forecasting, disaster risk management, and land management. While Kenya already integrates climate data into much of its policy making the full value has not been captured yet. This chapter considers Kenya's landscape for climate data, the barriers it faces—and the opportunities it can grasp—in strengthening and leveraging these data.

Climate data come in many forms and are available in a variety of digital apps and platforms. These range from apps that evaluate temperature and rainfall in an area over the course of a day to platforms that document the long-term effects of climate change across various sectors. Table 6.1 provides examples of digitized data being used for adaptation and mitigation purposes across in Kenya.

Table 6.1. Data-driven solutions enabling adaptation and mitigation In Kenya

	Adaptation / resilience	Mitigation
Agriculture	Big data platform, Digicow, Kilimo, ACRE index-based insurance	Digicow
Forestry	KEFRIapp	Sensor data and satellite images
Transport	Regional Systemic Risk Assessment Tool	Transport Inventory and Greenhouse Gas Emissions Reporting (TrIGGER) tool
Energy	PAYG off-grid energy solutions	Smart metering
Cross-sector	KMD Map Room, ICPAC HazardWatch	Kenya Carbon Emissions Reduction Tool (KCERT) carbon calculator

6.1.1. Data collection and storage

Climate data in Kenya are generated in a variety of ways at local, regional, and national levels. Institutions such as the Kenya Meteorological Department (KMD) analyze weather station and satellite imagery to develop national-level information on meteorological variables, such as rainfall and temperature, and climate hazard risks. Meteorological centers such as the ICPAC do the same on a regional level. National and regional analysis relies heavily on global climate monitoring centers, such as the United Kingdom's Met Office and the IRI, as well as locally collected climate data. Collaboration between local and international climate data collection efforts is crucial in understanding the complex interplay between global weather patterns and regional climate conditions. It also compensates for the lack of comprehensive local climate data and allows for the development of more accurate predictive models and sustainable solutions to mitigate.

Granular climate risk and hazard data are scarce, and decision-makers often have to rely on global data sources, which lack detail. Recent expansion in automatic weather stations and the launch of KMD's Map Room[78] represent much-needed developments in this area, helping the country overcome gaps in its meteorological records by combining quality-controlled station records with proxies that are freely available from global sources: satellite data for precipitation and climate model reanalysis data for temperature. KMD and its partners, including the World Bank and ICPAC, are working to improve data collection processing and analysis capacity for more precise and timely forecasts and outputs, and to facilitate data sharing with stakeholders.

Box 6.1. Automatic weather stations delivering climate data

In 2022, 154 automatic weather station were established in 24 counties, at a cost of Sh500 million. This was supported by the World Bank through the Kenya Climate-Smart Agriculture Project. Data from the 120 synoptic, 17 agromet and 17 hydromet stations are relayed to computers in project counties and KMD headquarters in Nairobi.

Global datasets can help to some extent, but there needs to be better integration of local data. In the absence of local-scaled digitized data, it is worth leveraging already available, complimentary cloud services that can be customized to integrate with local data. These include ECMWF-GEOGLOWS hydrological streamflow forecasting[79], GADAS[80], ClimateEngine[81], Google Earth Engine[82], and the World Bank's Climate Change Knowledge Portal[83], which are available at no cost. There are also many subscription services, such as SecureWatch.[84]

Data standards are necessary for robust spatial and statistical data series. Repeated data collection and sharing can help harness the potential of data to extract a wide range of insights and solutions to Kenya's climate challenges. Interviews with sector stakeholders indicates that data collection methods and tools often change over time, making it challenging to use the data for comparison, planning, and policy making. Reliable data series in Kenya require not only regular collection, but also consistent standards and collection methods to ensure useful comparison over time. Accurate surveys are expensive and therefore dependent on prioritized efforts and continuous funding.

Several stakeholders raised issues regarding duplication of data collection and platforms, including for key climate data. In some cases, similar data is collected on different platforms funded by different partners, resulting in unnecessary expenses. Sustainability is also a concern, as platform development is often funded, but not maintenance or user licenses. To address these issues, better government and donor coordination is vital, as are sustainability plans that factor in operational costs, capacity building, and organizational mandates.

Vendor lock-ins challenge interoperability and sustainability. Data collection, analysis and visualization are often carried out by external consultants or international agencies that either maintain ownership of data or cannot hand over data to the local partner resulting in potential data loss. Moving towards open data standards and platforms can mitigate some of these challenges.[85]

6.1.2. Open data

Kenya launched an open data initiative in 2011, to make key government data freely available to the public through a single online portal. Despite a promising launch, the initiative has been subject to several changes and setbacks. The KNBS website currently links to eight different data sharing portals,[86] some of which are hosted on its own site. This includes the Kenya Open Data Portal, which is meant to be an umbrella site granting free access to public government datasets in easy reusable formats.[87] The two key entities involved —ICTA and KNBS—are under different government ministries, presenting bureaucratic complexities.[88] While the national government maintains the ambition to create more openness and access to data, it has yet to adopt the Open Data Charter, a collaboration between over 100 governments and organizations working to open up data based on a shared set of principles.

According to *Open Data Watch*, Kenya ranks 104th out of 195 globally and 5th out of 16 in East Africa.[89] While it ranks 1st on data coverage in East Africa, it ranks 9th on openness. The results (table 6.2) show that Kenya performs well against its regional peers on data coverage, albeit with gaps in relation to climate data (e.g., GHG emissions), but there are substantial deficiencies for the indicators that measure data openness. These include a lack of machine-readable data format, lack of terms of use of data, and lack of proper data download options on the KNBS website.[90]

Table 6.2. Open Data Watch Kenya scores

Data category	Coverage	Openness	Overall
Agriculture and land use	40	50	45
Resource use	88	30	56
Energy	100	30	56
Pollution	38	60	50
Built environment	70	40	55
Environment subscore	**64**	**42**	**46**

Source: Open Data Watch 2022. https://odin.opendatawatch.com/Report/countryProfileUpdated/KEN?year=2022

6.1.3. Data storage

Kenya faces challenges in storing climate data securely, and the risk of data loss is significant. Interviews with stakeholders indicated that climate related data are stored in diverse ways, including on on-premises servers with limited IT support, and sometimes on individual laptops. Datasets have been lost due to storage practices and a lack of backup. On-premises hosting practices can result in higher aggregate costs, pose security and operational risks, and make cross-government data sharing and use difficult. Centralized data storage is often more robust, provided backup data storage or cloud solutions are available to ensure security and resilience of critical data and systems.

6.1.4. Data enablers and safeguards

Regulatory enablers and safeguards are needed to ensure trusted and safe data usage. Creating a conducive climate data ecosystem requires the right mix of laws and policies, institutional arrangements, and technical architecture. Getting the right "enablers" and "safeguards" in place for data sharing is of central importance to developing this.[91]

As the digital economy grows, digital threats such as cybercrime, data breaches, and identity theft follow. Without adequate safeguards, data providers may be concerned about potential abuses, ranging from weak security of data transactions to the opaque collection and sale of personal data by third-party data brokers. Policy priorities include enhancing privacy protection in private and public systems and ensuring the security of critical information and infrastructure. The data governance assessment from the World Development Report 2021 points to strengths and weaknesses when it comes to data enablers and safeguards . While most core enablers and safeguards are in place in Kenya, such as those related to e-commerce and cybersecurity, a few important digital foundations are missing, or not fully implemented (table 6.3).

Table 6.3. Availability of data enablers and safeguards in Kenya

Enablers			
E-commerce/e-transactions law	Digital ID system for online authentication	Open data act/policy	Data portability rights
Available	Not available	Partly available	Available
Safeguards			
Personal data protection law	National cybersecurity strategy/plan	Regulation of non-personal government data	
Available	Available	Available	

Source: World Development Report Global Data Regulation Diagnostic Survey Dataset 2021. https://microdata.worldbank.org/index.php/catalog/3866.
Note: Information as of 2020

6.1.5. Data usage and sharing

While the potential of digital solutions to collect and analyze data in Kenya is evident, their availability to policy makers and the public remains limited. Apart from meteorological climate and weather data, available data mainly consist of generic statistical indicators and inventories, such as those submitted under the Sendai Framework for Disaster Risk Reduction[92] and the Sustainable Development Goal (SDG) Global Indicator Framework.[93] Although these statistics are useful, the lack of regularly updated and disaggregated sector-, location-, or climate hazard-specific data makes it difficult to accurately assess and respond to climate risks and gradual climate shifts, both in terms of adaptation and mitigation. National and sector wide GHG emissions data are also partially outdated.[94]

Requesting climate data from government agencies can be a lengthy process, with data often issued in paper, rather than digital, format. Developing data standards and time series would help reduce the burden of this process and improve access to data, enabling the implementation of effective disaster risk management and adaptation plans. At county level, there has been notable advancement in efforts to identify climate risks and prioritize actions, supported by the Financing Locally-Led Climate Action (FLLoCA) Program, a World Bank project co-funded by Denmark, Netherlands, Germany and Sweden, which is pioneering the first national model of decentralizing funds to counties and devolving decisions to the local communities to give them greater influence on climate investments and solutions. However, while some counties have achieved progress with GIS analysis, a lot of this work is still outsourced to development partners and consultants.

According to the World Bank *2023 Climate Change Institutional Assessment*, Kenya's Climate Change Act establishes the overall coordination mechanisms for the climate agenda but does not provide detailed guidance on coordination arrangements.[95] Overlaps in mandates across government entities and levels complicates coordination. Coordination between national ministries is not always consistent. This results in limited data dissemination, both horizontally and vertically. The lack of a centralized database for national hazard and climate risks, and other data used for climate adaptation and mitigation is creating a challenge for coordination between agencies and levels of government. Addressing inadequate data storage and the limited data exchange/sharing between national, county, and municipality levels is vital, as well as developing more user-friendly ways of presenting information for decision making. This effort will require stronger cross-government coordination and platforms, as well as decentralized information management units to collect, maintain and leverage climate data across diverse use-cases.

7. Recommendations

In Kenya, climate hazards are both a future risk and a reality affecting people and sectors today. Farmers are feeling the impact of changing weather patterns and telecom cables are being uprooted by flash floods, disrupting services. With a mature digital ecosystem and ambitious climate commitments, Kenya is well positioned to leverage digital technologies for climate action. These technologies can measure and monitor the effects of climate change, create more efficient energy systems, and enable more climate-resilient farming practices. As shown in this note, they can help promote accountability and transparency around climate finance and much more. Focusing on the following areas can help the country adopt the more strategic approach it needs to scale and leverage digital technologies more effectively.

Breaking policy silos: A whole-of-government approach to green digitalization will break policy silos and ensure the effective use of digital technologies in climate action. Although Kenya boasts many novel climate solutions, platforms and apps are not always scaled up, or are standalone solutions that lack cross-government integration. In some cases, climate-related platforms are duplicated, and some sustainability plans are weak. A more strategic approach would help ensure interoperability, ownership, and scale of effective solutions, and allow the country to close down ineffective or siloed solutions. The difficult balance is honing a more strategic approach while not stifling the bottom-up initiatives that have driven digital climate innovations to date. Kenya has made strides to enhance crosscutting coordination, but green digitalization calls for a whole-of-government approach. Digital government institutions need to integrate climate considerations in their digital plans and regulations, while sector ministries and implementing agencies may require guidance and capacity building to apply digital technologies effectively to climate action.

Targeting resilience efforts: Effective use of digital tools will produce reliable and accurate data collection, allowing the government to target resilience efforts to those who need it most. Climate change disproportionally affects low-income populations, threatening livelihoods, health, and opportunities. Targeting resilience measures to the most vulnerable groups requires reliable, accurate, and easily accessible data that are tailored to specific needs. Projects often overlook recent informal developments that are generally the most climate-vulnerable. Access to climate data and early warning systems can inform diversified livelihood options, such as water harvesting, drought-resistant crops, agroforestry, and alternative income-generating activities. Empowering local communities with tools for citizen science addresses two key issues: accessing scarce data and mobilizing local communities. Digital tools can empower, formalize, and accelerate the work of community-based data collection and local advocacy groups.

Strengthening digital foundations and investing in the long term: While Kenya is a regional digital leader, gaps still exist. Enhancing digital skills and expanding digital connectivity can help build stronger digital foundations, enabling adaptation and mitigation efforts. The digital transformation should connect climate-vulnerable populations and create partnerships within and beyond the government to offer relevant digital services that enhance resilience, such as early warning systems, insurance schemes, and social protection. Investing in connectivity, devices, and apps to close the digital divide is crucial, but it is, important to plan beyond one-time investments. Climate solutions often fail because they fail to consider or finance recurring costs, such as operations and maintenance, skills, and human capital, or because the technology is too complex. As such, all projects should leverage open standards, locally available devices, and engage local communities in solution development.

Protecting Kenya's infrastructure assets: From city centers to rural areas, Kenyans rely on stable digital services for many tasks and the infrastructure that provides them should be treated as critical infrastructure in national contingency plans. Mainstreaming knowledge about current and future climate risks into infrastructure planning and taking measures to climate-proof digital infrastructure are also vital. On average, each $1 low- and middle-income countries invested in more resilient infrastructure yields $4 in net benefit.[96] Including climate risk screening in public infrastructure management regulations and guidelines can increase the resilience of all new infrastructure and ensure appropriate maintenance protocols are applied after asset completion.

Positioning Kenya strategically: Kenya is endowed with ample renewable energy. The digital sector is the largest purchaser of renewable energy globally. Access to reliable and affordable renewable energy is a key asset that can attract sector investments and position Kenya as a regional hub—for example, for green data centers. Ensuring a conducive policy environment is critical.

Appendix 1. Mitigation examples across sectors

A.1. Agriculture

Climate challenge

The agricultural sector is Kenya's largest source of GHG emissions, accounting for more than 60 percent of total national emissions in 2019. Methane emissions from livestock represent nearly half of the sector's total emissions, and emissions associated soil management on agricultural lands are the second largest source, producing 42 percent of the sector's emissions.[97]

Examples of digital tools for mitigation

- Digital technologies can help lower emissions across the entire agrifood system—energy, fertilizer, transportation, processing, and sales—through direct, enabling, and behavioral effects.
- On-farm, digital technologies can promote efficient use of natural resources and inputs—for example, informing feeding strategies that cut feed requirements, thus reducing large indirect land use for livestock.
- Digital technologies can improve animal health monitoring, boosting livestock productivity and reducing global GHG emissions per livestock unit.
- Pastoralist systems can also benefit from digital technologies that locate grazing grounds and waterholes and limit overgrazing.

A.2. Forestry

Climate challenge

Land use, land-use change, and forestry are a source and sink of emissions and a key sector for reaching net zero emissions. Between 2001 and 2019, the sector changed from positive to negative emissions (figure 4.1).[98] Kenya has never implemented a full national forest inventory. Since 1990, the Food and Agriculture Organization of the United Nations' (FAO) Global Forest Resources Assessment[99], which uses remote sensing for global and regional analysis of the world's forest resources, complements the information collected through national reporting. The most recent FAO assessment shows that Kenya has a net loss of about 350,000 hectares of natural forests between 2000 and 2020, with a slight increase in forest area since 2015[100] This implies a net uptake of CO_2 in recent years. Global Forest Watch estimates that Kenya experienced a net change of -6.0 percent. [101] Studies show that Kenya lacks the essential information typically provided by a complete national forest inventory[102]

Examples of digital tools for mitigation

- Digital tools help monitor, manage, and analyze land use, land use change, and forestry activities to provide accurate and timely data that informs decision-making.
- Producing a national forest map and monitoring change is time-consuming. One solution to the big data problem is to automate the whole process. In collaboration with the National Centre for Earth Observation at the University of Leicester, KFS co-developed a rapid deforestation monitoring system, which sends alerts every five days to help detect changes in forest resources, such as a change in forest cover. The system uses Copernicus Sentinel-2 images at 10-meter spatial resolution, allowing detection of even small-scale logging in the forests.[103]
- The Timbeter App used by KFS is expected to enhance public plantation management, including reducing illegal logging.[104] Timbeter uses artificial intelligence and machine learning for timber measurement and accurate log detection.

A.3. Transport

Climate challenge

The transport sector is responsible for most of Kenya's energy-related CO2 emissions, not including emissions from waterborne navigation.[105] Projections show that, between 2015 and 2050, total road transport emissions will increase by 380 percent.[106] This stands in contrast to the 's emissions reduction target of 3.46 million tons of carbon dioxide equivalent in 2030.[107] Kenya's public transport sector is largely dominated by privately-owned public service vehicles, including buses, minibuses (*matatus*) and motorcycles (*boda-bodas*).

Examples of digital tools for mitigation

- The government is taking measures to tackle climate change through transportation and logistics-related initiatives. Using digital resources such as geospatial traffic analysis, Kenya is leading the way in East Africa in compiling data on road transport emission factors, increasing understanding for prioritizing GHG emission reduction efforts.[108] The most potential lies in freight transportation, followed by electrification.
- Digital technologies are increasingly being applied in the public transport sector. Since 2014, the National Transport & Safety Authority and ICTA have facilitated the Transport Integrated Management System, a self-service portal that allows individuals to access transport services online. The government is also in the process of launching an intelligent traffic management system, which it hopes will revolutionize traffic management.
- Digital apps can facilitate shared economy models to accommodate transport needs.[109] Uber, Bolt, LittleCab, Safeboda, and other apps have developed products that facilitate on-demand e-hailing of taxis and freight vehicles. Studies across countries diverge on the net carbon footprint of ridesharing, and more research is needed.[110]
- E-mobility is at an early stage of development. Adopting battery electric vehicles in conjunction with the developing mass rapid transit could be a game-changer. There are several pilot activities introducing e-mobility in Kenya, mostly focused on electric two-wheelers and buses.[111] The Kenyan electric vehicle startup BasiGo[112] plans to deliver 15 electric buses to public service vehicle operators in Nairobi, allowing customers to access real-time data to track operations and monitor their location. Most electric vehicles in Kenya are motorcycles, with the existing e-motorcycle business model including direct sale, leasing, and battery swapping.

A.4. Carbon markets

Climate challenge

Carbon credit markets are increasingly financing greener transformation in Kenya by putting a market value on GHG emissions-reduction activities. Kenya took steps during the United Nations Framework Conference on Climate Change's 27th Climate Change Conference (COP27) to reaffirm its commitment to the African Carbon Markets Initiative with aims to increase participation in voluntary carbon markets.[113]

Examples of digital tools for mitigation

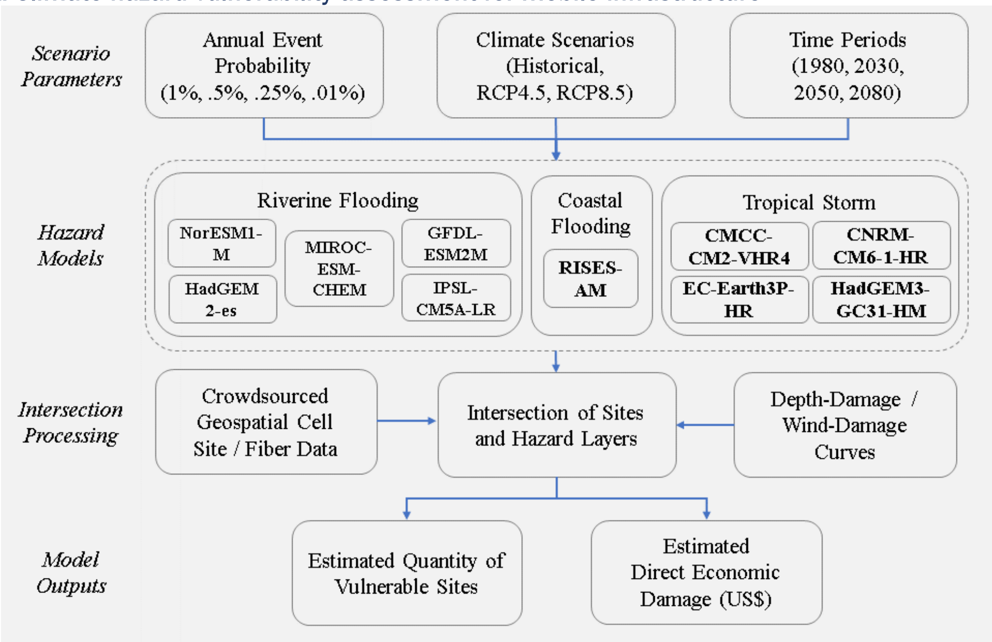
Carbon markets provide an opportunity for Kenya to channel finance into sustainable land use. Under the Paris Agreement, countries can devise their own methods to manage and supervise climate action, presenting both advantages and difficulties in standardizing data, verifying data in a consistent manner, and interconnecting registries. To tackle these obstacles, Kenya can use digital technologies and crosscutting platforms established by the World Bank[114] and others to reduce the cost of accreditation, avoid double counting of credits, and create closer connections between sellers and purchasers of carbon credits.

Digital technologies can enable carbon credit markets in agriculture, energy, and forestry. Despite their strong climate-positive impacts, most of Kenya's small carbon-sequestering projects do not attempt to access global climate financing markets due to the complexity, cost, and time involved. Safaricom Kenya and 4R Digital are joining forces to tackle this challenge using 4R Digital's Carbon Value Exchange (CaVEx), a digital platform that facilitates the digitization, tracking, and sale of carbon offsets and sequestration activities from a variety of micro- and small-scale projects in the Global South. Using technology advancements in remote sensing, device connectivity (the IoT), and digital payments, the platform will enable micro- and small-scale projects to be rewarded for reducing or removing carbon emissions in a highly transparent, auditable, and fair way. The overarching objective of CaVEx is to use available technologies to reduce the costs of collecting project-related data without compromising quality. CaVEx is initially being designed for e-mobility, solar water pumps, distributed solar power, and reforestation.[115]

Appendix 2. Methodology for vulnerability analysis

A scenario approach is adopted to assess vulnerability of digital infrastructure (see figure A1). The approach consists of three main components, including the (i) selection of scenario parameters, (ii) processing of global hazard models layers and affiliated data, (iii) intersection processing of geolocated mobile cells with hazard layers using depth-damage curves to estimate vulnerability assets.

Figure A1: Climate hazard vulnerability assessment for mobile infrastructure



Climate hazard data and infrastructure asset data: Global Aqueduct geospatial hazard datasets are obtained, selected for key scenario parameters of interest, and then processed for both riverine and coastal flooding layers.[116] Data layers are selected for two different climate scenarios (as well as a 1980 historical baseline), based on the IPCC 5th assessment report. These include (i) Representative Concentration Pathway 4.5 (steady carbon emissions) (intermediate climate outcomes) (RCP 4.5) and (ii) Representative Concentration Pathway 8.5 (rising carbon emissions) (limited climate outcomes) (RCP 8.5).[117] Crowdsourced data for December 2022 are gathered from OpenCelliD for current mobile infrastructure networks, covering 46.7 million global cells for 2G, 3G, 4G and 5G, and then separated by country. For fixed fiber optic network data, spatial layers are utilized from the Network Startup Resource Center and processed on a country basis.

Vulnerability analysis: Mobile cellular towers generally consist of the three main design types identified within the literature review, including monopoles, self-supported structures, or guyed structures. These assets usually rely on steel or aluminum for the structural frame, utilizing concrete at the base of the tower either for the foundation plinth or to secure guy lines. Vulnerability to hazards and the consequential damage cost is estimate using a depth-damage curve approach which is a standard way in the literature to relate the depth of flooding inundation to a potential direct economic cost of damage. Due to limited information relating to the depth-damage relationship, scenarios are used to explore this variability. The investment costs for rebuilding mobile cells are adapted from the existing literature[118], to enable damage costs for different sized events and climate scenarios to be estimated. Broadly, the cost of building a new three-sector 4G macro cell site is treated here as approximately US$90,000, equating to approximately US $30,000 total capital expenditure per cell. Thus, a cell costing US $30,000 with a flooding depth of 0.6 meters and a damage quantity of 0.5, leads to a direct damage cost estimate of US $15,000. As identified in the literature review, the specifics of the damage depend on the cell tower construction. At the lower end of the fragility curve, damage to electronic equipment could take place. Whereas in more severe outcomes, this could include the full destruction of both active electronic radio equipment and passive civil engineering tower structures, requiring a total rebuild of a site. Finally, the direct damage cost to the ith cell asset is calculated using the estimated asset replacement cost and the damage value from the depth-damage curve.

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[93] Statistical data on SDG global indicators are available from https://www.knbs.or.ke/sdgs/.

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[95] World Bank. 2021. *Climate Change Institutional Assessment.* Washington DC: World Bank. http://hdl.handle.net/10986/35438.

[96] Hallegatte, S, Rentschler, J and Rozenberg, J. 2019. *Lifelines: The Resilient Infrastructure Opportunity.* Washington DC: World Bank. http://hdl.handle.net/10986/31805.

[97] Government of Kenya. 2018. *National Climate Change Action Plan (Kenya): 2018–2022. Volume 3: Mitigation Technical Analysis Report. Nairobi: Ministry of Environment and Forestry.*

[98] This trend needs further validation as it is mainly based on changes in forest cover data, which have recently been monitored in a different manner.

[99] https://www.fao.org/forest-resources-assessment/en/

[100] FAO. 2020. *Global Forest Resources Assessment 2020. Report: Kenya.* https://www.fao.org/3/cb0019en/cb0019en.pdf.

[101] https://www.globalforestwatch.org/dashboards/global.

[102] Rodríguez-Veiga, P, Carreiras, J, Smallman, T L, Exbrayat, J-F, Ndambiri, J, Mutwiri, F, Nyasaka, D, Quegan, S, Williams, M and Balzter, H. 2020. "Carbon Stocks and Fluxes in Kenyan Forests and Wooded Grasslands Derived from Earth Observation and Model-Data Fusion." *Remote Sensing* 12(15): 2380. https://doi.org/10.3390/rs12152380.

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[104] Njane, M. 2022. "Technological Developments in the Forestry Sector in Kenya." FSK. https://fsk.or.ke/technological-developments-in-the-forestry-sector-in-kenya/.

[105] Ministry of Transport, Infrastructure, Housing, Urban Development and Public Works. 2021. *Transport Sector Climate Change Annual Report 2019–2020. Performance and Implementation of Climate Change Actions.* https://changing-transport.org/wp-content/uploads/Kenya-transport-annual-report_Jan-2021.pdf.

[106] GIZ, 2018, Greenhouse gas emissions from the transport sector: Mitigation options for Kenya: Methodology and Results. Kenya, 17 October, 2018.

[107] Ministry of Transport, Infrastructure, Housing, Urban Development and Public Works. Transport Sector Climate change annual report 2019-2020. Performance and implementation of climate change actions. https://changing-transport.org/wp-content/uploads/Kenya-transport-annual-report_Jan-2021.pdf

[108] For example, Kenya has adapted the TrIGGER tool, a simple bottom-up spreadsheet model for calculating national transport GHG inventories that includes country-specific data. https://changing-transport.org/tool/trigger-kenya/

[109] Kwoba, H and Mettke, C. 2020. *Digitalisation in Kenya's Road Transport Sector: Ride Hailing and Influences of Other Digital Applications in Kenya's Mobility.* GIZ. https://www.changing-transport.org/wp-content/uploads/2020_Digitalisation_Kenya_Road_transport_sector.pdf

[110] Ioannis, T. *et al.* 2021. Ridesharing services and urban transport CO2 emissions: Simulation-based evidence from 247 cities, Transportation Research Part D: Transport and Environment, Volume 97, 2021, https://doi.org/10.1016/j.trd.2021.102923.

[111] World Bank. 2023. *Kenya Country Climate and Development Report.* https://www.worldbank.org/en/publication/country-climate-development-reports.

[112] https://www.basi-go.com/.

[113] https://www.president.go.ke/wp-content/uploads/Remarks-by-H.E.-Hon.-William-Ruto-at-the-launch-of-African-Carbon-Initiative-ACMI-at-COP27.pdf; https://climatechampions.unfccc.int/africa-carbon-markets-initiative-announces-13-action-programs/.

[114] For example, the Transformative Carbon Asset Facility (https://tcafwb.org/) is a World Bank trust fund that supports countries' efforts to implement market-based carbon pricing and create conditions for private sector investments in low-carbon technologies, and the World Bank's Carbon Pricing Dashboard (https://carbonpricingdashboard.worldbank.org/) provides an interactive online platform with up-to-date information on existing and emerging carbon pricing initiatives around the world.

[115] https://fsdafrica.org/projects/carbon-value-exchange-platform-cavex/

[116] World Resources Institute (2022) Aqueduct Floods Hazard Maps, World Resources Institute. Available at: https://www.wri.org/data/aqueduct-floods-hazard-maps (Accessed: 24 February 2022)

[117] The former scenario (RCP 4.5) is seen to be an optimistic future, reflecting considerable carbon mitigation by 2040 onwards. Whereas the latter (RCP 8.5) is essentially a pessimistic business-as-usual case (rising carbon emissions) with very little carbon mitigation taking place (thus, Earth's current global trajectory is closest to RCP 8.5). Four main return periods are also selected for assessment, including events equating to 1% annual probability (1-in-100-year), 0.4% annual probability (1-in-250-year), 0.2% annual probability (1-in-500-year), and the most extreme 0.01% annual probability (1-in-1000-year).

[118] Oughton, E.J. et al. (2022) 'Policy choices can help keep 4G and 5G universal broadband affordable', Technological Forecasting and Social Change, 176, p. 121409. Available at: https://doi.org/10.1016/j.techfore.2021.121409.