Epidemiological modelling for public health decision making in sub-Saharan Africa

A strategic plan for capacity strengthening

Sheetal Silal, Craig Bardsley, Radhika Menon, Leyla Abdullahi, and Lisa White

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Oxford Policy Management Limited
Registered in England: 3122495

Level 3, Clarendon House
52 Cornmarket Street
Oxford, OX1 3HJ
United Kingdom

Tel: +44 (0) 1865 207 300
Fax: +44 (0) 1865 207 301
Email: admin@opml.co.uk
Website: www.opml.co.uk
Twitter: @OPMglobal
Facebook: @OPMglobal
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Executive summary

The COVID-19 pandemic raised global awareness of disease modelling among policymakers and the general public. Models were used to inform public health decisions that profoundly affected the lives of billions of people worldwide. The pandemic also highlighted substantial differences in the capacity to conduct disease modelling between countries, and particularly the apparent lack of such capacity in many low- and middle-income countries (LMICs).

In response to this, significant efforts were made by research organisations in high-income countries (HICs) to provide modelling results relevant to LMICs. However, data limitations and the generalised nature of globally produced models weakened their utility and raised concerns over their accuracy. The availability of high-quality modelling evidence to inform decisions and the capacity of policymakers to use this evidence is therefore critically important. Additionally, modelling expertise is not only of value in epidemic contexts, but can play an important role in the management of endemic disease.

This report explores what is required to strengthen national level modelling capacity in sub-Saharan Africa (SSA) to improve the capacity of countries to respond to future epidemics and to enable them to tackle endemic disease burdens more effectively. Here, modelling capacity is understood to include the capacity of local researchers to generate models, the capacity of policymakers to use them for decision making, and the effectiveness of communication and collaboration between these two communities. The report presents case studies on three African countries: South Africa, Kenya and Ghana. These studies reveal different levels of modelling capacity and different barriers and constraints, but also common themes and priorities.

We draw together the findings from these case studies to construct a conceptual framework that can be used to further develop capacity strengthening strategies. This framework emphasises several factors:

- capacity strengthening efforts should begin with a detailed analysis of current circumstances across the research–policy ecosystem;
- capacity strengthening should involve a coordinated package of interventions, potentially requiring collaboration between multiple funding organisations that aim to achieve a sustainable shift in the national research–policy ecosystem; and
- these packages of interventions will usually need to target multiple levels, including individual skills and organisational capabilities, as well as the connectiveness and coherence of the research–policy ecosystem.

The final section of the report and its annex provide details on a range of interventions that could be included in such an approach. They are analysed in terms of their relative scope, depth, and sustainability. While we cannot provide detailed guidance of exactly what interventions should be applied in any particular context, our report aims to enable funding agencies and other stakeholders to coordinate the design and implementation of interventions in a way that will generate sustainable systemic strengthening of national capacity in SSA.

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List of abbreviations

CDC	Centers for Disease Control and Prevention
CHAI	Clinton Health Access Initiative
CIDER	Centre for Infectious Disease Epidemiology and Research
CoMo	COVID-19 International Modelling
DSI-NRF	Department for Science and Innovation National Research Foundation
FCDO	UK Foreign, Commonwealth and Development Office
GHS	Ghana Health Service
GSS	Ghana Statistical Service
HIC	High-Income Country
KEMRI	Kenya Medical Research Institute
LMIC	Low- and Middle-Income Country
MASHA	Modelling and Simulation Hub Africa
MoH	Ministry of Health
NHLS	National Health Laboratory Service
NICD	National Institute for Communicable Diseases
RSV	Respiratory Syncytial Virus
SADC	Southern African Development Community
SACEMA	South African Centre of Excellence in Epidemiological and Modelling Analysis
SACMC	South African COVID-19 Modelling Consortium
SEDI	Strengthening Evidence Use for Development Impact
SSA	Sub-Saharan Africa
USAID	United States Agency for International Development

1 Introduction: The importance of epidemiological modelling capacity for SSA

1.1 Context

The COVID-19 pandemic raised global awareness of disease modelling among policymakers and the general public, as mathematical disease models were used to inform public health decisions that profoundly affected the lives of billions of people worldwide. The pandemic also highlighted substantial differences in capacity to conduct disease modelling between countries, and particularly the apparent lack of such capacity in many LMICs.

In response to this, significant efforts have been made by research organisations in HICs to provide modelling results relevant to LMICs. For example, Imperial College London's Medical Research Council Centre for Global Infectious Disease Analysis has produced a dashboard to provide scenarios of how healthcare demands are likely to vary over the next 28 days[1] for most LMIC countries, including all countries in SSA. To produce these scenarios, the Imperial College team used a Susceptible–Exposed–Infected–Recovered model that integrated country-specific demographics and patterns of contact data. However, given the absence of some data from many countries, representative estimates are used for numerous data points such as household size, age of members of each household, and contact patterns.[2] Packages of interventions tailored to each country are impossible to include in such a platform because the information required to create potential future intervention options that are culturally appropriate and economically viable would be impossible to obtain each month without direct communication with policymakers and experts in-country.

During an epidemic, public health decisions can save (or cost) tens of thousands of lives, and the economic impacts resulting from the disease and the response to it can be measured in many billions of dollars. Given the importance of these decisions, a high priority should be placed on building the capacity to ensure they are informed by robust, context-specific and timely modelling evidence. Data limitations and the generalised nature of globally produced models weakens their utility and raises concerns over their accuracy. The availability of high-quality modelling evidence to inform decisions, and the capacity of policymakers to use this evidence, is therefore critically important. Additionally, modelling expertise is not only of value in epidemic contexts; it can also play an important role in the management of endemic disease.

1.2 Purpose of the report

This report provides a starting point for developing a strategy to strengthen capacity to conduct and use epidemiological models to inform public health decision making in SSA. It is

[1] https://mrc-ide.github.io/global-lmic-reports/.
[2] www.imperial.ac.uk/media/imperial-college/medicine/mrc-gida/2020-03-26-COVID19-Report-12.pdf.

important to stress from the outset that Africa is a highly heterogeneous region. This diversity is reflected in the existing capacity in epidemiological modelling in countries across the region. It is also reflected in the pertinent questions that modelling may address. Such heterogeneities in the supply of, and demand for, mathematical modelling underline the need for modelling capacity to be developed in a context-dependent fashion to achieve meaningful impacts on policymaking. If meaningful capacity building in epidemiological modelling can be delivered, the potential benefits in terms of efficiency gains and the number of lives saved are huge.

As the global demand for health data and analytic skills continues to rise, with established HIC institutions struggling to recruit talent, the supply of modelling capacity from HIC settings to work on SSA questions could drop and/or increase in cost. In anticipation of this risk, coupled with the need for context-specific epidemiological modelling, it is important to build regional capacity now.

Compared with many other scientific disciplines, mathematical modelling does not require significant capital investment in laboratories or equipment. Therefore, the majority share of the investment in building modelling capacity will be in the training, mentoring, and development of national talent, accompanied by some structural reform to ensure policy and research systems are able to use and sustain that talent. Given the potentially huge efficiency and cost savings resulting from the activity of policy-facing modelling capacity in a country, the return on investment could be very large and rapid compared to capacity building in other science, technology, engineering, and mathematics fields. Policy-facing epidemiological modelling is an interdisciplinary activity and can act as a catalyst to bring multiple scientific and policymaking partners together, especially in response to an urgent health challenge. Building capacity in epidemiological modelling in SSA may therefore act as an early step in the development of all scientific capacity in the region by demonstrating the rapid benefits of capacity building, while creating bridges between science and policy.

This report explores the challenges associated with strengthening capacity for epidemiological modelling in SSA and recommends actions to address them. Since the specific needs and opportunities vary substantially depending on context, we take a case study approach that examines the circumstances in three different SSA countries: South Africa, Ghana, and Kenya. These case studies illustrate contexts with different levels of existing capacity for epidemiological modelling and enable the report to build a general framework for capacity strengthening. However, they should not be interpreted as representative of any other countries. Any programme of interventions in a different LMIC country, in Africa or elsewhere, should be prefaced by a detailed landscape analysis of the specific context where interventions may take place.

The insights provided by these case studies are then used to construct a conceptual model to structure the development, implementation and monitoring of interventions intended to strengthen capacity. This framework outlines several stages that characterise the development of modelling capacity and introduces three categories of intervention that might be implemented. The framework emphasises that the focus of interventions should be on strengthening the overall system towards sustainable increased capacity; in most cases, this will require packages of interventions targeting different stakeholders in a complementary fashion.

The final section provides further detail on the various types of intervention, which are presented in detail in Annex A. While this report does not provide detailed guidance of exactly what intervention should be applied in any particular context, it aims to enable funding agencies and other stakeholders to coordinate the design and implementation of interventions in a way that will generate sustainable systemic strengthening of national capacity in SSA to generate mathematical models of epidemic and endemic disease, and to use them effectively to inform public health decision making.

2 Background: An introduction to the methods and uses for mathematical disease modelling

Epidemiological modelling covers a spectrum of techniques aimed at understanding the way that diseases spread and, more importantly, how they may be controlled. Techniques include statistical modelling, mathematical modelling, and economic modelling.

- **Statistical modelling** is data-driven and is used to understand the trends and patterns in data. It can be used for nowcasting and forecasting to predict the current epidemiology and where it might be in the next few weeks. Statistical modelling may also be used to estimate the efficacy and effectiveness of current treatment and prevention measures.
- **Mathematical modelling** uses mathematical language to describe the underlying biological and behavioural drivers of disease transmission. Mathematical models, once validated against historical data, can be used as tools for scenario analysis. Scenario analysis provides evidence to support policymaking, allowing the exploration and comparison of options for interventions against a disease to support decisions aimed at controlling that disease.
- **Health economic models** are used primarily to explore the potential costs and benefits of health interventions.

These techniques, if done in concert and as part of an interdisciplinary response to pragmatic questions from policymakers, can be extremely powerful tools to support a country's fight against disease. To become adept in any of these three fields requires years of study and practical experience. Before beginning that study, knowledge of mathematics (advanced calculus, ordinary and partial differential equations, linear algebra, equilibrium analysis, and dynamical systems), statistics (linear and nonlinear regression, frequentist and Bayesian inference, survival analysis, clinical trial data analysis, and data visualisation and processing), operations research (linear and integer programming, system dynamics, and simulation), and scientific programming (in languages such as R, C, and python) are a prerequisite. Once technical knowledge is gained, to achieve policy impact, extensive experience and training in the contextualisation of technical work is required, including translational science and communication, foundational knowledge of a range of global health topics (Malaria, HIV, Tuberculosis, maternal and child health, neglected tropical diseases, diagnostics, treatments, and vaccines), and contextualisation of the modelling output in terms of financing and Investment Case development.

Initiatives are emerging in multiple countries around the world, including LMICs, such as Thailand's Mathematical and Economic Modelling group and South Africa's Modelling And Simulation Hub Africa (MASHA). These groups routinely contribute to national and international policymaking due to their unique perspectives as national leaders in their field, and as such their impact is rapid and direct. In response to the COVID-19 pandemic, the COVID-19 International Modelling (CoMo) Consortium was set up. The CoMo Consortium members span 50 countries across five continents, with each national team working directly with senior policy partners to provide strategic support to address the COVID-19 situation in

their countries. A key feature of the CoMo Consortium is to acknowledge that each country has a unique and constantly changing combination of epidemiological, economic, logistical, and cultural conditions, and thus requires bespoke strategies over time. The COVID-19 pandemic also highlighted the need for such groups and skills to arise locally to support policy and decision making in countries in Africa.

3 Case study methodology

The next three sections present the findings of three case studies: Ghana, Kenya, and South Africa. These countries were selected because initial scoping work by the project team suggested they would allow us to explore regional variation across Africa and different levels of existing capacity and experience with generating and using mathematical disease modelling to inform decision making. It was essential to select countries that had some experience of aiming to use models to support decision making. However, the case studies should not be viewed as representative of other countries in their region or at a particular capacity level. As will be discussed in later sections of this report, each national context should be understood on its own terms prior to developing capacity strengthening policies or interventions. The aim of each case study is to describe the current extent to which epidemiological modelling is conducted in-country and informs public health decision making, as well as the barriers and constraints which prevent this from working more effectively. We have also collected views on the types of intervention that would be most effective in addressing these constraints.

The primary source of information for these case studies was key informant interviews with relevant stakeholders. To identify stakeholders, the team first identified the categories of stakeholder required to provide a variety of perspectives on the subject, ranging from key policymakers to early career researchers. Suitable individuals within these categories were identified through a combination of the project team's existing networks, internet research, and recommendations from other identified informants. The interviews were supplemented by a review of literature identified through internet searches or recommended by interviewees and other stakeholder contacts.

A template questionnaire was circulated to guide interviews, but the objectives and approach for the study were discussed extensively among team members prior to the commencement of interviews. Consequently, team members were given considerable latitude to deviate from the interview structure in pursuit of the overall objectives of the study. Likewise, a template was prepared for the case study drafts, but individual authors were instructed to deviate from this if they felt it appropriate to effectively convey the information provided by interviewees.

4 Case study: South Africa

4.1 Context

South Africa is often recognised as a leading nation in SSA in terms of general scientific research capacity and is home to several globally competitive research universities. This is reflected in the country's capacity to generate and use mathematical diseases models, which is more advanced than in any other country in SSA. The South African case study is useful in the context of this report for several reasons: as an example of what other SSA countries could aim to establish, as a resource and partner for capacity strengthening efforts elsewhere, and as an illustration of the challenges that still remain in a relatively high-capacity environment.

Within South Africa's National Department of Health, mathematical disease modelling has in the last decade provided a new and fresh way of making decisions as an improvement over what would traditionally have been based on historical assessment.

Resource mobilisation is a prime example where model scenarios estimate the impact and cost of intervention packages, providing useful measures for advocacy such as return on investment. Modelling has played an important role in supporting budgeting decisions in South Africa. The Investment Case methodology in particular has proven useful through providing scenarios that demonstrate impact and cost and an optimal mix of policy interventions.

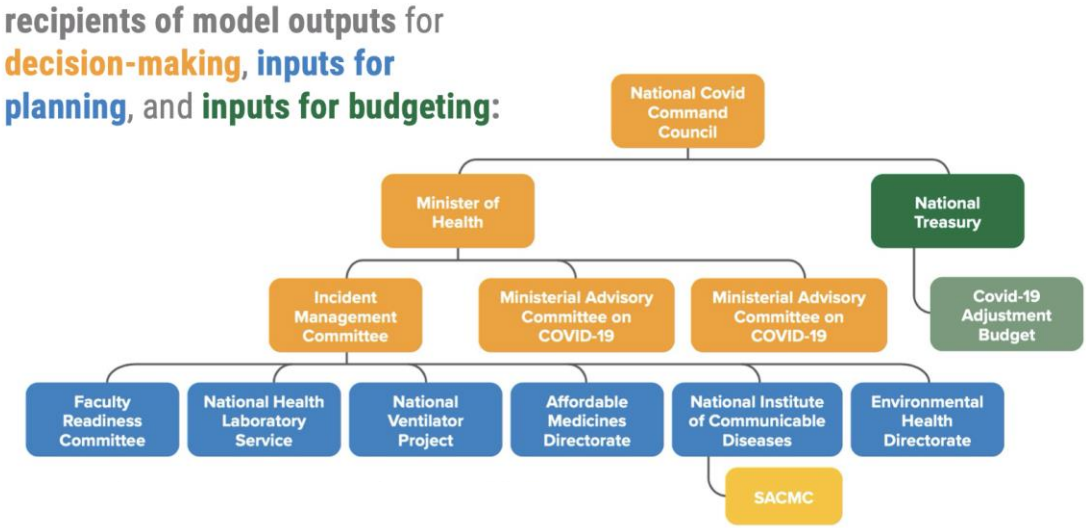
The modelling evidence generated to support government has traditionally been developed within South Africa, and it is from this base capacity that the South African COVID-19 Modelling Consortium (SACMC) was formed in March 2020, commissioned by government and coordinated by the National Institute for Communicable Diseases (NICD). To investigate the capacity of the modelling landscape in South Africa, a series of seven interviews were conducted with key stakeholders of generators and users of modelling evidence, including representatives from the National Department of Health, the National Treasury, the Bill & Melinda Gates Foundation, and the Clinton Health Access Initiative (CHAI), as well as early career and established disease modellers from the Department for Science and Innovation National Research Foundation (DSI-NRF), the South African Centre of Excellence in Epidemiological Modelling and Analysis (SACEMA), MASHA, the Centre for Infectious Disease and Epidemiology Research (CIDER), and higher education institutions in South Africa. While some interviews were conducted on an individual basis, others were conducted as focus group discussions.

4.2 Public health decision making context and awareness and the use of epi modelling to inform decision making

The National Department of Health in South Africa is responsible for public policy and implementation across the health spectrum. During the COVID-19 pandemic, public health and social measures were imposed through the declaration of a national state of disaster under the Disaster Management Act (Act 57 of 2002), by which the Minister of Co-operative

Governance and Traditional Affairs was responsible for suspending and reintroducing their operation as required (South African Government, 2022). The National Coronavirus Command Council was formed and added to the President's Coordinating Council and Cabinet as a structure for scientific evidence and submissions by different economic, health, and social sectors to inform executive decision making. SACMC reported directly to the Minister of Health and supporting officials across various government departments (**Figure 1**).

Figure 1: Recipients of modelling evidence in South Africa during the COVID-19 pandemic



Source: Silal *et al*., 2021

Even before the COVID-19 pandemic there was an appetite for including mathematical disease modelling in decision making for health outside pandemic settings, with successful use cases of modelling by government. The HIV Investment Case in 2016 was instrumental in shaping policy, partly due to the large monetary costs associated with the policy decision, and demonstrated an increasing willingness over time to rely on models to inform resource allocation. The Malaria Investment Case that followed a few years later reinforced the role of modelling in strategy design.

The ability of modelling to influence policy has not been constant over time and has changed with the government's attitude towards science. At the peak of the HIV crisis in South Africa, modelling was rejected and discredited as it was in direct contrast to government policy at the time. However, the change of government and funding of the HIV Investment Case saw cost-effective strategies for preventing and treating HIV being implemented as a direct result of modelling.

The COVID-19 pandemic has helped highlight the value of modelling for decision makers in South Africa. It has also helped them developed a better understanding of the limitations of models and increased their willingness to engage with them. One government official said:

> '*From government's perspective, modelling has provided a new way of thinking. … (in the past) decisions have been made on the spur of the moment, looking*

> *historically rather than forward looking. Modelling has brought a fresh new way for government to make decisions.*'

The COVID-19 pandemic has stimulated the appetite for modelling in government, ranging from traditional scenario analysis to technical analyses of data. A senior modeller put forward the following idea:

> '*The success of modelling in policy relies on the circumstantial confluence of factors: (1) support for modelling evidence in government; (2) a senior champion in government literate in the value of modelling to facilitate the process; (3) established modelling partners with a history/track record of working with government and the capacity and skill to provide modelling evidence; and (4) a funded project to enable the modelling. Increased dialogue between modellers and policymakers can result in direct response to the needs of government, and awareness of the benefits and usefulness of modelling. Consequently, modelling will not be a sought-after tool during crises only, but in general support of the health system.*'

The role of modelling changed over the course of the pandemic. It was very important to provide some projections during the early epidemic in the face of huge uncertainty. Early models were presented to senior decision makers; after the formation of SACMC, modelling projections were instrumental in informing appropriate policy relating to COVID-19 restrictions.

Policymakers in South Africa have always appreciated that models are not crystal balls, and affirmed that projections and recommendations were not statements of fact. They were prepared to accept that, as information changed, models would change too. Some government partners felt that the modelling that was provided, owing to a lack of evidence, did not contain enough policy options or levers to sufficiently inform policy and budgets. However, despite deviations between model projections and what actually transpired, the models provided a reference and bounding assumption on which to base decisions. A government official acknowledged that, while decisions themselves were considerably politically motivated, epidemiological modelling would have benefited from the incorporation of macroeconomic considerations to guide policy on balancing health and livelihoods. They particularly emphasised the critical importance of transparency and openness and of reporting without prejudice.

For emergencies like COVID-19, the model projections supported decision making across several government departments. The key findings from the models communicated to national stakeholders did not always filter down to decision makers at the implementing level, highlighting the importance of established, multi-level channels of communication. The path to impact in government is considerably accelerated with the presence of a modelling champion to facilitate and disseminate modelling output throughout government.

Similarly, the role of evidence brokers such as CHAI provides the perspective of a facilitator, who uses modelling evidence in subsequent analysis to pass on the relationship between the modeller and government to government or to brokers. From the evidence broker perspective, the primary advantage of modelling during the COVID-19 pandemic was to provide projections of a level of sophistication to support decision making for which there would ordinarily have been no backing evidence. Both epidemiological and economic

models were useful in this regard, particularly at the start of the pandemic when key procurement decisions and budget allocations were being made. Not all key decisions that should have been supported by modelling were, and the decentralised nature of governance in South Africa meant that the information gleaned from modelling evidence presented to national bodies did not automatically filter through to provincial government. Similarly, modelling evidence was useful for those governmental bodies that were high-performing. However, in low-capacity situations where decision makers are overwhelmed without the latitude to absorb modelling evidence, it is likely that modelling would be perceived as unnecessary. Herein lies the importance of data/evidence brokers who have established relationships with these decision makers and can facilitate the adoption of modelling evidence into policy and implementation at the appropriate levels.

In exploring the role of modelling in the decision making process, a view emerged among modellers that modelling is complex to understand and communicate and that decision makers are not always equipped to understand modelling, while modellers lack the ability to communicate their science effectively. They felt that communication with decision makers with respect to requirements and how modelling can be useful faded over the course of the pandemic. This often resulted in requests for modelling projects that were not possible or realistic. Had this space and engagement been maintained better, it would have been a source of decision maker literacy and would have helped guide the work of the modellers. Over time, as decision makers had more access to information on COVID-19 and gained more experience, they began to rely less on modelling.

The modellers concluded that the success of modelling should not be judged on whether recommendations were incorporated into policy, but rather on their being incorporated as one of the many components in a mix of multiple evidence considerations and non-evidence considerations (political pressures and influences) in the decision making process.

4.3 Key stakeholders in epidemiological modelling

The National Health Research Committee has set research priorities to ensure that health research agendas and research resources focus on priority health problems. These priority areas were determined based on the burden of disease, the cost-effectiveness of interventions aimed at decreasing this burden, the availability of human and institutional resources to implement interventions, and the health needs of the vulnerable and of communities (South African National Department of Health, 2021). Mathematical disease modelling is, and has been, used to support research in these priority areas.

The generation of modelling evidence, from the development of modelling capacity through to the communication of model output, depends on and is facilitated by key stakeholders throughout the modelling ecosystem. From the perspective of training and capacity building, these stakeholders include higher education institutions as the primary source of training and subsequent employment for modellers; the DSI-NRF as the main source of funding for postgraduate students; and established disease modelling units such as the DSI-NRF SACEMA, MASHA, and CIDER, as these organisations provide the chief route for training and mentorship in modelling for policy. From the perspective of users and benefactors of modelling, the primary stakeholders are the National and Provincial Departments of Health, the NICD, the National Health Laboratory Service (NHLS), and other government and

government-adjacent organisations that receive modelling evidence. The NICD and NHLS play particularly key roles in enabling modelling as they provide the means to routinely access data. Funders – such as the Bill & Melinda Gates Foundation; the Global Fund to fight Aids, Tuberculosis and Malaria; the Department of Science and Innovation; and other overseas development assistance partners – play a key role in enabling modelling and in supporting the salaried time of the modellers.

Modelling training is currently being provided at different levels through modelling units based in higher education institutions. The principal institutions that offer training in mathematical disease modelling in South Africa are:

- the DSI-NRF SACEMA at the University of Stellenbosch;
- MASHA at the University of Cape Town; and
- CIDER at the University of Cape Town.

These three units are globally competitive and have a long history of modelling to support policy (MASHA and CIDER) and carrying out research on priority diseases (SACEMA). These units often work with collaborators in other local institutions, such as the Health Economics and Epidemiology Research Unit at the University of the Witwatersrand, and with global collaborators on global health issues. They stand ready to support the national government during health emergencies, and the existing track record of each group enabled the rapid formation of SACMC at the start of the pandemic. Mathematical disease modelling capacity may exist at other higher education institutions at the individual level. The African Institute for Mathematical Sciences plays a role in providing an introduction to modelling and produces students who are strong candidates for entry into Masters programmes, but there is as yet no established postgraduate training programme in South Africa.

Despite having rich modelling capacity, both early career and senior modellers felt that South Africa was still far from where it should be in terms of providing training and developing capacity in the country and on the continent.

4.4 Data infrastructure and access

Modellers felt that South Africa has high-quality datasets for analysis in general, but while processes do exist to access the data from institutions like the NICD and the NHLS, they are often time-consuming and require the trust of the data holders. During the COVID-19 epidemic, the National Department of Health was the primary source of data, the use of which was mediated by the NICD. Thus, the process for accessing data had different requirements compared to obtaining access during non-emergency situations. While South Africa has established systems for collecting and maintaining datasets such as District Health Information Software 2.0, data managers felt that the pandemic revealed substantial weaknesses in the data environment. With the rush to develop data systems at the start of the pandemic, it was quickly realised that background data systems were not sufficient to support required data. Outbreaks require the collection of different types of dataset, including laboratory data, hospital data, mortality data, research data (such as genomic surveillance), and seroprevalence data. Each of data type requires a different system, and the lack of integration is a massive obstacle. Additional issues include fragmentation of data,

where data quality and availability are not the same in different sub-national areas. Other sources of data, such as contact behaviour data, are completely lacking.

Openness to sharing data and providing access to it were a challenge during the pandemic. Early in the pandemic, there were severe restrictions on the ability to share data with the research community and private sector who could use it productively. While this eased over time, there remained sensitivity, with the National Department of Health wanting to be perceived as the only authoritative source of evidence on the pandemic.

There are many improvements that can be made in the process of accessing and using data for modelling. The process for accessing data is generally well defined, though data requests are more likely to be approved where a strong connection exists with the data-owning institution, and when the researcher is known to the institution. Reputation plays a major role in enabling rapid access to data where it is available. Turnaround times to provide access to data are also incredibly slow.

The role of trust and the track record of a researcher are important factors that influence access to data. Early career researchers who are not based in institutions with such capacity, or who do not have access to mentorship from a senior modeller, therefore find it very challenging to access data and navigate the processes around them.

The country's data systems are not ideal in other ways. In some cases, rich datasets are available but there are insufficient staff to fulfil data requests, or the data are in an unusable format. The notion of helicopter researchers from the Global North was raised by modellers, where datasets were removed from local country access, prohibiting local analysis. It was pointed out several times that building capacity does not mean flying in a smart person from the Global North to do the required job. Governments should be funded directly to support a long-term local hire, who will then be retained post-funding. It was pointed out by data brokers that the funding of lower-level positions, such as interns, should also be done through mechanisms such as secondments from higher education institutions, with the purpose of attracting these skills into government and raising the median level of quantitative skills.

In an epidemic situation, timeliness and responsiveness are fundamental. Interviewees also pointed to the necessity of having the ability to bring in multiple stakeholders to enable the provision of modelling evidence.

4.5 Key constraints and opportunities for capacity strengthening

It is important to contextualise the challenge of increasing postgraduate study in science, technology, engineering, mathematics, and other subjects in South Africa within the country's history of social, political, and economic inequality. There are barriers to entry into tertiary education, and for the small percentage of students who acquire tertiary qualifications, many are employed by the private sector instead of continuing with postgraduate study. The economic and historical disadvantage of racial groups in South Africa has led to a situation where postgraduate study is reserved for those wealthy enough to afford it, or those fortunate enough to obtain a bursary. However, many students forsake bursaries in favour of better-paying private sector employment to meet their financial needs.

As a result, the demand for postgraduate study, let alone disease modelling, is often lacking. Innovation is required to harness this talent and direct it towards scientific study.

There is no degree in modelling where disease modelling can be taught as the primary focus. Therefore, formal training is provided with a focus on applied mathematics, statistics, or public health. Formal training is not considered adequate for becoming a modeller. Capacity building in modelling requires mentorship in practice. This is currently provided through supervision at modelling institutions. Outside these institutions, the insular nature of the departments within universities often prevents knowledge sharing and prohibits the holistic study of modelling, which is inherently interdisciplinary.

Opportunities for investment were identified by all stakeholders and can be generally classified into training, employment, environment, data systems, and funding.

Training

Training interventions could encompass a wide range of different activities. These would include:

- Competitive postgraduate and postdoctoral scholarships for students to higher education institutions in the fields of epidemiology, modelling, mathematics, and statistics.
- Secondments of early career or trainee modellers to government departments to provide trainees with first-hand experience of working within government priorities and constraints. Both early career and senior modellers felt that one of the best ways of training modellers is through active mentorship and allowing trainees to observe modelling for policy. While some mentorship is ongoing, the current pool of established modellers who act as mentors is small.
- Project funding for ‘blue skies’ research outside the immediate needs of government to further science, thereby growing the field. Funders cautioned that, while this element of modelling was critical, there is likely to be less appetite for it from government.
- Workshops to increase government literacy and familiarity with modelling. In performing modelling for government, funders felt that a participatory approach should be followed, acknowledging the need to empower the customer and take the customer along the journey.
- Investing in regional modelling capacity and networking through bodies such as Africa Centers for Disease Control and Prevention (CDC) and the Southern African Development Community (SADC) will help meet the demand for modelling on the continent and stimulate interest and demand from other countries in the region. It is likely that demand for modelling will increase as the continent develops. Though suggested by the modellers, this view was additionally emphasised by the funders who, recognising previous mistakes the importance of co-creating models with government. supported investment in the continent and stopping of ‘parachute modelling’.

Key constraints to the success of these training interventions for students include bursaries/scholarships that are inadequate to meet living expenses, as universities place limit on scholarships to meet tax requirements, resulting in low-value scholarships. The demanding nature of government jobs can also limit the value of workshops, though this can be mitigated by identifying champions to capacitate. Secondments are training opportunities

with multiple positive externalities for the student, the higher education institution, and government, and so need to be managed carefully.

Employment

Capacity building to develop a cohort of disease modellers has the desired impact only if employment opportunities are created simultaneously. Even with the large number of higher education institutions and research organisations in South Africa, the number of positions to absorb disease modellers remains limited. Novel opportunities for employing modellers in government, higher education institutions, or other non-traditional avenues need to be created.

Environment

- Early career modellers felt that local workshops/conferences of established local researchers, students, and stakeholders in modelling and policy would facilitate networking and the establishment of local modelling communities.
- Data brokers suggested that investing in administrative capacity to facilitate networking, secondments, and coordination between institutions would accelerate the exposure of modelling locally and across the continent.
- One senior modeller felt that ‘Providing training in soft but adjacent skills to modelling such as leadership, grant-writing, and scientific communication would advance modelling careers beyond technical training.’
- Senior modellers suggested that, with several institutions having the capacity to provide agile and comprehensive model-based support to government, establishing a coordinating entity might simplify the modelling-to-evidence pipeline. Inspired by the success of SACMC, such an entity could provide a forum to connect researchers in, and adjacent to, modelling under a single umbrella (demographers, modellers, statisticians, and economists). Such an entity would additionally provide robust training for students, as well as opportunities for collaboration and mentorship, thereby providing a realistic source of employment and facilitating secondments in government and support for early career researchers. This idea was additionally supported by government and funding representatives.
- Early career modellers suggested developing a repository of resources for modelling to provide information on key datasets required, such as population data, spatial files, survey data, etc. This would alleviate several barriers to entry for trainee modellers.

Data systems

During the South African epidemic, funding was not the primary constraint in establishing data systems. The primary constraint was standing capacity at data institutions to provide what was needed in a timely manner. Long-term funding is required to build up the standing capacity in these institutions to preserve institutional knowledge and enable an agile response in the future. This requires maintaining a critical level of internal capacity at all times. Both early career modellers and those who work in data access suggested that transparency, openness, and access to data processes need to be reconsidered in South

Africa. The current social network/trust-based approach enables access but is not equitable, and certainly not accessible without a senior champion.

Funding

Funders did not play a key role in enabling modelling during the early stages of the pandemic, when researchers shifted resources or performed voluntary work to aid national government. However, rapid funding can enable the incorporation of capacity and the removal of obstacles. It contributed to funding modeller's time on COVID-19 support to government in subsequent waves. There were nevertheless several opportunities identified by the funder interviewed for a paradigm shift in the long-term funding pipeline, as follows:

- There is a need to migrate investing access from the Global North to the Global South. In particular, there is a need to stop 'fronting' and 'window dressing', where African institutions are considered the recipients of grant funding, but the majority of funds are moved to northern institutions.
- There should be a shift from a short-term to a long-term outcome focus. This will support the establishment of a pipeline to enable modelling capacity.
- There should be an acknowledgement that capacity strengthening is long-term process. Funders should encourage collaboration between modellers, as diversification rests on the shoulders of the funders. It may well be the case that good capacity exists in less advantaged universities, but this talent also needs to be nurtured.
- Capacity development may be accelerated with leveraged funding for modelling. Examples include co-funding a percentage of a modeller's effort with government to allow short-term grants to become long-term grants. This additionally supports the idea of participatory modelling and the co-creation of research.
- There is a tendency for donor agencies to focus on their own agendas rather than on collaborating with other donors. An opportunity exists for mechanisms to be created to co-fund capacity building, thereby supporting the long-term goals of capacity building while simultaneously alleviating the administrative burden on governments of engaging with multiple institutions.

While modelling in the rest of Africa is dominated by northern institutions, nurturing capacity for modelling in South Africa has its own challenges, including the historical disadvantage of large groups of the population, inequality in access to postgraduate study, and relying on loans and family commitments that force students to enter the higher-paying corporate workforce.

Institutions in the Global South have a narrower space to operate compared to the Global North. With a primary focus on teaching, institutions have a very low core capacity for support. In Africa, the ability to fill and ride over the funding gaps between short-term projects is limited. This results in greater job insecurity and wasted effort in terms of hiring new staff at the start of each project. Short-term surge or project funding creates instability where institutions cannot employ or develop staff with certainty, resulting in high turnover and reduced development of institutional knowledge.

Pandemics may manifest differently in the future, but the data systems to record them will be similar. A review of the national data landscape is required to enable a unique health

identifier to link datasets across the health system. A pool of local researchers needs to be developed to work with these data systems. While the problem is systemic, in a country with vast socio-economic inequalities, interventions need to be broad reaching from the school system to higher education institutions.

5 Case study: Kenya

5.1 Context

Mathematical modelling has been used in Kenya for over 20 years in the area of malaria. With the onset of COVID-19, epidemiological models became an important tool in the country to understand the transmission dynamics of the disease. The government recognised that, to successfully manage the pandemic, it needed to understand how the virus that causes the disease is transmitted and whether mitigation measures are effective.

For example, during COVID-19 pandemic, the Kenyan government continued to use data-driven models to predict cases of COVID-19 and implement policies to combat COVID-19 in the community and within the health system (Nanyingi, 2020). To develop the Kenya case study, we interviewed modellers from the Kenya Medical Research Institute (KEMRI)–Wellcome Trust research programme; Africa CDC; the Ministry of Health (MoH); and Strathmore University in Kenya.

This case study shows that the successful use of modelling to inform decision making depends on several factors, including policymakers' understanding of models, modellers' understanding of policymaker priorities, available funding opportunities, and local modelling capacity to ensure sustainability.

5.2 The use of epidemiological modelling to inform public health decision making in Kenya

At the outset of COVID-19, MoH was responsible for gathering data on COVID-19 cases. It established a committee that was made up of mathematical modellers, epidemiologists, national public health laboratory representatives, and policymakers to facilitate the use of modelling evidence in decision making. As the COVID-19 epidemic spread through Kenya, policymakers were uncertain about the effectiveness of interventions and required evidence to inform their decisions. For example, Kenya relied on global response and interventions, implemented interventions and measures recommended by the World Health Organization, and rolled out vaccination when vaccines became available. Modelling was used to make different kinds of predictions, including on the transmission of the virus, the effectiveness of community-based interventions, and the impact of vaccines (Wangari *et al*., 2021; Kairu *et al*., 2021).

COVID-19 made policymakers in Kenya more appreciative of modelling. MoH is the main decision maker on health in the country, and it relied heavily on local modellers for evidence. Modelling was also used to address related questions in other sectors. For example, the policymakers' questions on whether the schools should resume or whether restrictions should be lifted needed the use of modelling. According to interviewees, MoH actioned some decisions based on the modelling evidence. Although the business community approached MoH to relax restrictions that interfered with the functioning of businesses in the country, this was resisted. More restrictions were put in place based on the modelling evidence that showed the country was still at risk.

In seeking to use modelling evidence to support decision making, Kenya was confronted with weaknesses in its health data collection systems. An interviewee from MoH noted:

> '*During COVID-19, the actual number of infected patients differed from the number of reported cases. There are a number of factors [in] both [the] clinical and health system that led to missing data, to include but not limited to weaker surveillance systems, poor contact tracing and active case detection, [and] slow testing and clinical diagnosis.*'

Epidemiological modelling for other diseases

Over the last two decades and prior to the COVID-19 pandemic, mathematical modelling has been used to study malaria. Most notably, the KEMRI–Wellcome Trust research programme has examined how malaria parasite exposure affects disease outcomes. For example, epidemiological modelling has been applied to various questions:

- model bases statistics have been used in malaria studies to understand disease risks at a population level;
- point process models have been used to compute a continuous surface of risks to ascertain how the risk of malaria changes within different counties; and
- models using small area estimations have been used to predict insecticide treated net distribution and how many children have access to improved sanitation between counties.

Modelling has been used to examine intervention coverage or disease prevalence. Modelling data have been used, for example, in the stratification of malaria interventions based on how risk varies across the country. This has enabled the national malaria programme to provide targeted interventions.

Modelling has also been used to understand the transmission dynamics of respiratory syncytial virus (RSV) within the household between infants and other household members. It has also been used to understand the duration of RSV shedding.

5.3 Broader context of research capacity and evidence-informed policymaking

Overall, the use of evidence in health for decision making was considered very weak until the last decade when MoH started emphasising the need for more evidence. One of the main barriers identified in the translation of evidence for decision making is a lack of understanding among policymakers regarding how to use evidence. There is a capacity gap in generating and utilising evidence in the country at both an individual and institution level. Collaboration with institutions that champion the use of evidence for decision making, such as the African Institute for Development Policy, has enhanced both individual and institutional capacity within MoH on the use of evidence for decision making.

> '*MoH is collaborating with several organisations including KEMRI, the African Institute for Development Policy, and the University of Nairobi for improving the implementation of the national research strategy.*' – Interviewee from MoH

> '*KEMRI, with support from the African Institute for Development Policy, has started conducting evidence-informed decision making training for researchers, including policy brief writing. Funding constraints has meant that the same training has not been rolled out for policymakers.*' – Interviewee from KEMRI

5.4 Epidemiological modelling capacity in Kenya

Despite the pockets of excellence noted above, all interviewees believed that Kenya lacked sufficient capacity to generate and use epidemiological modelling. Currently, there are only a few groups working on modelling in Kenya. This includes the Wellcome Trust and Centre for Epidemiological Modelling and Analysis at the University of Nairobi. These institutions have been collaborating to support training courses on modelling through international grants for Masters and PhD programmes.

> '*Strathmore University and Jomo Kenyatta University are in the early phase of offering modelling training. The faculty of Strathmore University is currently considered a strong team and we are open to collaboration from potential modellers to strengthen the collaboration.*' – Interviewee from Strathmore University

There are few experts within the country who not only understand mathematical modelling but can also utilise evidence for decision making. These experts obtained advance training from abroad and have called for mass capacity building and mentorship among potential modellers in Kenya to increase the pool of experts. Our interviewee from MoH noted:

> '*There are only three experts who can utilise modelling evidence for decision making. Therefore, a lot more investments need to be made to build on the modelling capacity among policymakers, as they are the end users to the products for decision making*.
>
> *Some Kenyan modellers have had to move to other developed countries because there have been less modelling work happening in the country. Importantly, funding for mathematical modelling is limited in the country and getting opportunities to do mathematical modelling are fewer, forcing people to cross the borders*.'

Most of the modelling conducted in the country is supported by international organisations led by the Wellcome Trust in the UK. International funders have helped build local capacity to use epidemiological modelling and apply it to the local context.

> '*I was funded for my time by another institution in the UK for two years while I was supporting the ministry during COVID-19 pandemic. The [funded] training ensures trainees have the capacity to use the data around and translate the data into information that can be used for decision making.*' – Interviewee from MoH

While the appreciation of modelling has increased during the global pandemic, given that much of Kenya's capacity is externally funded, this may not be sustained.

> '*KEMRI in Nairobi has the potential to build capacity in modelling, given that they are currently developing a new Centre for Data Science. The institute also runs a school for post graduate studies and has a strong faculty.*' – Interviewee from KEMRI

5.5 Data infrastructure and access

The essential value of data-driven policymaking has been emphasised by COVID-19. Good data are key to the development of contextually appropriate mitigation measures. MoH has a database on disease prevalence and severity that was applied during the pandemic to address different issues / assess different aspects, such as virus circulation prediction, community intervention effect, and vaccine impact? These data are provided by KEMRI and fed into the MoH database. However, an interviewee from KEMRI reported:

> '*There is very little capacity to use this data for carrying out epidemiological modelling work because most modelling teams, apart from the KEMRI–Wellcome Trust, are just starting out.*'

The generation of high-quality data was considered a challenge as the government does not have many professionally trained statisticians. Accessing data is a challenge because of institutional bureaucracies.

5.6 Analysis of key constraints and opportunities for capacity strengthening

The COVID-19 pandemic has highlighted the weaknesses in the modelling capacities in the country. Several constraints were identified, as follows.

Shortage of modellers

The limited scale of expertise, and its concentration in one or two institutions, generates real challenges for the use of modelling to inform decision making. One of the interviewees, a modeller in Kenya, said they were very short-staffed and could not answer many research questions through modelling within a short timeframe. The responses were therefore delayed. At some point the pressure was so high that they had to seek support from external players, including the University of Warwick.

According to interviewees, MoH had not put in much effort into pandemic preparedness, particularly in the area of epidemiological modelling. The interviewees believed MoH should train some of its staff on epidemiological modelling through expert institutions in preparation for a future pandemic

Insufficient knowledge to translate modelling evidence

Interviewees also reported constraints in communicating modelling findings to decision makers. Most of the modelling outputs needed to be synthesised and translated into plain language for policymakers to understand, as modelling is still a new subject for them. Where this was not done, policymakers found it challenging to understand the modelling evidence.

One interviewee, a local modeller, said:

> '*We had to package the information as simple as possible which was a challenge. … We had to rely on trust, there had to be some level of trust between the person who implements the science and the one using the science.*'

There were also some communication challenges with the media, who misinterpreted statements and results in their reportage to the public. For instance, one interviewee reported that some media outlets have picked up eye-catching statements and put out modelling results in the public domain without understanding the findings.

Interviewees offered several ideas to facilitate and sustain capacity development in the country among researchers and policymakers, as follows.

- Statistical research scientists and epidemiologists within the government and research institutes should be trained, championing mathematical modelling work. Government should fund some Masters and PhD training on modelling:

  '*The government should ensure that there is sustainability in responses by training a pool of researchers to be readily available in case of outbreaks.*' – Interviewee from MoH

- Decision makers could take some introductory courses to help give them a better understanding of modelling, and of how to interpret an epidemiological modelling finding and use it in decision making:

  '*There is a need to train the decision makers in a bit of modelling and be taught about interpretation of results.*' – Interviewee from MoH

- There is a need to train media personnel on how to report on modelling results:

  '*The media are the ones who publish these results to the common citizen, from the ministry or directly from the institutions. To some extent, capacity building around communicating epidemiological results should be strengthened to ensure our media personnel can boil it down.*' – Interviewee from Welcome Trust

- Modelling should be included in universities, and undergraduates should be introduced to modelling and its importance in problem solving:

  '*There needs to be a lot of work in interesting younger people studying mathematics in university to take up modelling roles and be trained on how to link up the maths they do in class to how it can be used on policymaking.*' – Interviewee from Strathmore University

Need for evidence-informed decision making

- Interviewees emphasised the need for evidence-informed decision making. This will enable the policymakers to understand the value of modelling:

  '*The push for evidence-based decisions is making modelling popular.*' – Interviewee from Strathmore University.

- There should be more opportunities for policymakers to engage with modellers and understand the modelling process so they appreciate its value.

Funding

- Most of the modellers are relying on funding opportunity from institutions from abroad. To sustain mass capacity building and mentorship, the government should factor in modelling activities during budgeting as an aspect of preparedness.

Data access and sharing policy

- Data access was also reported as a challenge given the data are owned and held by different research institutions. Interviewees highlighted the need for a central repository within MoH. In addition, the government should develop and implement a data sharing policy.

6 Case study: Ghana

6.1 Context

Ghana was one of the first countries in SSA to close its borders in late March 2020 following the onset of the COVID-19 pandemic. When Ghana recorded its first two COVID-19 cases in March 2020, the government quickly decided to impose a lockdown in Accra and Kumasi, restricted social gatherings and movement, and closed schools, workplaces, and places of worship (Assan *et al*., 2022). Although the government lifted the lockdown during its third week of implementation, it had a large economic impact, triggering job losses and business closures (Schotte *et al*., 2021).

It is not clear whether the government had any local evidence to draw on at the time of making these decisions; its actions appeared to follow the measures being taken in other countries globally. The use of epidemiological modelling to inform decisions related to lockdowns and intervention strategies in several countries across the world also sparked the interest of Ghanaian policymakers in developing an in-country epidemiological model.

In this case study, we look at how epidemiological modelling has been generated and used to inform decision making on COVID-19. We also try to understand what the key stakeholders think about the varied capacities required for conducting and using epidemiological modelling for infectious diseases. This includes generating quality and reliable data, making it accessible, identifying policy-relevant questions for carrying out mathematical modelling, and translating evidence into action. We explore who the key stakeholders are in this area and summarise the ideas offered on capacity development interventions that may be feasible and relevant in Ghana.

For this case study, we interviewed representatives from the Ghana Health Service (GHS), the Ghana Statistical Service (GSS), the UK Foreign, Commonwealth and Development Office (FCDO) Ghana, an early career modeller, and an experienced modeller in the country. Conversations with the GHS and GSS were carried out as group discussions with several officials. We were unable to get responses from MoH and from a modeller from the CoMo Consortium, despite repeated follow-up emails.

6.2 The use of epidemiological modelling evidence to support public health decision making in Ghana

Prior to COVID-19, epidemiological modelling in Ghana was carried out to a limited extent to examine the spread of infectious diseases such as Malaria and HIV. For HIV, agent-based, deterministic, and compartmental models have been used. The GSS has been working with the National Aids Control programme to draw on administrative and operational data to collect data on key HIV indicators for the SPECTRUM system developed by the Joint United Nations Programme on HIV/Aids. The system allows for the projection of trends in HIV prevalence and assessment of impacts.

Modelling on malaria has looked at mosquito population and human population dynamics and how they are linked. Modellers have, for instance, worked with the Malaria Control

programme to look at the impact of various interventions in the three geopolitical zones in the country. Drawing on data from the Noguchi Memorial Institute for Medical Research, they have undertaken modelling to look at the impact of different interventions (e.g. test kits, drugs, etc.) and provide evidence on how strategies could be calibrated for different regions.

The modellers we spoke to said that, while Ghanaian academics do write papers on mathematical modelling, these are often theoretical and rarely draw on data to look at practical applications for addressing real-world problems.

In line with the global trend, epidemiological modelling received more attention and interest in Ghana as a result of the COVID-19 pandemic. According to an interviewee who has been engaging with the government on response efforts, the Ghanaian government approached the Ghana Academy of Arts and Sciences to undertake some modelling work early on after the pandemic hit. MoH and the National Technical Coordination Committee for COVID-19 in the Presidency may have considered the results of this modelling exercise to make a decision on the lockdown and other restrictions. However, the scope and the quality of the work done remains unclear as the results were not published or made available to the public, said the interviewee.

The FCDO, through the Strengthening Evidence Use for Development Impact (SEDI) programme, decided to fund an epidemiological modelling project in July 2020. The project was led by the GHS and the University of Ghana in partnership with MoH and the CoMo Consortium. The stakeholders involved in the project were interested in developing an in-country mathematical model to guide the implementation of non-pharmaceutical interventions. However, it took considerable time to bring all the stakeholders together and build a partnership. Issues related to the ownership of the project and the lack of trust between partners affected participation and the timely release of data, which in turn stretched the timeline for the project completion. FCDO Ghana, supported by the SEDI team, had to play the role of the broker to get all the partners together on the table and convince them of the value of epidemiological modelling. Consequently, it took nearly a full year to produce reports from this project.

For the SEDI project, the team used a generic age-structured COVID-19 transmission model developed by the CoMo Consortium to examine the outbreak in Ghana. The project aimed to generate evidence to support the formulation of strategies that would mitigate the incidence of COVID-19. It examined the epidemiological trajectory of COVID-19 in Ghana between 12 March 2020 and 30 June 2021 and assessed the effectiveness of the control measures implemented during the period. The model estimates suggested that the interventions implemented by Ghana contributed to a significant reduction in disease mortality and transmission. The model also used scenarios to look at the impact of five separate interventions (handwashing, mask-wearing, social distancing, international travel bans, and vaccination).

The policymakers we interviewed said that the experience of working on the project was very useful in developing in-house capacity to work on a modelling exercise. However, the reports did not find much traction among decision makers because the results came very late. Vaccinations had begun and lockdown measures had been withdrawn by the time the reports were shared with decision makers. The results were therefore not seen as very relevant.

Apart from these efforts, Ghanaian academics have used mathematical models to examine the transmission dynamics of COVID-19 and the trajectory of the epidemic in the country (Dwomoh *et al*., 2021; Acheampong *et al*., 2021; Frempong *et al*., 2021; Barnes *et al*., 2022). The published papers have been authored by academics affiliated with departments of biostatistics, statistics, and mathematics. It is unclear if the evidence from these papers aided government decision making in any way.

6.3 Key stakeholders in epidemiological modelling and the public health decision making context

All the interviewees identified the GHS and MoH as the major decision makers and users of epidemiological modelling evidence. Specifically, key units within the government using the evidence were considered to be the Public Health Directorate and the Research and Development Division of the GHS, and the Policy, Planning, Budgeting, Monitoring and Evaluation Directorate in MoH. Most interviews agreed that both the GHS and MoH needed to be a part of any epidemiological modelling project. While MoH develops policies, GHS manages service delivery and owns the epidemiological data. In our conversation with the GHS, they expressed an interest in building their own modelling unit.

The GSS was named as a key stakeholder by a couple of interviewees. GSS had developed a concept paper for epidemiological modelling but has so far not been able to take it forward. FCDO Ghana has had some preliminary discussions with the Office of National Statistics in the UK to support the GSS in carrying out the kind of analysis that the Office of National Statistics does for the UK Government.

Representatives from all the government units named as key stakeholders have expressed an interest in developing their capacity in epidemiological modelling.

Interviewees named several universities and research organisations as entities that may have individuals with the skills to carry out modelling work. Universities with public health, biostatistics, and mathematics departments were considered key units. A few interviewees also named research centres dealing with infectious diseases at the community level. These field research units in Dodowa, Navrongo, and Kintampo carry out public health and biomedical research. They are affiliated to the GHS and serve as health and demographic surveillance centres that collect and own a lot of data.

FCDO Ghana was considered both a funder and an evidence broker in this area by a few interviewees. The FCDO has led on brokering relationships between government partners and academia, but has also been engaging with other development partners to assess their interest in this area. The United States Agency for International Development (USAID) and the World Bank have supported modelling on essential health services, but not on infectious disease outbreaks or pandemics. They are nevertheless interested in exploring what they could offer to health security. The World Bank announced an emergency package of US$ 100 million in April 2020 for supporting the Government of Ghana to help prevent, detect, and respond to the COVID-19 pandemic through the Ghana Emergency Preparedness and Response Project. This project was meant to strengthen Ghana’s National Laboratories by providing robust systems for the early detection of COVID-19 cases and providing real-time disease surveillance and reporting systems for outbreaks.

The Bill & Melinda Gates Foundation was also seen as a funder in this area, following their recent announcement of funding for capacity development in epidemiological modelling for malaria (US$ 3 million for three years, targeted at researchers and academics in African universities).

The Centre for Disease Control in Ghana was considered a stakeholder at a more operational level. One of the interviewees said they may have done some modelling work, but the results may not have been shared with the government or other development partners.

The World Health Organization was also named as a guiding agency in public health, and the GHS has had conversations with them about strengthening their epidemiological modelling capacity.

Table 1 lists the key stakeholders named by the interviewees.

6.4 Perception of capacity in epidemiological modelling in Ghana

We asked interviewees about their perception of the capacity to both generate and use epidemiological modelling evidence in Ghana. They were asked to consider the broad range of capacities required for epidemiological modelling. This included the capacity to generate and share high-quality data, carry out modelling that is policy-relevant, and engage with decision makers and users through the entire process.

Most interviewees agreed that the overall capacity to carry out epidemiological modelling is low in Ghana. This is in line with the findings of a recent scoping review, which looked at applied epidemiological models of infectious disease studies that involved first or last authors affiliated to African institutions (Adetokunboh *et al*., 2021). Ghana was found to be at the lower end of the spectrum, with just two peer-reviewed publications up to April 2020.

Table 1: Key stakeholders in epidemiological modelling in Ghana

Government	University or research institutions	Funders and coordination agencies
Public health directorate and research and development division in the university	School of Public Health in the University of Ghana	UK FCDO
Policy, planning, budgeting, monitoring, and evaluation division in MoH	University of Health and Allied Sciences	USAID
GSS	University of Development Studies	World Bank
	University of Cape Coast	Bill & Melinda Gates Foundation
	Ghana Academy of Arts and Sciences	World Health Organization
	CK Tedame University of Technology and Applied Sciences	Centre for Disease Control

Government	University or research institutions	Funders and coordination agencies
	Kwame Nkrumah University of Science and technology	
	Dodowa Health Research Centre	
	Navrongo Health Research Centre	
	Kintampo health research centre	
	West African Centre for Cell Biology of Infectious Pathogens (more in terms of bioinformatics than epidemiological modelling)	

The capacity of modellers to engage with policymakers was also considered low. Interviewees had mixed views on the capacity to generate high-quality, reliable, and timely data. Based on the experience with the SEDI project, one interviewee noted:

'*When GHS released the data to the School of Public health in the University of Ghana, the analysts there complained it is not in good shape and since there are gaps they needed to make assumptions*,'

One interviewee said the elections in the country in December 2020 had an impact on how COVID-19 data were recorded and published. There was a general belief that data were deliberately being withheld and that districts were being encouraged not to report cases. However, the interviewee also added that this was a common challenge in countries facing elections and Ghana may have been more transparent than other countries in a similar situation.

Interviewees highlighted challenges regarding the reliability and accuracy of COVID-19-related data in Ghana, but also emphasised that these were common problems in LMICs. Stigma related to testing, lack of health facilities in rural areas, and incentives against reporting have affected the quality and reliability of COVID-19 data.

COVID-19 data from Ghana formed a part of the Surveillance Outbreak Response Management and Analysis System, and one of the interviewees said the same system could be used for other infectious diseases. Both the public and private sector have supported the collection of COVID-19 data in the country.

Most interviewees thought the capacity to conduct epidemiological modelling is not high. While all the courses that students require for advanced mathematical modelling are taught in universities, academics are unable to link theory with practical application. Most academics also lack programming skills.

'*The capacity to do epidemiological modelling is limited, even though we have quite a few mathematicians who do modelling in academic circles, particularly in universities. But it is not tailored to policy, it is just an academic exercise*,' said a modeller.

A few university students have used models for their Masters or PhD dissertations, but most often they do not have a background in epidemiology, nor do they do work that may be considered relevant.

A modeller listed several areas where capacity needed to be developed: ‘How to use data to fit a model, how to use relevant data to estimate model parameters, how to carry out sensitivity analysis for most important model parameters, how to use these models for future prediction, and impact of key interventions—these are key areas where we need capacity development.’

Most interviewees believed that decision makers and users within the government do not themselves have the in-house capacity to carry out epidemiological modelling. Key units within the GHS and MoH have a few public health experts, epidemiologists, and statisticians but they are not trained in epidemiological modelling. However, most interviewees agreed that government interest in this area has increased since the pandemic began.

The capacity to translate research to policy was considered a major gap by most interviewees.

6.5 Key constraints and opportunities for capacity strengthening in epidemiological modelling

The stakeholders we spoke to highlighted challenges to, and opportunities for, developing capacity and encouraging more work in this area.

Trust-based relationships between key stakeholders

All the interviewees highlighted the need to develop trust-based relationships between key stakeholders if epidemiological modelling work is to move forward in the country. Work on the SEDI project underscored the issues of ownership and politics within and between institutions that could potentially derail such projects. MoH, the GHS, and the University of Ghana were all interested in leading on the SEDI project. The project was not able to start until this leadership issue was resolved and roles and responsibilities were made clear. For this to happen, FCDO Ghana had to convene several meetings with stakeholders and encourage them to participate in the project. FCDO Ghana engaged closely with officials at MoH and, through these discussions, the ministry eventually nominated GHS to lead the process.

The lack of trust has also meant government agencies are wary about sharing data with academics and researchers. Data are considered to be power, and governments may feel the need to control them. FCDO Ghana had to offer guarantees for the SEDI project before the COVID-19 data were released. The delay in the release of data was yet another factor that affected the project timeline.

Decision makers are of the view that modellers may use their access to data to serve their own personal goals.

‘*Academic incentives are different from those of practitioners. Academics want to get published and promoted. But practitioners do not want to be treated just as providers of data*

and hand over the data to someone else who will write up the article, get published, and take the credit for it,' said an interviewee.

A modeller working on malaria elaborated on all the work they had to put into getting access to the data:

> '*For malaria, it wasn't easy to get access to the data. I had to write letters, talk to people in their offices, and convince them about why I wanted to use the data for my study. I had to present a proposal to them.*'

Similarly, on the SEDI project, researchers had to work closely with the GHS and complete all the documentation requirements before they could get access to the data.

Engagement between modellers and decision makers

Modellers working on the SEDI project said that, since decision makers were not mathematically inclined, they were not aware of what went into a model, or of what questions could or could not be answered by the models. Researchers therefore needed to engage closely with decision makers to arrive at the questions that could be answered with mathematical models.

One of the decision makers we spoke to was of the opinion that policymakers need to lead on identifying the questions that need to be addressed: '*We need to bring the problems to the table, which then modellers can support in addressing*.'

Funding for epidemiological modelling research and capacity development

Most interviewees agreed that there was very little funding available for epidemiological modelling research, which has affected the development of capacity in the area.

Universities may occasionally share requests for research protocol submission, but they are mainly related to outcomes of diseases. There have not been any scholarships available for studying epidemiological modelling. The recent call from the Bill & Melinda Gates Foundation and the FCDO funding for the SEDI project were considered rare exceptions.

One of the modellers described this chicken-and-egg situation. International organisations may not be giving research grants, as they may think Ghanaian modellers do not have the requisite capacity. Similarly, organisations within the country also do not want to spend money on training people, because they do not understand the importance of studying the dynamics of infectious diseases. However, without any funding for this work, capacities are not getting strengthened and the incentives to engage in this space are limited.

'*If we don't have a lot of people who understand epidemiological modelling or can do epidemiological modelling, it becomes challenging to push for budgetary support*,' said another interviewee.

Students who specialise in mathematics are most often drawn to jobs in the financial services sector (e.g. actuarial science). The lack of job opportunities in the area of epidemiological modelling has meant that students from public health or mathematics departments may not consider this an area they want to specialise in.

Flexibility and practical orientation of academic courses

The modellers we interviewed said the structure of courses in universities did not allow students to develop a specialisation in epidemiological modelling. While universities offered separate courses in epidemiology, public health, or mathematics, they are not linked together.

'*What we need is a fusion of statistics, epidemiology, and mathematics*,' said a modeller.

They suggested that academic programmes in universities should be structured in a flexible way to allow students to pick courses from different departments.

One of the modellers suggested that students should be introduced to programming software that is used for mathematical modelling so they can simulate datasets and gain experience in using modelling and looking at projections on the daily incidence of disease, hospitalisation, disease-induced deaths, and so on.

As a starting point, academics in universities needed to be trained in the practical application of epidemiological modelling so they are well-positioned to impart this knowledge to students.

Both the modellers we spoke to had to go to universities in other countries (South Africa and the Netherlands) to take advanced courses in epidemiological modelling.

'*If capacity development is meant to be long term, you have to train people in academia. You will then have a constant stream of students who appreciate this area and know how to use models to inform decision making*,' said one modeller.

Evidence translation for decision making

A few of the interviewees said that more work was needed to support academia in doing better at engaging and communicating with decision makers.

'*Some work is needed for academia to learn and understand how best to relate to policymakers and service delivery arms to package their work in a way that is useful. The whole area of translating research to policy is a massive area of weakness*,' said one interviewee.

The government officials we spoke to said the use of research evidence in decision making may be influenced by the issue at hand, the actors involved, and political economy factors. However, research is unlikely to be used if researchers do not make an effort to disseminate their work, package it, and make it accessible to policymakers.

The role of boundary spanners and evidence brokers was also emphasised for breaking silos.

'*People who are in policy understand how the data is used. But you need boundary spanners. In Ghana, experts stay in their silos. Experts in academia, experts in statistical analysis, expert modellers in institutions, experts in the GHS … they stay in their own domains. Work is therefore quite fragmented*,' said an interviewee.

6.6 Ideas for capacity development interventions

We asked all the interviewees to suggest what they thought might be feasible and helpful ideas for capacity development in epidemiological modelling. All the interviewees agreed that any new capacity development initiative would need to be led by Ghana. It could be supported by development partners, but it would need to take a long-term perspective.

'*A short and quick dip in and dip out will not work. This needs patience. Nothing less than a three- to four-year project is what will be needed in Ghana. It would need to take a mentoring and learning-by-doing approach so that strategies can be adapted and refined along the way*,' said one interviewee.

A few interviewees emphasised the need for capacity development to promote multisectoral working. They urged for the need to draw on economic data (e.g. social protection) and pushed for the need to use modelling to look at other chronic and communicable diseases, and different aspects of health and wellbeing. There are several government agencies that produce data, and some interviewees called for harmonising the instruments used for data collection so the data could feed into the work of multiple sectors.

An interviewee emphasised the need to build individual and organisational capacity. It is not enough to just look at individuals; there is also a need to look at their contexts and consider the institutional capacities that need to be built. Individuals need a supportive environment to perform; they also need opportunities to apply their learning.

Here are a few specific ideas for capacity development suggested by the interviewees:

- formal training with technical assistance so that people can be mentored while they are conducting epidemiological modelling;
- short courses for researchers to build their skills in epidemiological modelling and for policymakers to develop more awareness and understanding of this area (courses offered by the London School of Hygiene and Tropical Medicine, Imperial College, and Johns Hopkins University were of specific interest to academics);
- a web portal where modellers could post questions and have conversations with other modellers;
- training while an epidemiological modelling project is being implemented, and encouraging the application of that training to work in the government;
- targeted training of trainers to encourage the downstream transfer of knowledge;
- support to universities for building a stronger offer within the curriculum;
- the creation of positions within the government for epidemiological modelling experts, and empowering them to forge networks with academia and improve the quality of data collection;
- support for developing a modelling unit within the GHS, which could include training and procurement of software and equipment; embedding of a technical adviser in person (or remotely based for a few months) to assist with the development of this unit, and long-term collaboration with the CoMo Consortium;
- training and funding for producing quality and reliable data at the primary level; and

- leverage existing statistical working groups within the government to coordinate work on epidemiological modelling, including capacity development.

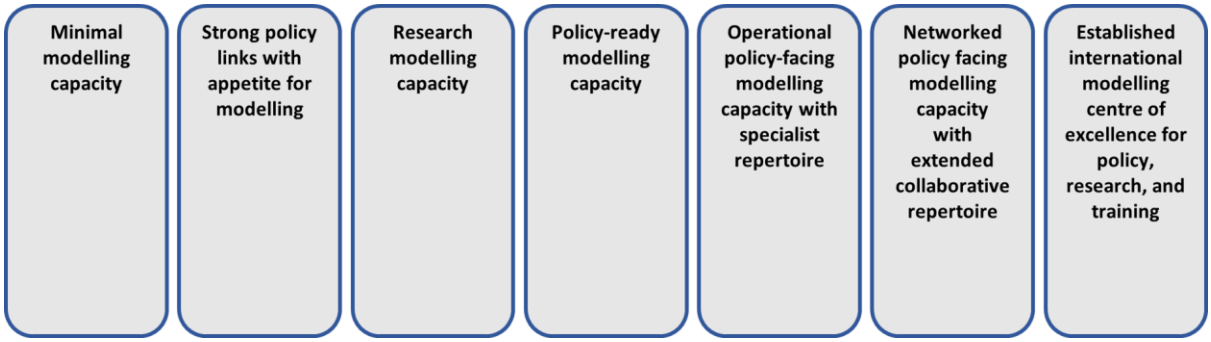
7 Capacity strengthening framework

7.1 Stages of capacity strengthening

To synthesise the lessons and observations made in the case studies, we propose a conceptual framework that identifies several stages of capacity within a national research–policy ecosystem. For ease of presentation, this framework is presented in a linear, 'pipeline' fashion (Figure 2). This captures the necessity of a realistic and staged approach to developing modelling capacity where, for example, it is unrealistic to expect to quickly build sustainable and effective modelling capabilities in a national context where no capacity already exists. However, the pathways to strengthen capacity are not perfectly sequential. Depending on context, it may be appropriate to address elements of multiple stages simultaneously, or to take a more policy-led or research-led approach to moving forward in the pipeline.

The purpose of this framework is to provide those who design capacity strengthening interventions with the conceptual tools to consider how individual interventions can be situated within a broader context, and to suggest how packages of interventions could be designed and coordinated to enable sustainable progress.

Figure 2: Capacity strengthening pipeline



The first three stages of the pipeline describe circumstances where a country does not yet have the capacity to use mathematical modelling in the policy decision making process, as follows.

1. **Minimal modelling capacity**: Here there are no, or very few, researchers within a country with the relevant expertise to conduct modelling, and those that exist have few if any links to policymakers. Likewise, policymakers are not aware of what capacity exists and lack the knowledge and incentives to incorporate modelling in their decision making. Global generated models or model-informed public health advice may be used, but policymakers lack the skills to assess the strengths and weaknesses of this.
2. **Strong policy links with an appetite for modelling**: The stage refers to circumstances where there is minimal modelling capacity but strong linkages exist between decision makers and researchers in academia, the public sector, and/or non-governmental organisations, with an appreciation of the potential value of modelling to support decision

making. Global generated models or model-informed public health advice may be used, but policymakers lack the skills to assess the strengths and weaknesses of this.

3. **Research modelling capacity**: Here there is capacity and skilled individuals to conduct epidemiological modelling work that is of good academic scientific quality (i.e. it can be published in reputable, peer-reviewed academic journals). However, the modelling work that is done is not suitable for answering priority policy questions. The research ecosystem lacks the capacity for modelling expertise to be incorporated into the policymaking process, either through the lack of appropriate policy-relevant skills among modellers or through an absence of networks for them to engage with each other.

As will be articulated below, moving from these early stages to reach policy-ready modelling capacity requires a combination of multiple capacity building interventions aimed at training in either (or both) academic modelling and policy-facing modelling, and strengthening the support and networking infrastructure. The later stages represent policy-facing modelling capacity that is already connected with policymakers and benefiting from various levels of networking in the region, with varying breadths of repertoire.

4. **Policy-ready modelling capacity**: This stage refers to a situation where the basic building block for policy-relevant modelling creation and use are in place, but there are significant barriers to the efficiency and effectiveness of this work and potential concerns over the sustainability of capacity.
5. **Operational policy-facing modelling capacity with specialist repertoire**: Here, there are good links and understanding between policymakers and modellers to the extent that the work done by modellers can be effectively incorporated into decisions, and the modelling community has some specialist expertise relevant to national priority areas. This could include specific diseases, or interdisciplinary collaborations to integrate economic considerations.
6. **Networked policymaking modelling capacity with an extended collaborative repertoire**: At this stage, there are multiple organisations with expertise and modelling capabilities, spread across government, academic, and non-governmental organisations (e.g. think tanks). Activities can be coordinated effectively among various stakeholders. Different disciplines and user groups can adapt and respond to changing circumstances and priorities.
7. **Established international modelling centre of excellence for policy, research, and training**: In the final stage of the pipeline, a country's capabilities to generate and use modelling evidence are recognised as world-class, and the country can actively contribute to regional and global disease response. Furthermore, the capacity to use modelling evidence is embedded in government institutions, and high-quality modelling researchers have secure career pathways and opportunities for long-term research funding that does not depend on short-term, project-specific positions.

Moving into and through these stages requires a combination of capacity building interventions aimed at linking with policymakers, networking with other modellers in the region, career development, and sustainability.

These stages are not absolute; their conceptual value lies in that they help systematically organise our description of capacity from a systems perspective. This is best illustrated by reflecting on how the case studies fit within this framework.

Ghana includes dimensions of Stage 2 and Stage 3. It possesses academically oriented modelling capacity, which is not effectively engaged with policymaking. Simultaneously, there exists appreciation and appetite within government to make better use of modelling and strengthen capacity.

Kenya fits roughly into Stage 4, with some aspects of Stage 5. While there is some national capacity and evidence of the use of local modelling work to inform decision making, this is not as effective or systematically embedded as it could be.

South Africa sits within Stage 5, with aspects of Stage 6 and Stage 7. Some work done in South Africa is world-class, and collaborations with government and across various modelling disciplines are established and have been strengthened over the course of the COVID-19 pandemic. However, South Africa's capacity remains tenuous, and structural changes to the research funding landscape are required to ensure the sustainability of its capacity.

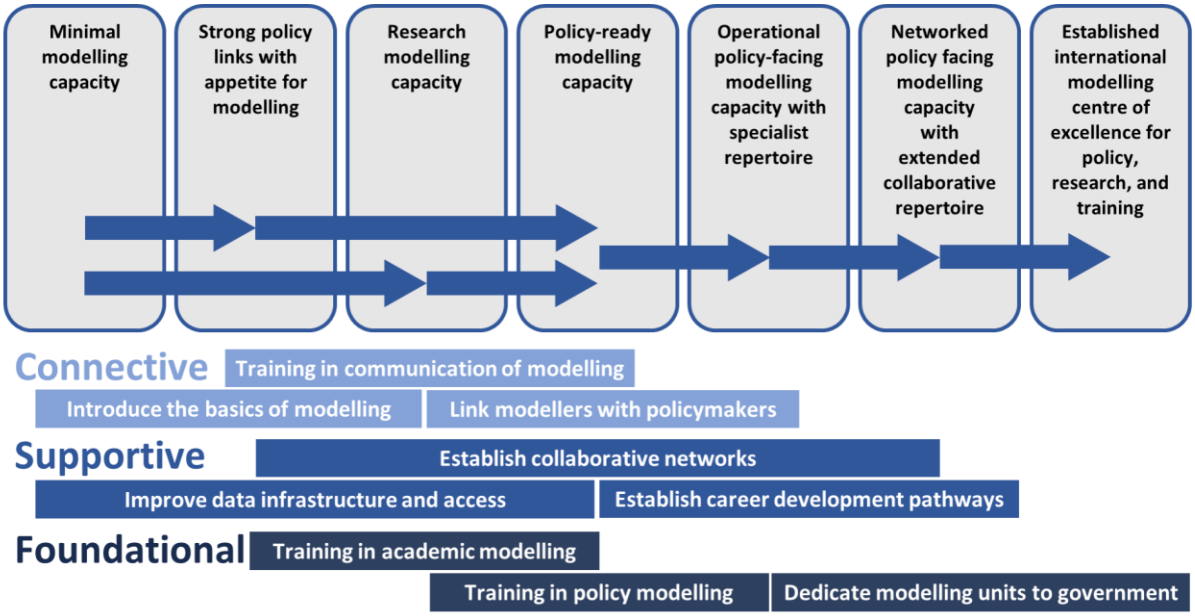
7.2 Types of intervention

Given the epidemiological modelling capacity is embedded within a complex research–policy ecosystem, no single intervention is likely to generate systemic change. This framework therefore encourages consideration of packages of interventions that can be characterised as foundational, supportive, or connective.

1. **Foundational interventions** cover essential training and activities that are required to develop capacity from the earlier to the later stages of the pipeline. Training in academic modelling is essential for capacity to develop from a minimal level and from a level where there are strong policy links and an appetite for modelling. Training in policy modelling is required for those with academic modelling skills in order to be ready to take on policy questions. To reach full utility, modellers who have begun to support policy must establish dedicated collaborative links to government either by being within, or hosted by, a government department, or by an official recognition of government advisory status.
2. **Supportive interventions** are aimed at improving the effectiveness, scope, and sustainability of the foundational capacity. If relevant to the context, improvements to data infrastructure and access may be necessary to ensure models are using appropriate input values and can be compared with historical data before being used for scenario analysis. The repertoire of existing policy-facing capacity may be extended through equitable collaborative networks across the region. To ensure sustainability of capacity, attractive career pathways must be established.
3. **Connective interventions** ensure impact by establishing essential links between the key stakeholders and sustaining effective intersectoral communication. At the early stages, introducing the basic concepts of modelling to policymakers is important. Once capacity has begun to develop, training in the communication of modelling would ideally be delivered in parallel, preparing the ground for linking modellers with policymakers once there is policy-ready capacity in place.

Figure 3 demonstrates these flows between stages and aligns the groupings of intervention that would be required to implement these transitions.

Figure 3: Categories of capacity strengthening intervention



7.3 Use of the framework

The first step to use this framework in the design and implementation of capacity strengthening initiatives is to identify where a country's current national capacity is situated along the pipeline. The framework is a guideline structure for complex systems and processes, so actual circumstances may not always fit neatly within a single stage. A country could be characterised as between stages or have certain 'pockets of excellence' that have stronger capacity than the wider national circumstances.

The key point is that the design of a capacity strengthening intervention should begin with a thorough analysis of the current landscape and a clear target stage. The framework is set up to allow the user to select the most contextually appropriate starting point (green), a target end point (red), and a package of interventions. The more ambitious the desired end point, the more time and complexity will be required in implementing a package of interventions.

The recommended approach to produce a package of interventions is to select individual interventions that align with the relevant stages along the pathway, from starting point to target endpoint. Selecting contextually relevant aligned interventions will avoid redundancy. Selecting a spread of interventions that cover the three main categories of foundational, supportive, and connective interventions will allow for effective, efficient, and impactful capacity to be built.

We illustrate the process with a few examples.

Figure 4: Transforming academic modelling capacity to policy-oriented capacity

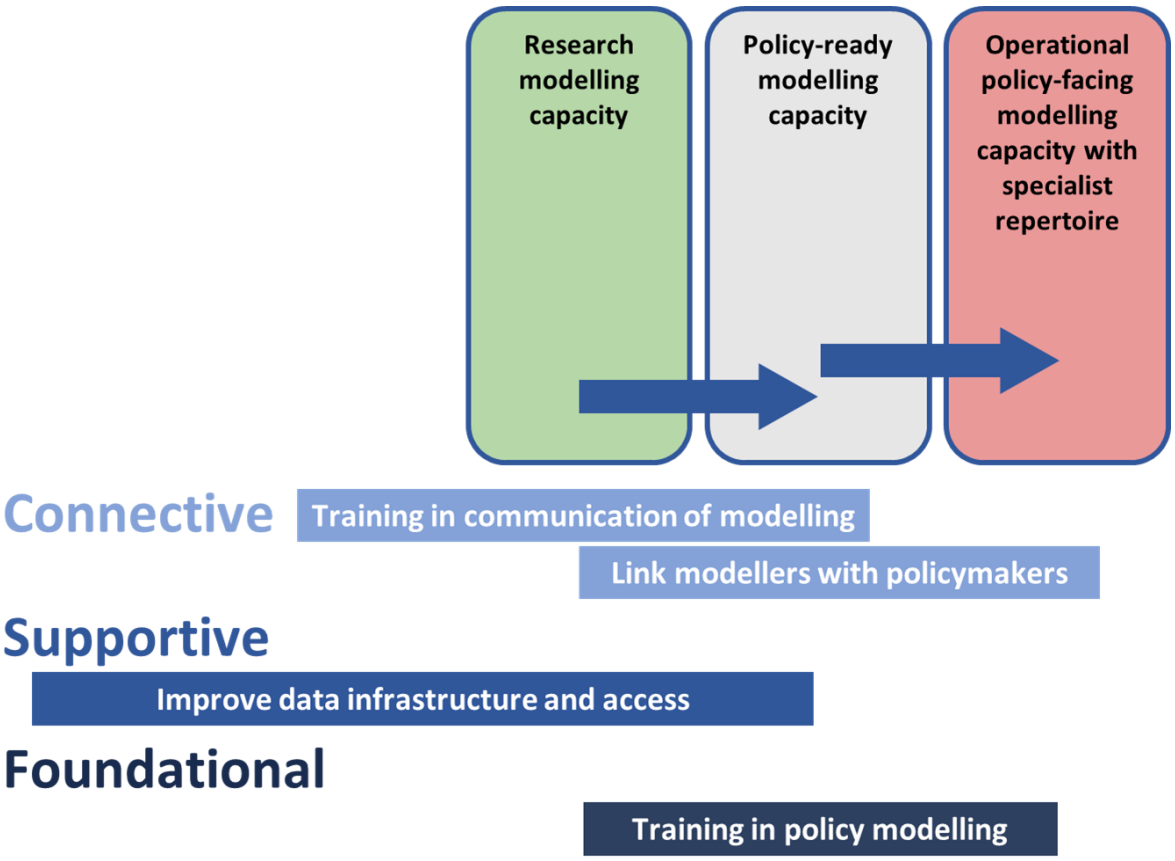
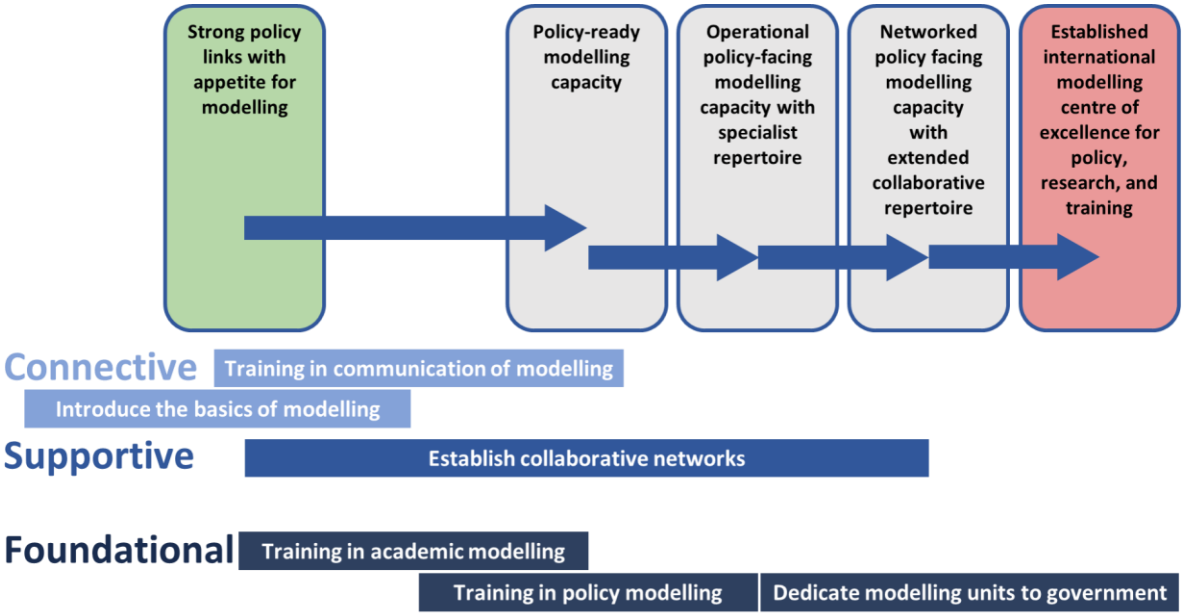


Figure 4 demonstrates the transformation of research modelling capacity with a specific skills set (for example a modelling group within a university) to operational policy-facing capacity for that same skills set. A foundation in policy modelling training is supported with improved access to data, while the group is trained in the communication of modelling and supported to link with policymakers. This could be achieved in a year or two, with low to intermediate levels of funding. However, in pursuing such an objective, the sustainability of the end stage needs to be supported with core funding.

Figure 5 represents a more extensive investment, starting with a group within a government department without existing capacity for modelling and aiming to become an international centre of excellence. Starting with introducing the basics of modelling, full training in academic and policy-facing modelling would follow. In parallel, it would be essential to establish links with collaborative partners in the region to support and mentor this new group. The process would be complete after establishing the intra-departmental links to dedicate the unit to the government. This process would take at least 10 years and would require significant and sustained investment.

Figure 5: A long-term strategy to establish modelling capacity



In the following section, we provide more details about specific interventions and propose some preliminary views on how these could be applied to our case study countries.

8 Summary of potential interventions

A series of interventions were suggested in the case studies. These interventions varied regarding target, mode of delivery, and outcome. Figure 6 summarises the interventions, showing groupings by target audience:

- decision makers and consumers of policy modelling (government);
- senior established modellers with formal training and practical experience (modellers);
- trainee modellers or graduates with a strong non-modelling quantitative background (student/early career academic);
- tertiary academic institutions (higher education institutions);
- established African networks such as SADC and Africa CDC (coordinating bodies); and
- evidence brokers and supporting organisations to government (non-governmental organisations/adjacent organisations).

These interventions are further evaluated individually with respect to scope, depth, and sustainability to determine the desired outcome (Annex A). The range of interventions proposed is indicative of the multiple facets of the epidemiological modelling ecosystem that require strengthening in order to bridge the gap between science and policy. A single intervention is not likely to be a panacea for capacitating modelling, and not all interventions will be equally suitable to countries at different levels of modelling capacity. A framework is required to select interventions for heterogeneous settings.

8.1 Intervention subthemes

8.1.1 Foundational

Training in academic modelling

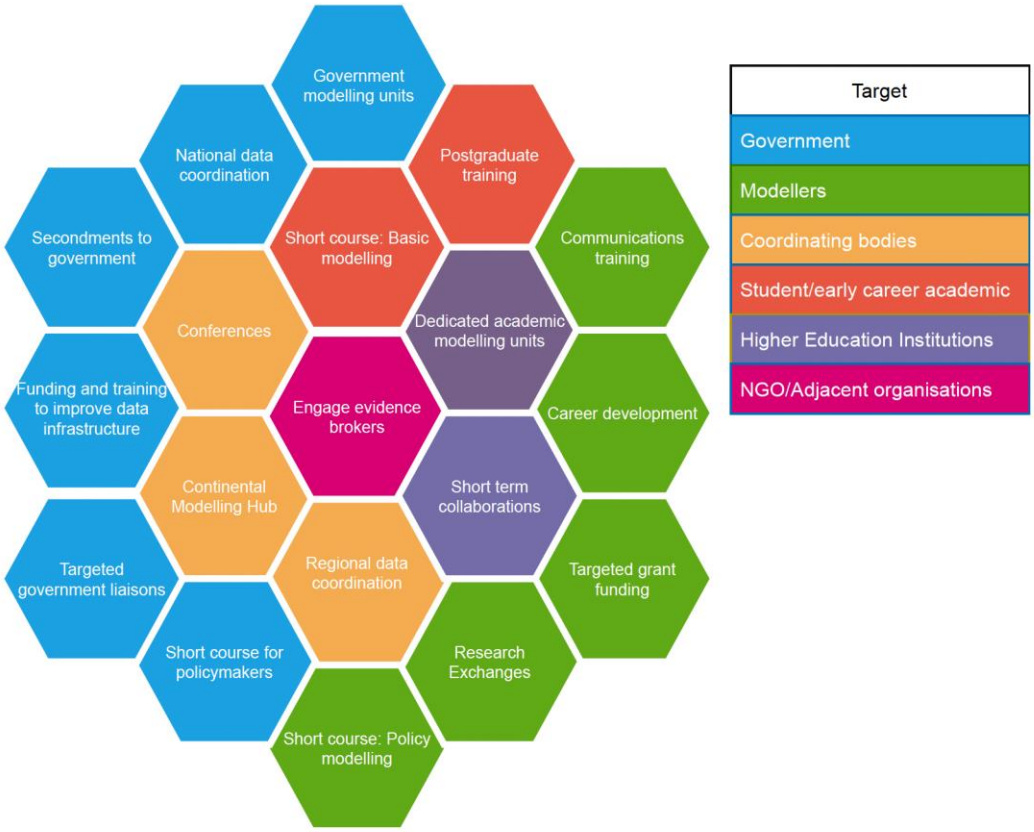
Central to the any capacity strengthening strategy is the need to establish a cohort of researchers with the skills to conduct modelling work that is grounded in, and contributes to, the global cutting-edge in modelling methodologies. This requires investment in postgraduate and postdoctoral research training programmes, training opportunities for early career researchers, and opportunities for established modelling researchers to secure funding for ‘blue skies’ (i.e. not necessarily directly linked to policy challenges) to continue contributing to the development of their research disciplines.

Training in policy modelling

Developing models that can be used directly for public health decision making is distinct from academic modelling research. A range of interventions, the appropriateness of which will vary with context, could be implemented to strengthen these core skills. They include short courses to introduce academic modellers to the techniques required for policy-relevant modelling, research exchanges with institutions with policy modelling expertise, and

research funding opportunities that specify collaboration between institutions to strengthen capacity while undertaking policy-focused modelling research.

Figure 6: Range of intervention types and their target stakeholders



Dedicated government modelling units

The third set of foundational interventions includes efforts to establish modelling units outside traditional academic research organisations. These may be located either directly within government agencies or within independent research and policy organisations (i.e. think tanks). The advantages and disadvantages of this approach to strengthening foundational capacity will vary with context. Establishing units within government agencies may provide the most direct route to policymaking, but such units may be constrained by political or bureaucratic factors. Units within independent organisations may avoid the constraints and bureaucracy of traditional academic organisations, but may have less supportive infrastructure and networks and are unlikely to be able to provide formal accredited research training.

8.1.2 Supportive

Establish collaborative networks

The establishment or strengthening of networks between institutions through virtual communities and resource hubs, conferences, and exchange programmes provides a relatively low-cost mechanism to spread capacity and learning across a greater number of

organisations and individuals. However, sustaining such networks requires ongoing commitment from participating organisations and some level of sustained funding. This can be challenging to secure over time, as tangible outputs and outcomes from such networks can be difficult to predict, monitor, and attribute.

Improve data infrastructure and access

Access to high-quality data is essential for high-quality modelling work. The interventions required to ensure this will vary between contexts and may differ dramatically in their cost. In some circumstances, policy and process changes may substantially improve capacity by making existing datasets more readily accessible to researchers. In other contexts, substantial investment may be required to improve to quality and coverage of national data systems. Such investment will have benefits far beyond the specific applications to epidemiological modelling.

Establish career development pathways

In addition to core training in research methods and opportunities for research project funding, several interventions can support the career development of modelling researchers. These include training in more generalised ‘soft’ skills, such as leadership and grant/scientific paper writing. A more substantive supportive intervention would be to create roles that are jointly funded by government agencies and academic institutions to conduct policy modelling.

8.1.3 Connective

Introduce the basics of modelling

As a connective intervention, training courses could be implemented that do not aim to produce newly trained modelling researchers. Instead, they might aim to increase awareness of how modelling works and how it can be used to inform policy. Such training, or exchange visits, could be targeted at government officials, undergraduate students, or early career researchers in related disciplines who may be interested in developing their own skills or collaborating with modelling researchers.

Link modellers with policymakers

A crucial area for intervention is to strengthen the linkages between modelling researchers and policymakers. There are various ways to achieve this, which will vary depending on the context and resources available. The simplest intervention is to provide policymakers with training in how to use modelling evidence. More extensive interventions would focus on support for evidence brokers or government modelling liaisons, as well as secondments of modelling researchers into governments for short-term or long-term assignments. Policies that require modelling evidence to secure programme funding could incentivise officials to engage with modelling work. As highlighted in the South African case study, it is important to ensure that awareness of modelling evidence and its implications is distributed broadly within governments, including among those responsible for implementing policy.

Training in modelling communication

The final category includes communications training for modellers on how to present their work to policymakers and the wider public. In addition, training could be provided to communications professionals, such as journalists, on how to understand and appreciate modelling evidence.

8.2 Application of interventions to case studies

Table 2 presents initial thoughts on how these interventions could be applied in the case study countries, in order to advance them along the capacity strengthening stages identified in the previous section. This list is not exhaustive, and interventions should not be designed without further analysis of context.

Table 2: Preliminary suggestion of interventions in case study countries

	Foundational	Supportive	Connective
Ghana (short term)	Provide training to academic modellers in modelling for policy	Strengthen networks between modellers and government agencies to build trust	Provide training to government officials to understand the value and use of modelling evidence
(long term)	Establish postgraduate and postdoctoral training centres for modelling	Reform academic career pathways and research funding to support modelling expertise; harmonise and improve the availability of government data that can be used for modelling	Establish modelling units and/or positions for modelling researchers within government agencies
Kenya (short term)			Provide training to government officials and journalists on the effective use of modelling evidence
(long term)	Establish postgraduate and postdoctoral training centres for modelling	Improve the quality of data infrastructure to inform models	Support evidence brokers to embed understanding of modelling more fully in government agencies
South Africa (short term)	Increase dedicated capacity within the government to conduct modelling work	Improve the transparency of processes to access datasets	Ensure academic training includes ‘soft skills’ to communicate modelling to the government and general public
(long term)	Strengthen the pipeline of postgraduate and postdoctoral training	Reform research funding to enable secure career pathways for modelling researchers	

Ghana may benefit the most from short-term interventions, as there is much work to be done to improve networks among various groups of stakeholders and strengthen the policy relevance of modelling work. However, this is unlikely to be sustainable unless it is followed by sustained and larger-scale efforts to increase overall capacity levels. In Kenya, because pockets of excellence exist and there is some recognition of the value of modelling within the government, there are fewer opportunities for ‘quick wins’. Here it is essential to broaden capacity beyond its current focus within KEMRI. While South Africa is relatively advanced in terms of capacity, it needs to continue replenishing and strengthening its pipeline of expertise, stabilising sources of funding, and improving the extent to which modelling expertise is embedded within government systems. This could enable it to strengthen its role as a continental and global leader in modelling.

9 Conclusions

There is a strong case for making strengthening capacity to generate and use epidemiological models a priority for national governments and donor agencies within SSA. Few other areas of research have such substantial potential to inform public decision making at relatively low cost. However, given the general institutional weaknesses in research ecosystems found in many African countries, investment in modelling capacity should be done strategically, with clear objectives aimed not just at supporting individual skills, but also at generating systemic change.

Sustainable systemic change is a complex task, and so will require the application of a complex set of interventions and strong national leadership.

This report has provided a list of potential capacity strengthening interventions, and a conceptual framework to assist with selecting and structuring intervention packages. However, this can only be understood as the first step in the development of a capacity strengthening strategy that is sufficiently detailed and robust to match the importance of the challenge. While we have made some recommendations regarding appropriate interventions, these are by no means definitive.

To further develop such a strategy, it may be valuable to establish a consortium of funders, national governments, research organisations, and regional bodies to coordinate activities and share learning. This could build on work done by the African Union in the context of the COVID-19 pandemic. However, we would recommend that the focus of strategic action should be at the national level, where there is the greatest opportunity to integrate public health and research capacity strengthening strategies.

A consortium of international funding agencies, working directly with interested national governments and advised by expert, local researchers, could work to develop a more detailed series of national ‘road maps’ to build capacity at the country level. Undertaking this work through a consortium would allow coordinating investment around coherent packages of interventions, enable shared learning on effectiveness, and lead to international collaboration between African nations and with the wider world as appropriate.

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Annex A Description of capacity strengthening interventions

A.1 Foundational interventions

Subtheme	Intervention	Description	Target	Depth	Scope	Sustainability
Training in academic modelling	Postgraduate and postdoctoral training	Provide core academic training to appropriately educated individuals to allow them to develop the potential to pursue a research career as a mathematical disease modeller	Students and early career academics, government employees	Where successful, PhD and postdoctoral training could launch a research career producing high-impact work over several decades and training additional generations of students and modellers	Multiple years of funding required to train each student; the number of research organisations in Africa with the capacity to provide training and absorb trained academics is limited	Sustainability of training depends on continued opportunities in the system for researchers to conduct research and engage with policy, and competitively funded scholarships with opportunities for employment
Training in policy modelling	Short course on policy modelling for global health	Introduce policy modelling techniques to researchers with existing skills and competencies to engage with the material	Modeller	Can equip existing researchers with relevant skills to contribute to policy-related modelling work	Highly variable depending on specific design; could vary from small number of participants to many participants across the continent	Depends on the existence of ready opportunities to apply new knowledge gained
	Research exchanges	Provide opportunities for short research visits to other African	Modeller	Can equip existing researchers with relevant skills to contribute to policy-	Support for individuals in these roles could be highly impactful, but will likely be limited by the number of centres to host the	Sustainability of hands-on training depends on continued opportunities in the system for researchers to conduct policy modelling

Subtheme	Intervention	Description	Target	Depth	Scope	Sustainability
		institutions engaged in policy modelling		related modelling work	exchange and requires alignment of numerous factors in order to be successful (e.g. policy problem to model, data availability, supportive environment, available candidate away from academic duties)	research and academic institutions to enable time away from core academic duties to conduct research
	Targeted funding for policy modelling opportunities	Provide research funding opportunities with a strong policy modelling focus where leadership is targeted at African institutions, and collaboration between African institutions is required	Modeller	Can equip existing researchers with relevant skills to contribute to policy-related modelling work	Multiple years of grant funding are required. The number of organisations and researchers applying to the funding call may be large	Depends on the commitment of government to collaborate with and support local academics to apply for funding, and academic institutions to allow buyouts of time for academics to hold large grants and conduct research away from routine academic activities
Dedicate modelling units to government	Establishment of specialist units within government agencies	Governments establish units within ministries or agencies with the capacity to conduct policy modelling, serve the needs of government, and influence decision making	Government	If successfully implemented, could generate culture change and step-change in effective use of modelling to inform policy	Potentially wide-ranging across government public health policy	Depends on the commitment of government to sustain the unit, but otherwise highly sustainable

Subtheme	Intervention	Description	Target	Depth	Scope	Sustainability
	Establishment of specialist units outside of government agencies	Specialist academic units are established outside of government, such as national institutes and collaborative centres with the capacity to support the modelling needs of government and influence decision making	Higher education institutions	If successfully implemented, could generate culture change and step-change in effective use of modelling to inform policy	Potentially wide-ranging across government public health policy and academic institutions in-country	Depends on the commitment of funders and/or government to sustain the unit, but otherwise highly sustainable
	Funding for research, including blue skies research, and stable funding for research centres	Dedicated funding to support African modelling research outside of particular crises or individual projects	Higher education institutions	Could generate substantial advances in the quality of modelling work. Will make it easier to retain expertise within the field and improve efficiency of research by reducing the amount of time required to pursue individual funding efforts	Will likely focus resources in a small number of centres of excellence, but the influence of these centres may be substantially increased	Sustainability is a key challenge. Opportunities to secure steady funding streams are essential

A.2 Supportive interventions

Subtheme	Intervention	Description	Target	Depth	Scope	Sustainability
Establish collaborative networks	Creating a network/hub for communication	Create a network of modellers across the continent to facilitate knowledge sharing through formal and informal means, accelerate problem solving, and foster collaborative research	Coordinating body	If successfully implemented, could provide a forum to accelerate problem solving and mutual knowledge transfer to catalyse modelling to inform policy	Potentially wide-ranging across academic and research institutions in Africa	Depends on commitment from constituent organisations to engage in the network, and funding to facilitate it
	Regional/continental conferences and exchanges	Provide annual/semi-annual opportunities for engagement	Coordinating body	Provides a forum for government officials and academics across the continent to exchange experiences and support mutual knowledge transfer	Potentially wide-ranging across academic institutions and governments in Africa	Depends on commitment from participant organisations to provide meaningful engagement, and funding to facilitate it
Improve data infrastructure and access	Funding and training for improvements to data infrastructure	Customised support to national MoHs to support the development and/or improvement of data systems and	Government	Improved systems for generating data with established ports of access can enable policy modelling in countries where it was not possible before	While limited in its scope on a per-country basis, the benefits reach far beyond the scope of policy modelling	Depends on governments to engage in data infrastructure development, and take over long-term maintenance of new/improved systems

Subtheme	Intervention	Description	Target	Depth	Scope	Sustainability
		training to maintain them				
	Funding data coordination (nationally)	Customised support to national MoHs to support the coordination of existing data systems with a central port of access	Government	Improved systems for generating data with established ports of access can enable policy modelling in countries where it was not possible before	While limited in its scope on a per-country basis, the benefits reach far beyond the scope of policy modelling	Depends on governments to engage in data coordination and take over long-term maintenance of new/improved systems
	Funding data coordination (regionally)	Establish a regional mechanism to coordinate aspects of national data systems with a central port of access	Coordinating body	Improved regional coordination of data with established ports of access may foster national data coordination to enable policy modelling in countries where it was not possible before	Multiple years of funding are required to maintain a regional coordinating centre, though it may be linked to existing entities such as SADC, Africa CDC, and the African Union. The benefits of data coordination extend beyond policy modelling	Depends on the central body to coordinate data, and long-term funding to enable it. Also depends on governments to contribute to coordinating mechanism
Establish career development pathways	Leadership training	Provide short courses or sustained training to early and mid-career modellers	Modeller	Leadership training could set modellers' research careers on an upward growth trajectory, producing high-impact work over several decades and becoming a leader on the continent	Significant numbers of modelling researchers could be supported at relatively low cost, but outcomes are limited by the job opportunities available at academic institutions	Modelling researchers likely to retain and apply skills throughout their careers, and share them with students and colleagues

Subtheme	Intervention	Description	Target	Depth	Scope	Sustainability
	Grant and scientific writing training	Provide short courses or sustained training to early and mid-career modellers	Modeller	Improved grant and scientific writing with subsequent awards and publications could set modellers' research careers on an upward growth trajectory, producing high-impact programmes of research over several decades	Significant numbers of modelling researchers could be supported at relatively low cost, but outcomes are limited by grant opportunities targeted at modelling with the leadership in Africa	Modelling researchers likely to retain and apply skills throughout their careers, and share them with students and colleagues
	Co-funded positions in government and academic institutions	Establish positions in government and academic institutions that are co-funded and dedicated to policy modelling	Government/ higher education institutions	If successfully implemented, could generate culture change and step-change in effective use of modelling (and academic research in general) to inform policy	Limited in terms of the number of positions to be created, but wide in applicability across the continent	Depends on government and academic institutions to take over and maintain funding of the created positions

A.3 Connective interventions

Subtheme	Intervention	Description	Target	Depth	Scope	Sustainability
Introduce the basics of modelling	Short course on introductory modelling	Introduce basic modelling techniques to researchers with the existing skills and competencies to engage with introductory material	Students and early career academics, government employees	Can equip existing researchers with relevant skills to begin a training programme in academic and policy modelling	Highly variable depending on specific design; could vary from small number of participants to Massive Open Online Courses (MOOC)	Will produce a small group of researchers likely to retain, grow, and apply skills throughout their careers, though many may share their skills with students and colleagues
	Scoping research exchanges	Provide opportunities for short scoping research visits to other African institutions engaged in policy modelling	Students and early career academics, government employees	Can equip researchers basic modelling skills to begin a training programme in academic and policy modelling	Support for individuals in these roles could be impactful, but will likely be limited by the number of centres hosting the exchange	Will produce a small group of researchers likely to retain, grow, and apply skills throughout their careers, though many may share their skills with students and colleagues
Link modellers with policymakers	Short course on modelling for policy	Provide policymakers with a solid understanding of how modelling works, what is required to do it effectively, and the types of policy question to which it can contribute	Modeller	Policymakers may be able to make more effective decisions supported by modelling evidence	Likely limited to a small number of potentially influential policymakers for a short duration. The challenge is likely to be to identify ways to convince policymakers to commit time to training, and to implement training when engaged in core duties	Sustainability may be at risk if individual policymakers move to other positions or disengage when performing core duties. This intervention may require sustained commitment from governments to regularly train new officials

Subtheme	Intervention	Description	Target	Depth	Scope	Sustainability
	Targeted development of government modelling liaisons	Target and train individuals within government to be aware of the basics and benefits of policy modelling	Government	Government modelling liaisons may be able to engage with policymakers to communicate and champion the use of modelling evidence in decision making	Though limited to a small number of government employees, the potential to influence decision making is large, particularly if liaisons are mid-career or themselves in an influential position and because the onus is not on senior policymakers to be trained in modelling	Sustainability may be at risk if government modelling liaisons move to other positions. This intervention may require sustained commitment from governments to train new officials every few years
	Engage the services of evidence brokers	Provide evidence brokers who have established working relations with governments with training in the basics and benefits of policy modelling	Evidence brokers	Evidence brokers may be able to engage with policymakers to communicate and champion the use of modelling evidence in decision making. This removes the additional burden on government	Though limited to a small number of employees within evidence-brokering organisations, the potential to influence decision making is large, because the onus is not on policymakers to be trained in modelling and the evidence brokers have an established and working relationship with government	Sustainability may be at risk if evidence-brokering organisations cease the relationship. This intervention may require sustained commitment from evidence brokers to train new officials every few years

Subtheme	Intervention	Description	Target	Depth	Scope	Sustainability
	Secondments for researchers into governments	Researchers assigned to positions within government to conduct ongoing policy-relevant modelling work and understand processes of government decision making	Modeller/ government	Likely to be transformative for the researchers involved, though may negatively impact on traditional academic career pathways. Could contribute to culture change and improved policy processes in government organisations with the right high-level support and political will	Support for individuals in these roles could be highly impactful, but will require the alignment of numerous factors in order to be successful (e.g. a supportive environment; the right candidate)	Could potentially be highly sustainable if costs are taken on directly by the government agencies involved
	Conditional funding opportunities	Funding opportunities for governments where modelling evidence is a requirement of the application process	Government	Likely to be transformative for researchers and policymakers involved. Could contribute to a change in decision making processes in government organisations	Potentially wide scope across the continent, though limited by the funding opportunities available	Sustainable if application conditions are met by local modelling groups rather than international modelling groups
	Short-term collaborations	Academics/groups enter into short-term collaborations to provide modelling evidence to government on a particular	Higher education institutions	If successfully implemented, could generate culture change and step-change in effective use of modelling to inform policy	Potentially wide-ranging across academic institutions in-country	Reliant on the commitment of funders, though not sustainable unless the mandate of the collaboration is clearly defined

Subtheme	Intervention	Description	Target	Depth	Scope	Sustainability
		issue/general support				
Training in communication of modelling	Communication skills for modellers	Provide researchers with training in how to communicate findings to policymakers, the scientific community, the media, and the wider public	Modeller	Empowering researchers committed to the value of policy modelling could improve the likelihood that modelling evidence will be understood and used	Significant numbers of modelling researchers could be supported at relatively low cost, but outcomes are limited by the size of the modelling research community and opportunities to communicate with policymakers	Modelling researchers are likely to retain and apply skills throughout their careers, and share them with students and colleagues
	Training for the media	Provide training to journalists on understanding how disease modelling works and how its findings should be interpreted	Media	It is unclear how far influencing the reporting and public understanding of modelling evidence will change how modelling directly influences policy	Potential to reach a wide range of the public and influence wider political debates about public health policy	It is unclear whether influencing the media will bring about long-lasting change