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COVID-19 MULTI-MODEL COMPARISON REPORT

GUIDANCE ON USE OF MODELLING FOR POLICY RESPONSES TO COVID-19

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Partners of this work provided direction and technical input to the CMCC reports. For more information on the governance and funding of the CMCC, please visit our page on the DECIDE platform: *https://decidehealth.world/CMCC*.

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ABBREVIATIONS AND ACRONYMS

BBC	British Broadcasting Corporation
BMGF	Bill and Melinda Gates Foundation
CDC	United States Centers for Disease Control and Prevention
CGD	Center for Global Development
CMCC	COVID-19 Multi-Model Comparison Collaboration
COI	Conflict of Interest
CoMo	COVID-19 Modelling Consortium
COVID-19	Corona Virus Disease 2019
ETC	Ebola Treatment Centre
HITAP	Health Intervention and Technology Assessment Program
HTA	Health Technology Assessment
H1N1	Hemagglutinin Type 1 and Neuraminidase Type 1
H5N1	Hemagglutinin Type 5 and Neuraminidase Type 1
ICL	Imperial College London
ICU	Intensive Care Unit
iDSI	International Decision Support Initiative
IHME	Institute for Health Metrics and Evaluation
LMICs	Low-and-Middle Income Countries
LSHTM	London School of Hygiene & Tropical Medicine
MHESI	Ministry of Higher Education, Science, Research and Innovation
MOH	Ministry of Health
MRC	Medical Research Council
NCCC	National Coronavirus Command Council
NORAD	Norwegian Agency for Development Cooperation
PPE	Personal Protective Equipment
R&D	Research and Development
SEIR	Suspectable-Exposed-Infectious-Recovered
SEIRS	Suspectable-Exposed-Infectious-Recovered-Susceptible
SIR	Suspectable-Infectious-Recovered
SI	Susceptible-Infected
SIS	Susceptible-Infected-Susceptible
UCL	University College London
USAID	United States Agency for International Development
WHO	World Health Organization

PREFACE

As COVID-19 spreads worldwide, national (and sub-national) governments and development partners are making use of a rapidly growing body of evidence to develop policies mitigating against this devastating pandemic. Mathematical models and computational simulation models play a unique role to inform resource planning and policy development (among other uses) through scenario analysis and short-term forecasting. Already in the first six months of this outbreak, we have seen many models at the sub-national, national, regional and global level being developed at an impressive speed.

For many low-and middle-income countries (LMICs), global and regional models can play an important role in country response planning in the absence of locally developed models. While at this stage of the epidemic, the availability of a diversity of modelling approaches is positive (given the varied needs of decision-makers and uncertainty surrounding this novel threat), without guidance, the modelling landscape has also become very hard to navigate for decision-makers. Moreover, it is crucial to bring in the decision-makers' views early on into model development to ensure that the assumptions, data, outcomes, and policy scenarios correspond as much as possible to local characteristics and local policy needs.

A group of national governments, funders and development partners supporting COVID-19 responses in LMICs have come together under the COVID-19 Multi-Model Comparison Collaboration (CMCC). The objective of the CMCC is to enhance the use of mathematical and computational simulation models during the COVID-19 outbreak by ensuring their policy relevance, robustness, and usefulness. The CMCC was convened with funding from the Bill and Melinda Gates Foundation and Ministry of Higher Education, Science, Research, and Innovation (MHESI), Royal Thai Government. It brings together the international Decision Support Initiative, the World Bank, World Health Organization, and the Thai Ministry of Public Health to provide management and technical expertise to deliver global knowledge products. Other partners of the CMCC include Data 4 Sustainable Development Goals Partnership (Data4SDG), UK Department for International Development (DFID), Norwegian Agency for Development Cooperation (NORAD), The US Centers for Disease Control and Prevention (US CDC), and the United States Agency for International Development (USAID).

This report has been prepared by engaging with a group of policymakers in LMICs who are responding to the epidemic in their countries (through virtual consultations and online surveys). It will be a valuable resource for decision-makers to understand how models can be used for policymaking and how to assess the model's fitness-for-purpose based on local policy questions and relevant model characteristics. This report will also benefit modellers and funders as it provides a digestible summary of policy needs expressed by decision-makers working on the ground, as well as practical recommendations to effectively report and communicate results. Overall, we hope this report will bring practical ideas for building a global, collaborative, and accountable modelling process that includes different stakeholders in this outbreak.

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All names are in alphabetical order.

BACKGROUND

Since the beginning of the COVID-19 outbreak, decision makers across the world have faced some of toughest policy decisions in their career. Models predicted that in the absence of a suitable mitigation strategy, tens of thousands (or in some cases millions) of lives could be claimed by the virus. For example, it was projected that 90% of the population of South Africa would get infected with COVID-19 by November 2020 if no effective mitigation strategy were to be put in place[1]. The Institute for Health Metrics and Evaluation projected that Brazil would experience between 30,302 to 193,786 deaths by 24th August[2]. To avoid those worst-case scenarios, multiple policies had to be set up in a record time: from procurement of equipment to care for patients, travel restrictions, rearranging routine healthcare services to restrictions on private lives and mobility (e.g. lockdowns). Models, alongside other types of evidence, played an important role in shaping national policies. Models have provided forecasts of the epidemic based on different policy scenarios; they have supported in the planning of healthcare resources to meet the COVID-19 demand and have supported countries in understanding COVID-19 transmission mechanics, including modelling the basic reproduction rate R0. A review[3] conducted only two months after COVID-19 was declared a global pandemic by the WHO found 31 epidemiological models (disease transmission and statistical), and without a doubt, this number has already increased at the time of writing. Experts Firth-Butterfield and Rao, writing for the World Economic Forum, stated that "in the history of humanity, perhaps no data models have been more recognisable than COVID-19's infection and death curves"[4].

While the potential benefit of models for policymaking is uncontested, it cannot be taken for granted. Some experts have pointed out (prior to this outbreak) that modelling-based evidence is also less readily accepted by decision-makers, which will prioritise expert opinion or empirical studies (Behrend et al. 2020). This is because models are often seen as a 'black box': complex to decipher for a non-modelling audience, making it hard to understand limitations from poor data, assumptions, and methods. In countries with no bespoke local models, decision-makers tend to rely on global models developed by academic groups in high-income countries. Those global models produced estimates for several countries, and the academic groups behind the models have constrained capacity to respond to needs on a case-by-case basis or adapt thoroughly models to particular country contexts. In addition, the mechanics of models are inherently complex and hard for end users to appraise, especially in the absence of user guidance and with

1 MASHA, HE2RO, and SACEMA 2020

2 Elliott 2020

3 Wynants et al 2020

4 The World Economic Forum COVID Action Platform 2020

variable reporting between groups.

The current emergency/crisis context also creates additional pressures that translates in the use of data and research methods that may be considered outside of 'traditional' approaches and that makes peer review and validation, two essential elements of quality control, very difficult. Shea et al (2020) find that because of those constraints, good and bad models are equally published, and that the risk of bias or misuse of evidence (with its corresponding negative impacts) is significant[5]. It is not surprising that in this context, policymakers and the general public have grown wary of models[6].

Figure 1 - News headline

This coronavirus model keeps being wrong. Why are we still listening to it?

A model that the White House has relied on has come under fire for its flawed projections.

By Kelsey Piper | May 2, 2020, 8:00am EDT

Source : Vox.com, May 2, 2020

To ensure models adequately support decision-makers, it is urgent to bring in the policy perspective into the model development, communication, and policy translation. Without stakeholder engagement, lack of awareness, understanding or confidence about models will hinder their use and impact (Behrend et al 2020).

The COVID-19 Multi-model Comparison Collaboration (CMCC) was brought together by a number of development partners and national governments to enhance the informed use of COVID-19 models in policymaking, with a particular focus on support to low-and middle-income countries (LMICs)[7]. The CMCC has two objectives: (i) to document model objectives and characteristics in an accessible, practical, and systematic manner, and (ii) to capture decision-makers' needs for modelling support to develop policy responses to COVID-19. To address this second objective, we convened meetings and structured discussions with a group of LMIC policymakers working on their national COVID-19

5 Shea et al 2020

6 Loannidis, Cripps and Tanner 2020

7 The Bill and Melinda Gates Foundation, the Centers for Disease Control and Prevention, the Department for International Development (UK), the Global Partnership for Sustainable Development Data, the international Support Decision Initiative (iDSI), the Norway Agency for Development Cooperation (NORAD), the Royal Thai Government, USAID, the World Bank and the World Health Organization (in alphabetical order).

response (referred to as 'the Policy Group' in this report[8]) and launched two surveys to understand decision-makers' needs across our network. It is important to note that those two surveys are not representative of the community of decision-makers, modellers or funders, as it was disseminated through CMCC networks. Further information can be requested about the survey results or questions, which are not included in this report.

This report builds on this engagement, as well as a review of the available literature. It is organised around six sections, namely an introduction to infectious disease models, overview of experience and intention to use models by decision-makers, determining fitness-of-purpose of models, reporting of results, communication best practices and accountability in using model to inform policy responses.

The audience for this report is decision-makers working on COVID-19 models (to learn about model use and possible adaptations), technical experts and modellers (to understand decision needs for future model iterations and find recommendations about stakeholder involvement or communication guidelines) as well as funders and development partners (to support relevant research and to assist the use of models in policy).

8 See composition of the group in acknowledgement

1. INTRODUCTION TO INFECTIOUS DISEASE MODELS

A. Overview of different types of COVID-19 models

Epidemiological models or mathematical models of infectious diseases intend to model how infectious diseases progress in a given population depending on existing and counterfactual conditions/measures and a disease's characteristic (e.g., transmission rate, incubation, asymptomatic case). There are several variations in epidemiological models whose use depends on the question being asked (which we discuss in the section to follow). Epidemiological models can also aim to inform public health interventions by evaluating what the likely future outcomes could be under different mitigation or policy measures, using a set of assumptions that intend to simplify the real world. Most models aim (i) to minimise risk of disease and (ii) maximise health for the study population. In short, models enable assessment of disease risk, improvement of surveillance, understanding the implications of risk-mitigating interventions, and allocation of resources during public health emergencies. Models can also be used in combination with data to understand processes that are occurring, for example to estimate the effective reproductive number in order to understand current transmission. In this section we will be focused on models that are projecting the impact of interventions in different populations.

Epidemiological models that can perform scenario analysis of interventions can be broadly categorised into mathematical or compartmental models, agent-based models and some types of statistical models. Compartmental models represent the traditional approach to modelling infectious diseases in which the study population is divided, in its simplest form, into compartments of "susceptible", "infectious" or "recovered" based on the natural history of the infection. Compartmental models track individuals in these groups collectively as they move through different infection states and can therefore be used to estimate the number of individuals in each infection state. Among compartment models, the Susceptible-Infectious-Recovered (SIR) and the Susceptible-Exposed-Infectious-Recovered (SEIR) model structures have been most commonly used for modelling COVID-19, for example, the model released by the Imperial College London team on 26 March 2020 uses the SEIR model structure[9]. The SEIR model is usually considered more realistic as it incorporates the period between infection acquisition and onset of infectiousness (latent or pre-infectious period). These models can also provide information on population sub-groups, which can move through these states at different rates. In the case of COVID-19, age-structure has been included in models making it possible to account for important differences such as contact rates within and between age groups, and differences in infectivity and disease severity.

9 Walker et al. 2020

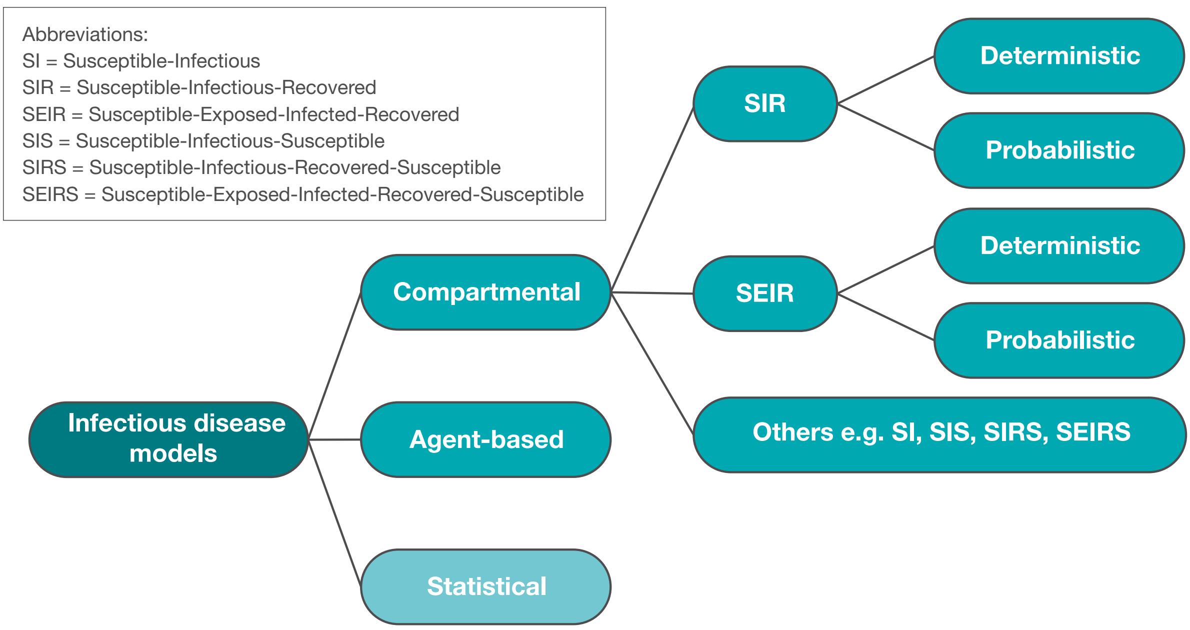
Agent-based models are another class of models that have been used to model the COVID-19 pandemic. These models use computer simulations to create a virtual world of agents (or individuals) who act in accordance with the rules defined by modellers. As agent-based models track the infection process for every individual in a population, it requires much more granular individual-level data, and is most computationally demanding and time-consuming to get results from.

Other models such as types of curve-fitting models that do not incorporate mechanism of transmission explicitly can be used too and rely on using data to fit disease incidence curves that are taken to describe disease dynamics in a population. In May 2020, Institute for Health Metrics and Evaluation (IHME) developed a hybrid model that marries compartmental and with their previous curve fitting models in an attempt to overcome the limitations of the curve-fitting model[10].

An additional distinction can be made between models that are deterministic and those that are stochastic or probabilistic. Deterministic models predict the mean number of events (e.g. infection) over time using fixed input parameters. A deterministic model can be run with a range of parameters, indicating the degree of uncertainty in the outcomes. Stochastic models incorporate random variations in the output and can give a different result for the same input parameters. Allowing randomness is a key advantage over deterministic models when the number of infections is small (i.e. beginning or end of an outbreak) or for modelling in small populations (e.g. hospital wards, schools).

The different model types have been shown in Figure 2 and the key advantages and disadvantages of each model type are summarised in Table 1.

Figure 2 - Universal classification of infectious disease models for projecting impact of interventions



10 Institute for Health Metrics and Evaluation 2020, June 15

Table 1 - Strengths and limitations of different types of models

Model types	Strengths	Limitations
SIR or SEIR models	Simple to run. SEIR more accurately represents COVID-19 natural history than SIR	Does not incorporate granular data on population characteristics
Agent-based models	Intuitive ; Allows more granularity on disease progression and contacts etc. ; Allows more flexibility to model individual-level interventions	More computationally demanding ; Need more individual data specific to the population e.g. size of social networks
Deterministic models	Simple and possible to check the calculation by hand as input parameters are fixed and outcome is the same for each run	Unable to estimate stochastic uncertainty
Stochastic models	Provides the range in which an outcome may occur – more appealing for decision-making purposes ; More appropriate for modelling transmission in small populations	More computationally demanding to simulate the distribution of possible outcomes

B. Data requirements

Data is a critical element of a model and policymakers can be partners in the process of making local data available for evidence generation. There has been a concerted effort to make health informatics, in the context of COVID-19, available to enable and encourage research on the topic even as challenges to open data remain, especially in LMICs[11] [12].

In addition to system-wide challenges to availability of data, modelling the epidemic trajectory of a novel pathogen like COVID-19 is particularly challenging as there are limited data on the disease globally. Normally, most of the key input parameters related to the natural history of the infection tend to not significantly differ across countries or regions and therefore can be retrieved from the existing literature. In some instances, it is useful to have a local data, allowing the model to incorporate unique features specific to a given population or country (especially in social or cultural context) and many unknown parameters may also be estimated from "fitting" the model prediction to the observed epidemiological data, such as the daily number of confirmed cases or deaths, if available.

Below is a list of common input parameters used in infectious disease modelling for projecting impact interventions (Table 2). The ideal situation would also be to populate all models using all local parameters ; however it is not likely to be achievable. Some of these will need to be setting specific, for some, use from other settings may be appropriate, but for others it is not clear whether extrapolation from another setting is appropriate, and this will need to be determined by either expert judgement or by fitting to data in the setting. One example is the proportion of cases that are severe, as we get an idea of how this is impacted by demographic features like age and co-morbidities it may be possible to extrapolate this to other settings, given these co-variate features. However, it may also be important to know the care received and that there might be other currently unknown factors impacting these rates that vary between setting, therefore setting specific data will still be very useful. Another example of a parameter that may vary considerably by setting is the number of contacts that people have with people of different ages in different settings, that will assume importance when answering certain policy questions such as shielding of vulnerable groups of a certain age.

As the epidemic progresses, it will continue to be important to have data from the different setting that is being modelled to determine the impact of interventions that have been put in place as well as in what stage of the epidemic and whether transmission is increasing or decreasing.

11 OECD 2020, May 12

12 Misra, Schmidt, and Harrison 2020

Table 2 - Selected examples of input parameters for models used to project the impact of interventions

Parameters of model	Setting-specific		Data needs
	Yes	No	
Basic reproductive number	X		Case/death data over time by demographic group
Incubation/latent period		X	Follow up of infected individuals
Duration of infectiousness (i.e. infectious period) in the absence of interventions		X	Follow up of infected individuals
Proportion of infections developing symptoms/becoming cases (by demographic group)	X	X	Cohort or serological studies combined with case data by demographic group
Proportion of cases that are severe (by demographic group)	X	X	Case and outcome data by demographic group
Proportion of cases that die (by demographic group)	X	X	Case and death data by demographic group
Time between illness onset to hospitalisation	X	X	Details of hospitalised cases
Time between illness onset to death	X	X	Details of hospitalised cases
Time between illness onset to recovery	X	X	Details of hospitalised cases
Proportion of susceptible/exposed individuals under quarantine	X		Information from ministries of health/healthcare providers
Proportion of infectious individuals under isolation	X		Information from ministries of health/healthcare providers
Mobility (e.g. number of passengers from local and international travel data)	X		Flight or transport data
Contact rates (between different subgroups)	X		Contact surveys
Total population size and population size by age	X		Demographic data
Birth/death rate (for long-term projections)	X		Demographic data
Healthcare capacity (e.g. number of hospital/ICU beds and PPEs available)	X		Healthcare facility reports

SECTION HIGHLIGHTS

- There are many models with varying strengths and limitations. The choice of models depends on the policy question and data available for modelling.
- Model inputs are important in making accurate estimates, to the extent possible. While some model inputs may be generalisable from other settings, others need to be contextualised.

2. EXPERIENCE OF USING MODELS IN PUBLIC HEALTH EMERGENCIES AND DURING THIS COVID-19 OUTBREAK

Models have been used extensively to guide decision-makers during past epidemics and pandemics such as the Ebola outbreak in West Africa and the 2009 H1N1 pandemic influenza response planning and response in UK[3] and the US[3 4]. Between 2014-2015 during the Ebola outbreak in West Africa, there were over 66 models that were published in peer reviewed journals predicting outcomes like number of cases, number of deaths, most affected areas or impact of mitigation measures[5]. Model results were used to inform resource allocation. For example, a model by the CDC that forecast that 70% of all Ebola cases in West Africa would require admission to Ebola Treatment Centres (ETCs) led to increased funding by development partners towards the establishment of more ETCs in Sierra Leone, Guinea and Liberia[6]. Following the emergence of H5N1 avian influenza in 2004-5, the MIDAS modelling consortium developed several models of the potential impact of different intervention strategies on the spread and health impact of influenza pandemics[13 14 15 16]. This work informed influenza pandemic planning globally, most notably in the US and UK[17 18]. This work examined how combinations of pharmaceutical and non-pharmaceutical interventions (e.g. antivirals, social distancing, movement restrictions) could be used to potentially contain or mitigate the consequences of the pandemic. Specific policy options – such as school closure – were studied in more detail in a variety of work[19 20 21], also informing policymaking both during the 2009 H1N1 pandemic and later.

In this current pandemic, many countries, such as the US[22], Australia[23], UK[24 25], South Africa, and Colombia, have publicly acknowledged the use of modelling to inform the policy decisions in the COVID-19 response from the onset. In Colombia, for example, the director general of the National Institute of Health, Martha Lucía Ospina Martínez recognised that COVID-19 control measures in the City of Bogota and the nation were

13 Ferguson et al. 2006
14 Halloran et al. 2008
15 Ferguson et al. 2005
16 Longini et al. 2005
17 Centers for Disease Control - US 2007
18 UK Government Department of Health Social Services and Public Safety 2011
19 Cauchemez, Valleron, Boëlle, Flahault, and Ferguson, 2008
20 Sadique, Adams, and Edmunds, 2008
21 Fumanelli, Ajelli, Merler, Ferguson, and Cauchemez, 2016
22 Wan and Johnson 2020, April 8
23 Australian Government Department of Health 2020
24 Tufekci 2020
25 UK Government

based on modelling findings[26]. In Uganda, the Minister of Health stated that modelling was a foundation in determining the COVID-19 response measures including banning of public transport and closure of schools[27]. In addition, President Cyril Ramaphosa cited, in his national address, models' findings as the primary basis for making the decisions that his government took to address the spread of COVID-19[8]. Model findings were also presented to the South African Parliament's portfolio committee on health to justify an extension of lockdown in the country[28].

Figure 3 - News clipping about President Ramaphosa's national address

> When President Cyril Ramaphosa announced the decision to implement an initial 21-day national lockdown in response to the threat posed by the COVID-19 pandemic, he referred to "modelling" on which the decision was based. A media report a

Source : The Conversation, June 8, 2020

Several models have been developed at global and regional level[29] by international and domestic modelling groups, respectively. International modelling groups are usually academic institutions (e.g., Imperial College London -ICL-, London School of Hygiene & Tropical Medicine -LHSTM-), consortiums of academic groups (e.g., CoMo based at University of Oxford or SDMS based at Johns Hopkins University), independent research groups (e.g., IHME based at University of Washington) or for profit consultancies or businesses (e.g. Boston Consulting Group). As pointed out earlier, some of those models borrow approaches and methods that were developed in high-income settings, but with local data and parameter inputs. Global models can produce results for a range of countries: at the time of writing, the model from ICL produces results for 202 countries and territories, whereas LSHTM produces results for over 120 LMICs. Funding support to those groups for model development comes from national governments (in the form of research grants), development partners (including charities or other not-for-profit organisations). Further discussion about the aims and objectives of those models, as well as the outcomes and policy-scenarios they contain, will be available through a model comparison report produced by the Technical Group alongside this report.

Other LMICs such as South Africa, China, Colombia, and Iran have developed their own individual country models (other government developed or commissioned from local modellers), which reflect the local context. This is in line with the recommendation that

26 Ministry of Health and Social Protection Colombia 2020

27 Xinhua Africa 2020

28 Pieter du and Kyle 2020

29 Some of those such as London School of Hygiene and Tropical Medicine's Imperial College London, IHME, University of Oxford's COVID-19 International Modelling Consortium (CoMo Consortium) are reviewed as part of the CMCC

governments put together a team including statisticians and epidemiologists to nowcast the effect of COVID-19 to inform their response[30]. Compared to global or regional models, the development of a local model allows the country to request estimates for locally relevant policy questions or adapted to context specific characteristics. For instance, in Iran, a model was developed in collaboration with the head of the National COVID-19 Committee and the Deputy Minister of Health to estimate COVID-19 infections, deaths and hospitalisations[31]. In countries where no local model was produced, it is likely that existing local capacities and funding were a major obstacle in developing such evidence[32].

30 Hevia and Neumeyer 2020

31 Sharifi et al. 2020

32 Rivers et al. 2019

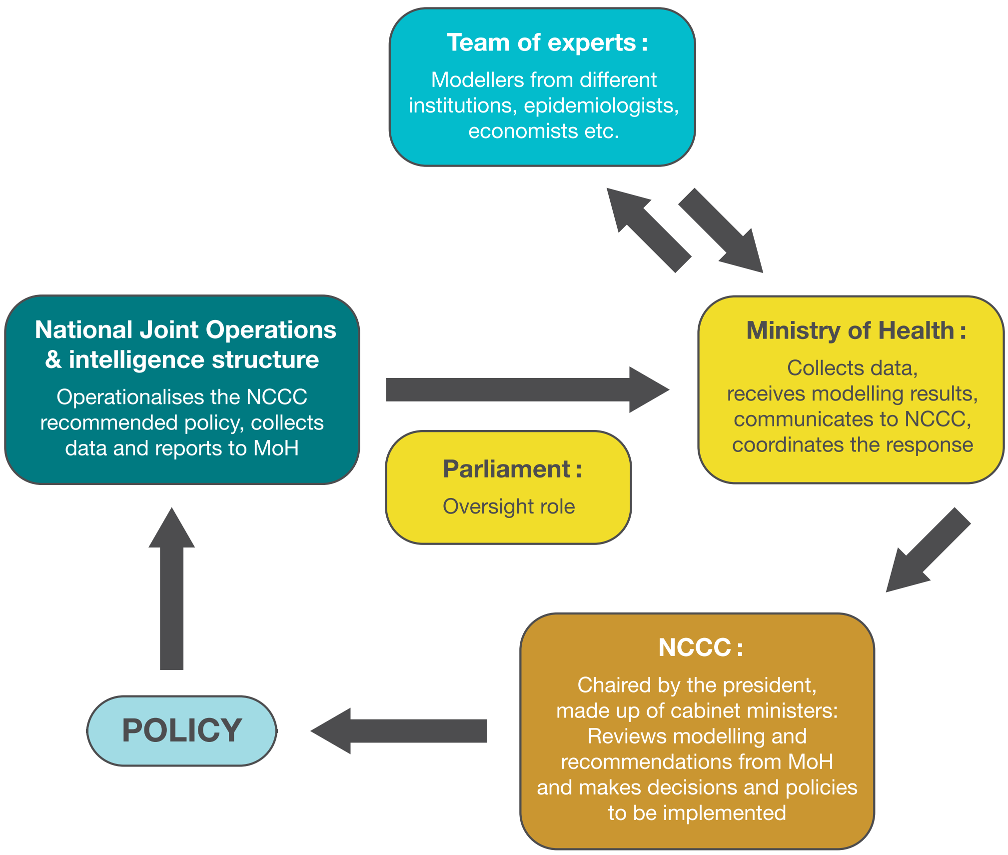
Box 1 - South Africa's work with local modellers

South Africa established a comprehensive plan of work and associated consortium at national level that is in direct contact with the government, including the Ministry of Health, the Treasury and president's office. There are direct links between the modelling group and the decision-makers: for instance, the National Treasury sets their COVID-19 conditional grant based on the work of the costing working group and the COVID-19 modelling consortium. In addition, the consortium works closely with international modelling groups.

The model that has been developed for the country looks at policy scenarios that have been developed in consultation with decision-makers, and account for policy decisions that have been taken by the country early in the outbreak (i.e., stringent lockdown). This is one advantage of this model over international models, which model 'broad' scenarios that often mismatch the situation on the ground.

Figure showing the process of using modelling findings for COVID-19 response in South Africa.

Source: author's adaptation from an article in the Daily Maverick[33]



NCCC: National Coronavirus Command Council

33 Merten 2020

Those ‘bespoke models’ are primarily developed by domestic modellers, although some groups have also been working on country specific models. For instance, Cooper/Smith (a data analytics consultancy) developed a model for Malawi, which was used by the Malawi Ministry of Health to inform their decision to lock-down (however, it was overturned by a court ruling). The model projected the number of infections, deaths, hospitalisations, and effectiveness of the different prevention measures[34]. Another example is Colombia, which has been working with local modelling teams at national and regional level. The capital Bogota has its own model, which was developed with support of a Colombian expert from University College London (UCL), this model is public on the COVID-19 local webpage.

SECTION HIGHLIGHTS

- Country governments are using COVID-19 models to inform policy response in various ways.
- Model outputs are not a standalone solution and must be used as a starting point for policy deliberations.

34 Cooper/Smith 2020

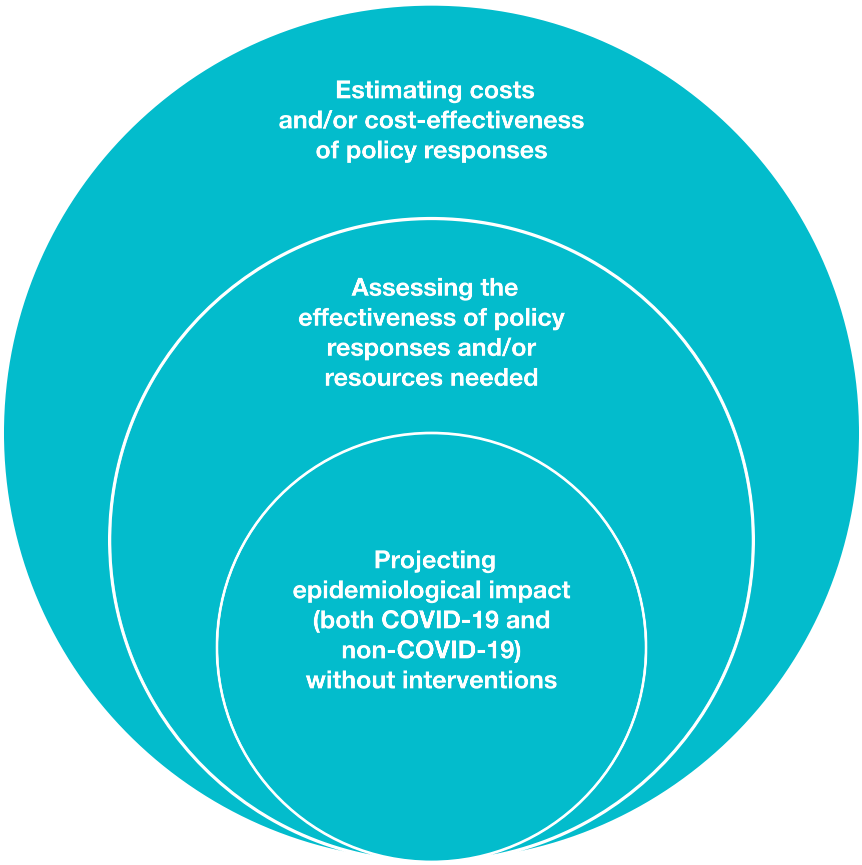
3. MODEL : FITNESS-FOR-PURPOSE

The previous sections have delineated the types of models and their use by countries in responding to public health emergencies. In this section, the suitability of models as the basis for making decisions during epidemics is further explored.

A. Relevant policy questions across the lifecycle of the epidemic in a country

The CMCC Policy Group conducted a survey among members and its network to identify outcomes of interest in the current pandemic. The policy questions have been categorised into three groups, epidemiological (COVID-19 and non-COVID-19), effectiveness of policy responses on health outcomes, costs and cost-effectiveness of policy responses, with each set of questions building on the other in the order above as shown in Figure 4 and described further in Table 3.

Figure 4 - Policy questions derived from the CMCC Policy Group survey



Policy needs and questions evolve together with the outbreak. At the very outset, the immediate need of policymakers is to understand the scope of the disease and the impact on health outcomes and resources if no action is taken (in other words the 'worst case scenario'). Policymakers may look to other countries to understand better what is needed as well as specific information on (unmitigated) transmission rates in the community or through importation. Such worst-case scenarios can support countries in understanding the potential magnitude of the outbreak in their settings and assess the need for policy action. For instance, during the Ebola outbreak, despite uncertainty and lack of information, an alarming early model forecasted 1.4 million Ebola cases as the worst-case scenario; and the publication of those estimates is likely to have contributed to the acceleration of the international response in the initial affected countries[35]. For this purpose, standard epidemiological models should be able to explore these issues.

As countries decide to apply measures to avoid this worst-case scenario, policymakers will want to better understand the effectiveness of different policy interventions in both health and non-health sectors. Typically, this will occur once a certain number of cases have been confirmed in the country, and the outbreak is 'officially' starting. For instance, models can inform how some mitigating or suppression strategies/policy options (e.g., lockdown versus shielding of vulnerable populations) will lead to a reduction in cases and number of deaths, or different requirements in medical care.

At that stage, some countries will also want to rely on epidemiological models that offer 'nowcasts' of the epidemic; in other words, short-term forecasts based on observed data used as part of disease transmission models (which is different from a scenario analysis which is not fitted to observed data). Such information can also support decision-makers on the investment needs for the healthcare system. One survey respondent highlighted "at this stage of [our country's] response, we are most interested in sub-national models to drive resource allocation and distribution, including human resource surge support, within country". Some models also include information about the timing/date of peaks, which can be helpful for countries to understand what future resource requirements will be, and whether the health infrastructure (e.g. intensive care unit) will be able to meet the demand for services.

However, respondents indicated that while outcomes featured in models are useful, there are other outcomes that are not easily available. Disaggregated information on impact, for example at the national and sub-national levels, amongst specific groups such as children and the elderly, has been highlighted as being important to respondents. In some densely populated countries, the relevance of social distancing measures needs to be better understood, particularly in populations living in slums or in refugee camps. The net health impacts, including the collateral impact of COVID-19 on other health domains, has also been raised as an area of interest by the Policy Group and our survey. One survey respondent stated, "it is important to determine the net health benefit of various

35 Rivers et al. 2019

options for responding to the pandemic that leads to the fewest deaths". This would entail modelling the impact of the outbreak, based on different policy scenarios, using a 'whole of health' approach.

As countries move past their 'peak' and begin to explore 'un-locking' their societies, policymakers will want to explore the impacts of, for example, reopening schools, including understanding the conditions under which this may be safely done. Such an analysis will require an understanding of disease transmission among children. On this front, new models are currently being developed and there is interest in LMICs to understand how to design exit strategies that will protect health and limit the risks of another outbreak or 'second wave'.

In addition to epidemiological modelling, there has also been a growing interest in economic modelling or health economics more generally. This is especially important in LMICs where there are significant resource constraints. Countries will, over time, need to grapple with the question of the costs associated with the measures taken to combat the outbreak as well as the costs of the outbreak itself (such as the costs relating to the procurement of additional hospital equipment). Addressing these questions will require adding economic forecasting and economic evaluation approaches to the disease modelling, including cost and utility functions. To give one example, one area that is garnering attention is the development of a vaccine against COVID-19. However, it is not clear if the vaccine, once available in the market, will meet the needs of countries. Early Health Technology Assessment (HTA), which is normally used to inform reimbursement decisions, can be applied at the research and development phase of this process as well. Thailand and Singapore[36] are currently working on such early HTAs to address some important policy questions before implementing a COVID-19 vaccination programme. These include: which population groups should be prioritised for vaccination? How many people should the government aim to vaccinate? Are there any measures, such as antibody testing before vaccination, that can maximise the impact of the available vaccines in the first place? What price is the government be prepared to pay for the vaccine?

Modelling that includes macro-economic considerations are also important given the growing and wide-ranging impacts of the pandemic (and the responses to it) on whole economies. Those two disciplines have long been almost completely separate. These models that include economics and epidemiology could estimate the consequences of household income losses, or the loss of health (through collateral health impacts) and their impacts on the economy, and how perceived risks of infection impact on individual consumption. All this may be important during the recovery planning phase, in addition to the direct healthcare costs of managing the pandemic.

36 Painter 2020

Table 3 - Description of policy questions from CMCC Policy Group Survey

Categorisation of policy questions	Definition of the categories	Examples of policy relevant questions for each category
Projecting epidemiological impact without interventions	This category relates to the estimation of the epidemic impact (health dimension only) of COVID-19 in terms of direct impact, for e.g. infected population, hospitalisation cases, deaths, as well as indirect impact, such as maternal mortality as a result of reducing health facility visits due to fear of contracting the virus among pregnant women. Under this category, the estimation focuses under the situation in the absence of any policy response to COVID-19 in a particular setting.	• Which countries or regions will follow a similar course of the epidemic as seen in China, US, and Europe? • What is the transmission rate in my country? And in different settings (e.g. healthcare workers).
Assessing the effectiveness of policy responses on health outcomes (scenario analysis)	This category relates to the estimation of the effectiveness of policy responses to COVID-19 in reducing the direct health impact, for e.g. reduced infection rate, hospitalisation cases, deaths. The scope can be broadened to estimate the indirect health impact i.e. collateral damage resulting from policy responses for e.g. excess mortality due to disruption to routine immunisation programs, reduced outpatient visits, etc.	• Can national models be adapted to make sub-national predictions (outcomes, timing strategies) incorporating the differences in capacity, preparedness, and risk factors driven by socio-economic and population demographic dynamics such as inequality, migration, testing capacity, access to care, etc. that is not well captured in the national level models? • What is the role of testing post lockdown i.e. the scale and types of testing to be undertaken to avoid resurgence? • When should schools reopen and if so, under what conditions? • What would be the minimum social distancing measures that could be employed to get the best (optimal) results in suppressing the epidemic curve? • What is the impact of the following on model outcomes? - Climatic conditions - Universal mask wearing - Migration - Active surveillance
Estimating costs and/or cost-effectiveness of policy responses	The category relates to the estimation of direct costs of policy response, for e.g. the cost of mass screening, ICU beds, PPEs, quarantining, etc, as well as the estimation of indirect cost of policy responses. The scope can be broadened to estimate the cost-effectiveness i.e. value for money of such policy responses.	• Considering the local context, which intervention is - Most effective - Cost-effective (considering the opportunity cost/collateral damage) - Feasible/acceptable

B. Choosing the appropriate model or research approach to answer policy questions

Models are instruments that help decision-makers understand how changes in disease transmission patterns can determine the future trajectory of the disease in a country. In choosing the appropriate model, decision-makers can ask a few questions to help them decide on the appropriate choice of research which may or may not involve models. What are the main policy questions in the country? Can those be sufficiently answered by models? Are there existing models available to answer the question and can be applied to the local setting? If not, is there local capacity to develop a new model or adapt an existing model, perform the analysis, and interpret the model results? Otherwise, users may deploy other research methods to address the issue at hand. The timeframe in which decisions need to be made is a critical constraint in determining the choice of evidence for policy use.

It is important to underscore that models are not a panacea for answering all policy questions. There is a growing appreciation for not relying on a single model to answer all questions and exploring expert elicitation methods to determine model result[37]. This process is relevant to ensuring accountability of the use of model results in decision-making, as discussed in more detail in a subsequent section of this report. Further, many questions gathered through our survey are actually not questions that could be answered through building models, such as why some individuals are not susceptible to the infection, duration of immunity, proportion of asymptomatic infections. For those questions, other types of evidence will need to be brought in. For example, in the Netherlands, a survey was conducted to elicit attitudes of citizens on prospects of reopening the country[38].

Those questions are important for decision-makers to make an informed use of models and, in general, data and other evidence sources, to support policy development. This process is depicted in Figure 5 below, in which the process is broadly categorised in terms of policy aims, modelling feasibility, model implementation, model reporting and commitment; reflecting both, questions for policymakers and questions for analysts. More information on the technical elements of comparing models may be found in the CMCC Technical Group report[39].

The first step is to define the policy question and determine whether it can be answered with a model. If the policy question cannot be answered by models, other types of research methods may be employed and if there are no existing models, decision-makers may need to revisit their policy-question, engage with modellers to incorporate their policy question in the model or use other research methods. If the policy question can in fact be answered by models, decision-makers should compare and try to identify the most

37 Shea et al 2020

38 Delft University of Technology 2020

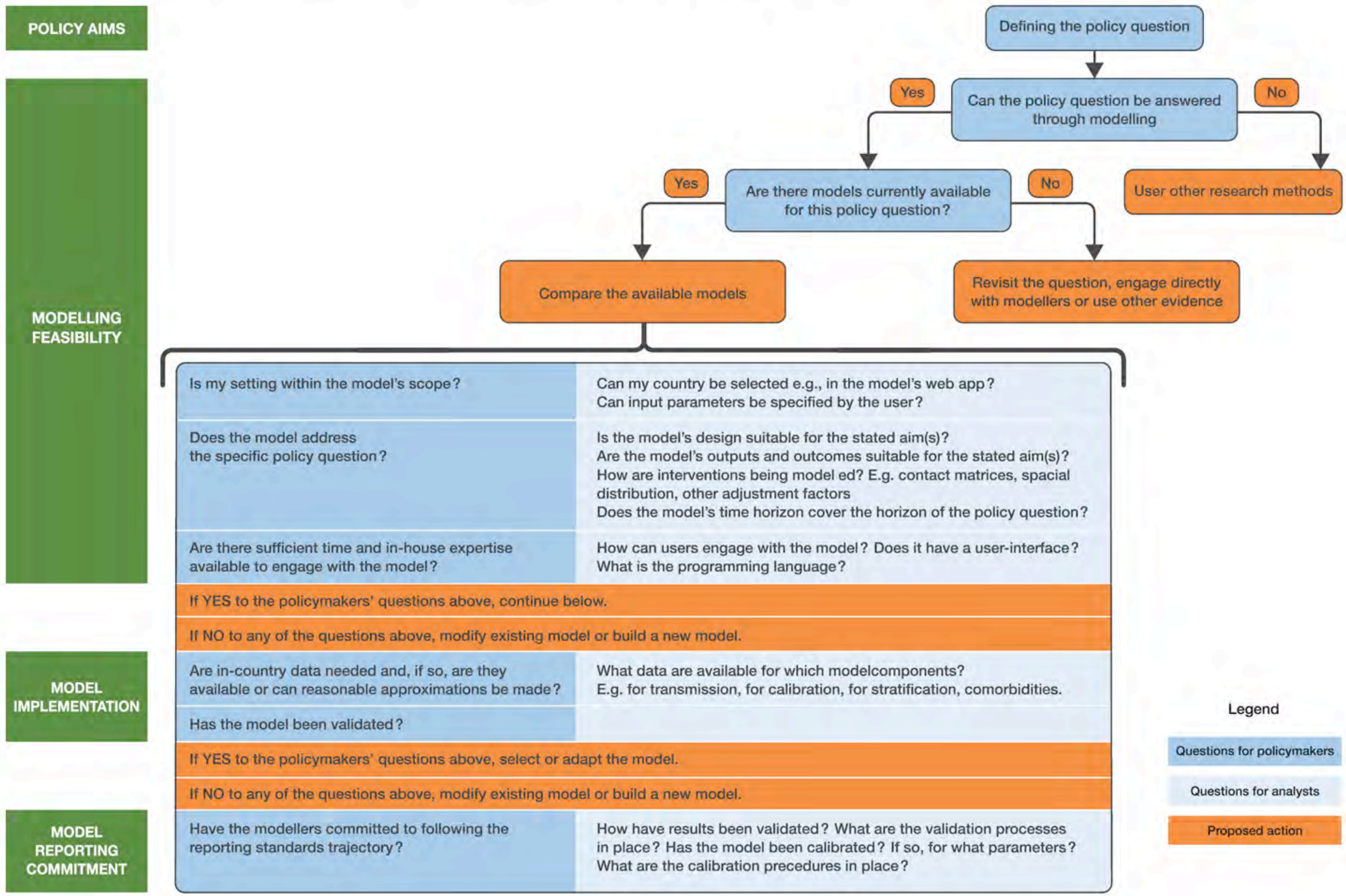
39 The COVID-19 Multi-Model Comparison Collaboration (CMCC) Technical Group. Model Fitness-for-Purpose Assessment Report. August 2020.

appropriate model to address the policy question on hand. In comparing the models available, decision-makers may consider whether their country or setting is within the scope of the model, whether it addresses the policy question of interest, and whether there is local capacity to use the model or adapt it. When implementing the model, availability of local data and validation of the model will be pertinent considerations. If a model checks all these boxes, the decision-makers can select or adapt the model for local use. If the model does not address these questions adequately, local researchers may modify the model or construct a new one. Finally, decision-makers should assess whether the modellers are able to commit to reporting their results in a cogent and comprehensive manner, as outlined by the reporting standards trajectory that is explained in a subsequent section of this report.

SECTION HIGHLIGHTS

- Not all policy questions on COVID-19 can be addressed by models.
- Fit-for-purpose assessments include type of policy questions, model availability, comparing and assessing technical aspects of the models available and the capacity to contextualise the model.

Figure 5 - Issues to be considered when deploying models to inform policy responses to COVID-19



4. REPORTING MODEL RESULTS

In this section, we highlight the issues related to reporting model results by the modellers to decision-makers and how they may support or hinder effective decision-making. Subsequently, building on from the previous section on 'fit-for-purpose' models, we provide key recommendations that decision-makers can follow as a guide to assess the quality of the reports. Furthermore, we propose a 'Reporting Standards Trajectory' that modellers, decision-makers, and funders should agree to use to improve the overall quality, transparency, and accountability throughout the evidence generation process (we discuss accountability further in a separate section).

A. Key principles to consider while assessing the quality of reporting

Using appropriate and high-quality evidence from models sits at the heart in the effort to fight the COVID-19 pandemic. However, assessing whether the evidence presented is appropriate and reliable can be challenging to a decision-maker, who may not be involved in the evidence generation process or may not possess the technical know-how to critically appraise such evidence[40] [41]. Hence, without a clear guidance or reference to what constitutes an appropriate and good-quality reporting of evidence, there is a high risk of decision-makers misusing the evidence and making misguided decisions[42].While there are several guidelines highlighting key principles and good practices for modellers on the conduct of modelling for policy making[43] [44] [45], there is no guidance for decision-makers on how they can critically assess the quality and appropriateness of the evidence, applied to epidemiological modelling. Recognising this gap but building on from such existing guidelines such as the International Decision Support Initiative (iDSI) Reference Case[46], we highlight six key principles that decision-makers can use as a guide while appraising the quality of reporting from modellers. These principles are aligned to the recommendations made on our previous section on fit-for-purpose models.

The six key principles and the corresponding components that decision-makers should look for in a report presented to them by the modellers are discussed below and highlighted in Table 4. While the highlighted principles in this report are not exhaustive,

40 Cairney 2016

41 Muscatello et al. 2017

42 Hardee 2020

43 Behrend et al. 2020

44 Den Boon et al. 2019

45 Price and Propp, 2020

46 Wilkinson et al. 2016

they reflect agreed principles in the field of ‘evidence for policymaking’, and therefore remain imperative to making informed decisions.

Table 4 - Key principles to consider while assessing the quality of reporting

Principles	Components in the report
1. Translation of policy question to research question	• The decision problem should be clearly stated. • The translation of the decision problem to the research question the model is addressing should be clearly and accurately described. • Any gaps between the policy and research question should be acknowledged.
2. Selection of appropriate model	• The choice of model to address the research question should be justified. • The parts of the policy question that are not addressed by the chosen model should be acknowledged i.e. the limitations of the model.
3. Contextualising the model	• The modellers should clearly report any effort to contextualise the model (structural change, including additional parameters, or using local data) and provide justifications.
4. Model validation	• Whether the model has undergone any form of validation and the corresponding outcomes should be transparently reported.
5. Adequately incorporating uncertainties	• The uncertainties within the model structure and the data should be adequately reported. • The implications of such uncertainties to the model results and hence, decision-making should be clearly reported.
6. Declaration of conflict of interest	• Conflict of interests should be published alongside model. • All funding sources should be disclosed.

Translation of decision problem to a research question

COVID-19 models are built to aid decision-making; therefore, it is imperative that such models accurately address the decision problem for it be impactful. Research questions (such as ‘when will the virus peak?’) should not be confused with decision problems (e.g. ‘is it safe to reopen schools?’). While in this example the research question may partially inform a decision to re-open schools, it does not directly address the decision problem given that other information is likely to be critical for policy making, such as the transmission rate among children, the present level of community transmission, and so on.

Therefore, as a pre-requisite, decision-makers should check if the modelling report clearly sets out the decision problem(s) the analyses are seeking to address. In this way, decision-makers have a means to assess the extent to which the evidence presented in the report is directly relevant to their particular problem. Furthermore, decision-makers should look for how their policy questions have been translated into a researchable decision problem, and whether the report adequately acknowledges the gaps in the evidence.

Selection of appropriate model

Answering a specific policy and therefore a research question, requires adoption of the most appropriate model which depends on the policy objectives, the model inputs, and the math underlying it. A variety of models are now being employed to tackle decision problems, but each model differs in its design, specification, assumptions, data used, and therefore, are suitable in answering different research and policy questions[47 48]. For example, if decision-makers want to reopen schools and seek to understand appropriate classroom sizes, using individual-level or agent-based models may be more appropriate since they are able to track individuals in the population and incorporate their characteristics[49].

Therefore, the decision-makers should seek within the report, a clear justification for the choice of the model made by the modellers to address the decision problem. Furthermore, the limitations of such a model must be clearly and transparently reported.

Contextualising the model

Models informing decision-makers should be sufficiently tailored to reflect the local setting and needs. The extent to which COVID-19 affects a population within a country will be driven by local demographics, contact patterns, health care capacity, and the proportion of potentially high-risk groups. On the latter, these include the presence of slum populations, levels of migrants, and people with comorbidities, as well groups whose risk may be influenced by cultural or religious values[50]. Additionally, the data sources of important input parameters such as infection rates, hospitalisation, case fatality rates, and so on, equally play a huge role in context setting. Using data that may not reflect the severity of the problem in the local setting may give misleading predictions and result in inappropriate policy responses[51]. For example, it may not be appropriate for countries like India and Brazil, which have a higher total number of infected cases and total deaths compared to China, to still use Chinese mortality data.

Models should be based on the best evidence available at the time they are developed.

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47 Holmdahl and Buckee 2020

48 Michaud, Kates, and Levitt, 2020

49 RAND Corporation 2020

50 Holmdahl and Buckee 2020

51 Chen et al. 2020

The ability of models to adapt to new evidence and scientific understanding should be regarded as a strength, not as a weakness, of the modelling approach.

Therefore, decision-makers should identify whether the report adequately informs which parameters and data have been localised and which have not. Where contextualisation has not been possible, a clear justification should be provided. An absence of locally relevant data to inform specific parameters could be an important reason. All in all, the report should highlight how relevant the findings may be for that setting so that decision-makers can make value-judgement regarding the appropriateness of the model results for decision-making.

Model validation

Model validation is the set of processes to verify that models are performing as expected, in line with their design objectives, and intended uses. There are several ways to validate a model; (i) face validity which involves experts evaluating the model design, inputs, assumptions etc., (ii) internal validity where the accuracy of coding is checked, (iii) cross validity where the results are compared against other models addressing the same questions, and (iv) external validity, where its performance in real-world is examined[52]. It can help determine potential limitations and possible impact of the model limitations. Weinstein et al.[53]argue that a model should not be criticised if independent calibration data are not available. However, a model criticism may be justified if independent data suitable for validation do exist and either the model fails to produce outputs consistent with those data (or discrepancies cannot be explained) or the modeller has not examined the concordance between model outputs and such data. As such, all models should be validated using goodness-of-fit statistics to assess how well the results fit the observed data to ensure that the appropriate model is selected. This can be difficult as case reporting may be sparse, testing may vary over time, and interventions may already be in place, impacting other variables, and will need to be included in the model to correctly infer parameters.

Therefore, decision-makers should identify in the report whether such models have been validated both internally i.e. able to consistently produce the same output, and externally by calibrating the model with different sources of observed data.

Incorporating uncertainties

No model can tell a decision-maker with certainty what the precise number of casualties will be from the virus over say the next two weeks or give exact dates to impose or lift a lockdown to get the best outcomes. There are still many unknowns that must be assumed by the models, in relation to for example, asymptomatic spread, transmission,

52 David M et al. 2012

53 Weinstein et al. 2003

adherence to interventions, and seasonality. These estimates can be imprecise (for e.g. case fatality will be influenced by several variables including age, ethnicity, presence of comorbidity etc), or its measurement/reporting is not consistent across countries[54] [55] [56]. These make the model data and assumptions subject to uncertainty and so reliance on a single forecast without considering the uncertainties in the model and the choice of inputs, can be misleading, dangerous, and costly.

Decision-makers should examine if the modelling report contains clear information regarding the uncertainties within the model structure and its parameters. Furthermore, the report should clearly indicate the implications of such uncertainties and highlight whether reasonable decisions can still be made.

Declaring interests

All models are born from a series of assumptions and hypotheses to best represent a decision problem and system under consideration. As a result, unlike some other types of evidence, model building can be prone to potential biases from researchers and their funding sources. For this reason, decision-makers should look for clear statements in the report about the modelling team's affiliations, including any potential conflicts of interest, and funding sources (past and present). While not all interests are potentially problematic, other interests may be conflicting and unavoidable, in which case, they should be discussed openly at the outset in order to have clear lines of accountability[57].

B. Reporting standards trajectory

The above section has established what constitutes a good quality of report by highlighting the key principles and corresponding components that enable decision-makers to distinguish if the evidence reported is fit for policy use. However, with a plethora of evidence generated at an accelerated speed by modellers and researchers since the outbreak of COVID-19, maintaining a good standard of reporting has become a challenging task. As a result, studies are being retracted[58], public are losing confidence in model outputs[59] [60], and the decision-makers are sheltering behind the statement, "following the science"[61], or making decisions without clearly acknowledging the evidence base[62]. Ethicists from Carnegie Mellon and McGill universities have rightly said, "Crises are no excuse for lowering

54 Kelly 2020
55 Harries 2020
56 Kay and King 2020
57 Boden and McKendrick 2017
58 Retraction Watch 2020
59 Adam 2020
60 Dayaratna 2020
61 Devlin and Boseley 2020
62 Krishnan 2020

scientific standards"[63], because policy decisions based on inadequate, inappropriate, and untimely evidence can have lasting health and economic repercussions[64].

The quality of reporting as well as its timeliness, therefore, holds a great importance for policy use and in maintaining accountability of modellers and decision-makers. We acknowledge the urgency of the pandemic situation and the lack of internationally accepted recommendation on the timelines for reporting evidence from models can make this task even more daunting. As a result, we propose a '**Reporting Standards Trajectory**', consisting of three stages of reporting standard, 'Minimum', 'Acceptable', and 'Ideal', which demands the modellers commitment in improving the quality of the report over time.

We conducted an online survey among the end users (i.e. decision-makers, researchers, and implementers), to identify key items that modellers ought to report before offering any policy recommendations. The information from these items were deemed important in understanding if the evidence presented is fit for the decision problem and therefore, improving the policy uptake of COVID-19 model results. These factors are ranked below by importance:

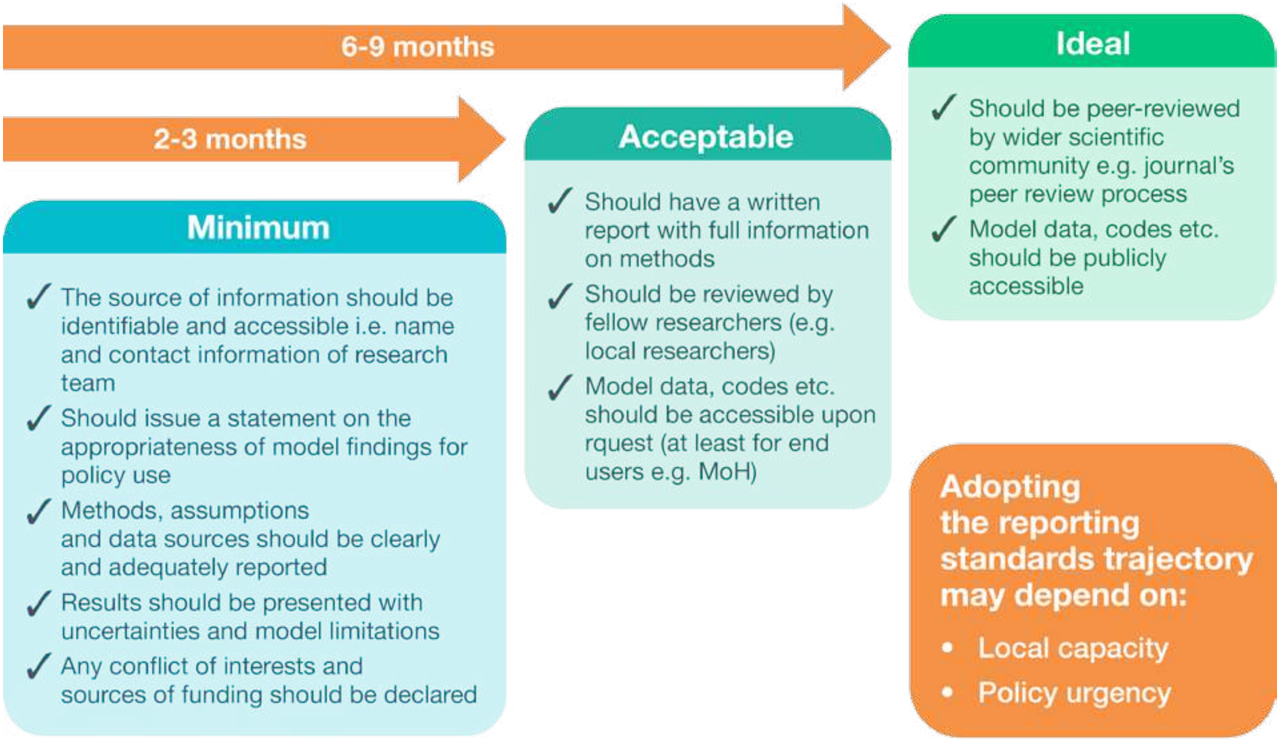
1. Clear and adequate reporting of crucial information relating to, for example, data sources, assumptions, uncertainty, limitations.
2. The contestability of the model i.e. data and codes used are publicly accessible and the findings are peer-reviewed.
3. Uncertainty is well characterised and is clearly presented.
4. Modellers have issued a statement regarding the appropriateness of the model findings for decision-making in a given setting.
5. Modellers have declared interests i.e. their affiliations and sources of funding.

Given the issues of quality and timing of reporting, accountability of stakeholders, coupled with our findings on the types of information sought by end users, we propose a 'Reporting Standards Trajectory', that all key stakeholders (modellers, decision-makers, and funders) should agree to, before collaborating to generate and use evidence from models for decision-making (see Figure 6). The need for and relevance of such a reporting standard trajectory was endorsed by the great majority of our survey respondents (>90%) (of which almost half are COVID-19 modellers and researchers) finding the proposed reporting standards trajectory conducive in enhancing the quality of reporting and ensuring accountability of stakeholders. The proposed reporting standards trajectory was reviewed and validated by the key stakeholders through our second online survey.

63 Carnegie Mellon University 2020

64 Donnelly 2020

Figure 6 - Reporting standards trajectory



The **"Minimum"** reporting standard contains a minimum set of criteria that modellers should meet before sharing the model findings to decision-makers. When decision-makers receive reports from models, they should have a means to communicate with the modellers either for further clarification questions, validation, or future iteration. Therefore, the modeller/modelling team should be identifiable and should share their name and contact information in materials. Second, the report should provide clear and adequate information on whether the evidence from the model is fit-for-purpose. This includes the decision problem(s) the model is addressing, choice of the model, methods used, efforts to contextualise, data sources, the assumptions made, and their limitations. Third, modellers should present the uncertainties in their results and clearly communicate any implications such uncertainty may have for making decisions (e.g. impact on cases estimates or mortality). Modellers who only report deterministic results without any sensitivity analyses should not be relied upon. Finally, it is critical that modellers transparently report their affiliations and disclose any sources of funding, such that any forms of biases can be identified, acknowledged, and clear lines of accountability can be maintained.

The **"Acceptable"** reporting standard builds on from the minimum reporting standards and includes additional criteria that should be met. Within the first 2-4 months of providing a 'Minimum' standard of report to decision-makers, the modellers should aim to provide an 'Acceptable' standard of report. This includes a written report to present their findings that contains all the information described in the 'Minimum' standard of reporting. This written report should be reviewed and challenged by fellow researchers to gain further credibility. Given the short timeline, this process may be conducted by local researchers from similar institutions such that the findings can be critiqued and validated before its use. Furthermore, to ensure the models are error free and reproducible, the model ingredients for e.g. data and codes used should be accessible to end users such as the Ministry of Health upon request.

The **"Ideal"** reporting standard builds on the 'Minimum' and the 'Acceptable' reporting standards and includes two additional criteria that should be met. Since this is the highest standard of reporting, and given the longer timeline of 6-9 months between moving from 'Minimum' to 'Ideal', the model findings should have been published or undergone a peer-reviewed process among the wider scientific community for e.g. in a journal's peer review process, and the model ingredients for e.g. data and codes used should be publicly accessible.

Adopting the reporting standard trajectory

As pointed out by many of our survey respondents, adoption of this trajectory will depend on local capacity and policy urgency. As these factors are subjective, and therefore, inherently difficult to define, funders, modellers, and decision-makers need to have a consensus and make a valued judgement on what the local capacity and policy urgency of that country may be and accordingly choose the right reporting standard. Below we describe how each of these factors may affect the choice of the reporting standard at the initial stage.

Local capacity refers to the overall capacity of a country to generate, appraise, and use model outputs for decision-making. Hence, 'local capacity' can encapsulate the supply side for e.g. the resources in place to capture local data, the technical expertise of the local COVID-19 modellers and researchers to generate high quality evidence in a timely manner, the availability and credibility of local peer reviewers to critique and review the evidence, as well as the demand side e.g. the ability of decision-makers to critically appraise the evidence before using it to make decisions[65]. Considering these factors, decision-makers and funders in settings with 'limited capacity' may accept the 'Minimum' reporting standard to make decisions as a first step, with an agreement to raise the report to the 'Acceptable' standard within 2-4 months, and finally to an 'Ideal' standard within 6-9 months. Conversely, settings with a 'higher' capacity should demand either the 'Acceptable' or the 'Ideal' reporting standard from their modellers from the initial stage.

Policy urgency relates to how quickly decision-makers need to respond to a situation to safeguard its people. While it is imperative that decision-makers act sooner rather than later, their decisions must be guided by good quality of evidence because in its absence,

65 Shroff, Javadi, Gilson, Kang, and Ghaffar 2017

the effectiveness of measures employed may not be realised[66]. For example, countries who used poor quality evidence (or indeed no evidence at all) to impose a full lockdown very early despite only a few reported cases, are now having to lift the lockdown at the peak of the epidemic due to economic pressures[67]. Therefore, urgent needs and decisions should be aided with at least the 'Minimum' standard of reporting. In other instances, where the urgency may not be immediate, for example, when to re-open the economy or issues relating to who to vaccinate once a vaccine becomes available, decision-makers and funders should at least demand reporting to be at the 'Acceptable' standard, if not 'Ideal'. We are not overstating the importance of these questions but merely noting the time modellers may need in generating and reporting a body of good quality evidence to address these issues, in contrast to questions faced at the start of the epidemic.

Attached to each stage is an explicit timeline for modellers to meet the reporting standards, i.e. 2-4 months to move from 'Minimum' to 'Acceptable' and 6-9 months for 'Minimum' to 'Ideal'. Several participants to the survey (including modellers) have raised the need for such timelines. One modeller stated, "the speed for developing reliable evidence is very important". Those timelines are by no means prescriptive. As discussed above, they can be flexible as they are heavily dependent on the local capacity and policy urgency. It is also worth noting that journal review and correction processes take time, as highlighted by our experts and survey respondents. However, 75% of the modellers we surveyed (n=18) found that timeline reasonable and realistic, the rest of the respondents answering, 'not sure'. Lack of transparency and information sharing reduces access and/or hinders the process of getting the model findings peer-reviewed. These issues need to be considered when adopting the proposed reporting trajectory. Realistic timelines should be drafted and agreed on by all three stakeholders (including funders) in advance.

The decision makers and funders can use the reporting standards trajectory as an explicit monitoring mechanism to assess the credibility of modellers, and by seeking modellers commitment to such, they can expect the quality and transparency of the reports to gradually improve over time. The general public can demand that decision-makers, whenever possible, use model results from modellers who have committed to such reporting standards trajectory and demand justification when this is not the case. Hence, the proposed reporting standards trajectory provides a mechanism to hold the model developers and users accountable to each other and to the general public.

SECTION HIGHLIGHTS

- Models can be useful in informing policy only if the results are relevant to the decision problem and reported adequately. Decision-makers may use the key principles highlighted in this section as a guide to identify both.
- The reporting standards trajectory can enhance the quality of evidence and increase accountability of decision-makers, modellers and funders.

66 Matrajt & Leung, 2020

67 Financial Times 2020

5. EFFECTIVE COMMUNICATION ON MODELS

Effective communication is essential element of knowledge translation and policy impact. The need for effective communication is profound in the case of modelling, given the inherent complex nature of model mechanics and the perception that models are 'black boxes' even to scientists who are not modellers. Communication is all the more important in the context of an outbreak such as this, given (i) time pressures faced by decision-makers to implement policies and react quickly to new developments ; (ii) the public interest and appetite for new evidence, (iii) the deep anxieties caused by the pandemic and the behaviour changes many members of the public are expected to make; and (iv) the growing concern around the impact of misinformation or 'fake news', which threatens policy responses across the world. A survey conducted in the United-Kingdom in April 2020 reveals that half of the country's population has come across false or misleading information, and that 40% are finding it hard to discriminate between bad and good information[68]. As highlighted by Dr Sheetal Silal, one of the lead modellers for the South Africa Modelling Consortium, "not everyone is a disease modeller and presented out of context, forecasts of the number of infections to come or burden on hospitals can contribute to the stress many people are experiencing"[69]. At the heart of the communication challenge is public and political trust in models and more widely in science[70], which has been shaken up by the outbreak[71].

For this reason, effective and clear communication, that leaves no room for misinterpretation (accidentally or deliberately) is crucial. As emphasised by science communication experts, the responsibility for doing so often falls on the scientists themselves[72], but communication (and in particular risk communication) is often not part of their curriculum[73]. One practical suggestion could be to work with science communication experts, especially given the workload and time constraints on researchers. However, such positions do not always receive funding, especially in the context of an outbreak where researchers are often understaffed. This section provides practical suggestions if this is not an option.

68 Ofcom 2020

69 Leakey, 2020

70 Romano, Sotis, Dominioni, & Guidi, 2020

71 Aksoy, Eichengreen, and Saka, 2020

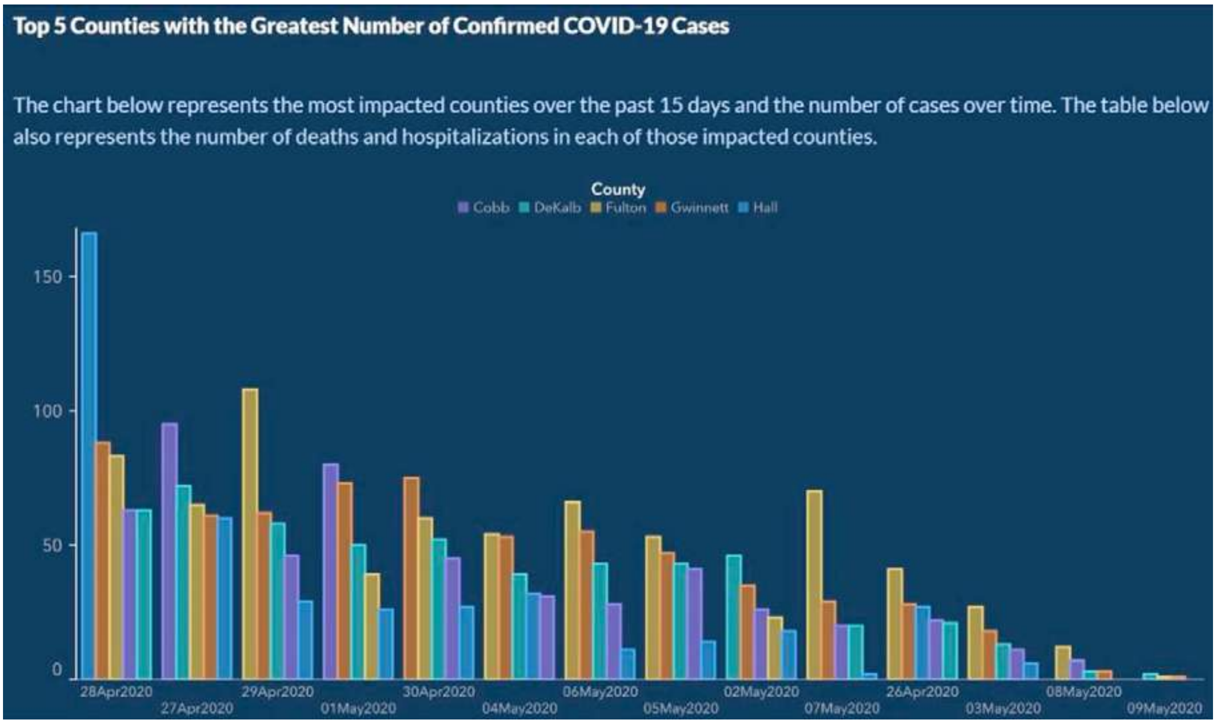
72 Leakey, 2020

73 Green 2020

Box 2 - The tale of a bad graph

In May 2020, the Department of Public Health in Georgia (United-States) published the following graph which appeared to show a downward trend in confirmed COVID-19 cases across five counties in the State.

However, it was quickly pointed out that the x axis, which was originally intended to represent time, was not sorted by date. On closer inspection, the chart appeared to be sorted by bar height to show a declining trend. For instance, while 26th of April appeared to be the first day of the data timeline, it appeared on the right-hand side of the chart, between 07th of May and 03rd of May.



Number of deaths in the state of Georgia

Source: Department of Public Health (withdrawn since public outcry)

The publication of the graph coincided with a decision to allow the operation of non-essential businesses and the lifting of the stay at home orders; prompting many to question whether the 'mistake' on the graph was politically motivated. Such instances have also shaped distrust in the general public's perception of data and evidence.

Source : Financial Times

This section builds on review of the literature on science communication and risk communication during emergencies (using peer-reviewed and grey literature), as well as a survey the CMCC conducted amongst users of COVID-19 model results to understand how different communication modalities (e.g. graphics) were perceived and understood. Again, our survey is not representative of policymakers since we launched it on our platforms (websites, twitter accounts, mailing list etc.) and as a result, the respondents are not sampled. The Winton Centre for Risk and Evidence Communication (at the University of Cambridge) also offers insightful pages[74] about COVID-19 communication. However, despite those limitations, we think that those efforts are informative in offering practical recommendations to improve communication.

A. Simple questions to start

Graphical representations and data visualisation only form part of a broader set of considerations when thinking of communication. Scientists disseminate their results to different audiences, and not all audiences would need the same level of information. Asking the following simple questions can help modellers and related scientists plan an effective communication strategy :

What are the main messages emerging from models ?

The aim of your models, together with what you consider to be a successful and effective communication strategy, are key issues in shaping your message and the way the information is presented[75]. This will inform how the information (model findings) is packaged, and the breath of the content/findings that will be communicated.

Who are you communicating to ?

When communicating model findings, attention should be paid to the kind of target group the communication is meant for. Some of the target audiences include: the general public (such as individuals, households or communities); policymakers who can be at national or regional levels; national and international organisations and funders who make decisions about which activities and programs to be funded or supported[76]. The model information to be communicated should be tailored to suit the target audience to enable them to understand the content, relate to and engage with the information presented, and ultimately, act on it. For instance, other scientists will be interested in more detailed information, including seeing underlying codes and scripts[77] for verification purposes. Decision-makers on the other hand, have expressed a preference for simple visual aids

74 Winton Centre for Risk and Evidence Communication 2020b

75 Illingworth 2017

76 World Health Organisation 2017

77 O'Donnell 2020

with summary messages. The target group may be consulted with to better inform the communication response.

What are the potential risks of lack of communication or bad communication?

Given the context of the outbreak (policy pressure, public appetite and vulnerability, fake news), there are real risks associated with miscommunication that go beyond minor annoyance or inconvenience. Again, as emphasised throughout this report, models are also used extensively to inform policy decisions that will affect the lives of thousands or even millions. As a result, the risks of poor communication cannot be understated. We recommend, identifying from the onset (i) the main message from the model results, (ii) potential caveats and sources of uncertainty in your model, (iii) model results that have a high potential for confusion or controversy. Ensuring accessible, open and honest communication on those points will help limiting the risks that your intended results are interpreted and reported in an inappropriate manner by the recipient parties.

B. Language adaptations

Modellers may be more accustomed to writing for an audience literate in 'modelling language'. However, as highlighted throughout this report, models will inevitably be picked up by a wider audience composed of readers with different science literacy or support. Decision-makers may however be supported by advisors or knowledge brokers with a high literacy to interpret models. Interestingly, journalists have produced resources early in the outbreak to support correct reporting (e.g. article on the Journalist's Resource on reporting on models[78]). However, the language in which models are conveyed remains important and modellers should ensure that their work is **accessible**[79]. In addition, in the context of global or regional models, translation multiplies the chances for misinterpretation[80]. We offer some language and writing advice for modellers.

Avoid professional jargon

This is often the first recommendation when discussing science communication, an expanding field of research in its own right. This is difficult as modelling is a highly-specialised professional field (including in its training) and modellers, along with others with highly specialised technical expertise, may suffer from the "curse of knowledge"[81] – namely the inability to communicate effectively with non-experts[82]. Simple tools have been developed to identify potentially less well understood terms; we feature one in the box below.

78 Ordway, 2020

79 Zhang, Li, and Chen 2020

80 Márquez & Porras 2020

81 Heath & Heath 2007.

82 Rakedzon, Segev, Chapnik, Yosef, and Baram-Tsabari 2017

Box 3 - The De-jargoniser : http://scienceandpublic.com

General vocabulary is classified by the frequency of use in written and spoken resources, often from newspapers, magazines, and books. It can be divided between rare, low, medium, and high frequency. A scan through research articles in several fields show that technical vocabulary could make up for over a fifth of the wordcount.

A 'de-jargoniser' has been produced from a review of 90 million words tabulated in over 250,000 articles published on the BBC website (including the science related channels). The tool allows the user to copy paste text and will highlight words that are of mid or rare frequency which may benefit from an explainer. A rapid use of this tool on Report 12 by Imperial College London shows that only 7% of the words were identified as 'rare' and thus potentially requiring explanation.

Clear definition of terms

Professional jargon cannot be avoided altogether, especially when it comes to modelling. It is important that researchers are clear on the methods and the data used, and as a result, it is sometimes preferable that specialised jargon is used to convey complex concepts to avoid ambiguity. Report writers could consider developing a glossary of definitions for complex terms that can be included in an annex or appendix as part of any supplementary materials. For more 'important' technical terms (e.g. 'agent based modelling' or 'contact matrices'), researchers could consider including a 'call out box' with a definition, that can be included directly next to the term rather than an annex as readers often do not query supplementary materials[83].

Specifically, in relation to COVID-19 models, one of the challenges encountered during the CMCC engagement has been about understanding the details of the specific scenarios that have been modelled. A box summarising the scenarios (and what they represent or correspond to in 'the policy world') should be clearly featured in all modelling work. If the models are presenting forecasts (rather than scenario analysis), i.e. they are fitted to actual observed data and provide a projection of the 'likely 'outcome, then this element should also be clearly communicated (and vice versa, when the models are not fitted to observed data).

83 Pop and Salzberg 2015

Messaging: being clear on what your models tell you

Some of the COVID-19 model reports have several hundred data points in various tables or throughout the text or contain dozens of graphs. It is clearly important to present all the information available for a particular country to minimise any perceived bias and accusations that important information has not been included. However, it should also be recognised that decision-makers and their advisors will not necessarily have time to go through hundreds of pages or indeed even short reports containing many data points. Modellers should consider developing 'top line' messages, that can be generated automatically for each country. Those could be included in 'call out boxes' that point to the main conclusions of the models.

Finally, when comparing scenarios, it would be helpful if comparisons were explicitly made or if results were ranked (for instance in terms of impact). For instance[84], for the text "the number of cases in scenario 1 is **149,987** and in scenario 2 is **306,987**", consider adding in the call out box something along the lines of "the number of cases in scenario 2 is over twice those in scenario 1". This would be especially relevant for efforts that include multiple scenarios, as for instance with the LHSTM model short reports[85] which features 11 scenarios. Other comparisons with known phenomenon/outbreaks (e.g. the seasonal flu) may be employed to further illustrate the scale and magnitude of the figures, although those comparisons should be made wisely[86].

Identify the potential for misconstrued information

This current outbreak has caused anxiety, panic and collective fear across the world as evidenced by problems of hoarding and panic buying, including the stockpiling of drugs and protective equipment in some countries[87]. Researchers on risk communication recommended "efforts to decrease sensationalism, to portray an honest picture, and to elicit the help and understanding of the public"[88]. When researchers reflect on their model findings, they should identify points that may be subject to confusion or controversy.

C. Graphical representations

Graphics (e.g. bar charts, line charts) are a great way to showcase a large quantity of data that would otherwise not be easily digestible in tabular formats, this is relevant for decision-makers who may have less time to study extended reports. Our survey finds that 95% of respondents found graphical representations very helpful. Contrary to what may

84 This does not correspond to any scenario or write-up but was included as an example for this report.

85 Pearson et al. 2020

86 Winton Centre for Risk and Evidence Communication 2020a

87 Hawryluck, Lapinsky, and Stewart 2005

88 Abrams and Greenhawt 2020

be expected, graphics are even more compelling and useful when the data tell a complex story and exhibit unusual patterns[89]. However, as we have already seen in the example from the Georgia Department of Public Health, graphs can also be misleading and prone to errors or manipulation. In our survey, we asked individuals to rank several graphs based on whether they were clear or easy to interpret. One graph scored respectively 88% and 80% on those two attributes, whereas another scored 54% and 35%. This illustrates the fact that not all graphs are equally understood and that their design must be thought through. Moreover, beyond the choice of graphs, as we will see, the scale of the outcomes will also highly impact the appraisal/perception of the lay reader.

Clear labelling

It may appear obvious, but all graphs need to be properly and individually labelled. A member of the CMCC Policy Group emphasised: "Graphs need to be brief, clear, and easy to understand" (although arguably this depends on the audience and their experience and capacity). We have come across graphs that were grouped into a single figure with no clear labelling about what each portion of the graph corresponded to. In one report, the number of cases and deaths were plotted against time, but the x-axis was not labelled, making it hard for readers to understand whether the data were plotted against days, weeks or months.

It important to ensure that the reader always: (i) sees a clear labelling of the axes; (ii) understands how the outcome is expressed (e.g. if representing cases, whether the data points are expressed as counts or rates); (iii) knows the source of the information.

In addition, it is necessary to make sure that when figures are pulled out from a graph in the main body of the text (e.g. when discussing results) that they are always properly referenced back to the correct graph.

Create different charts instead of trying to overlay several into one

Many of the reviewed model reports combine several graphical representations (e.g. bar charts, chart lines, shading of areas). Those charts have been rated lower in the ease of interpretation and clarity in our survey. To further compound matters, the overlaying of different graphs can impede the visualisation of a trend (for instance if two trendlines have very different scales, e.g. one in hundreds and the other in millions) or requires the researcher to create 'dual axis charts', which create even more confusion for the reader.

Unless the chart is trying to display the relationship between the two variables, then creating two charts will be less prone to misinterpretation.

89 Cleveland and McGill 1984

Express model outputs to support end-user decision making

Researchers need to anticipate the needs of end-users (whether policymakers or other stakeholders) when communicating model outputs. To give one example: the number of tests may be usefully expressed as a 'rate per 1,000' when comparing different countries on their relative efforts on scaling up testing. However, such rates are less helpful when projecting ICU bed requirements, and the total number of beds is much more helpful because it can support decision-makers in resource allocation and the planning of equipment and staffing needs. The total number of required ICU beds can also inform decision-makers about whether existing capacities will be overwhelmed by the number of projected cases, a reason why such model estimates have featured heavily in discussions around 'flattening the curve'. The number of cases can be presented in a graph of cumulative cases to show how fast the epidemic will grow, which can also indicate when the 'peak' is likely to occur. In addition, a graph of daily cases can be useful to show daily variations[90]. In contrast, information estimating the cumulative number of tests performed may not be useful.

A recent study by Romano et al has also highlighted the influence of how outcomes are represented in a graph on perceptions about the seriousness of the outbreak (Box 4). In this outbreak, logarithmic scales have been used extensively. Here the vertical axis on relevant graphs that often show the number of cases or fatalities, is graduated by orders of magnitude (1, 10, 100, 1,000), rather than equal increments (10, 20, 30). Log scales are used when the range of data is very wide, so that important changes are not obscured by the scale of the graph[91]. However, the use of log scales may lead to policy makers arriving at inappropriate conclusions as found by Romano et al.

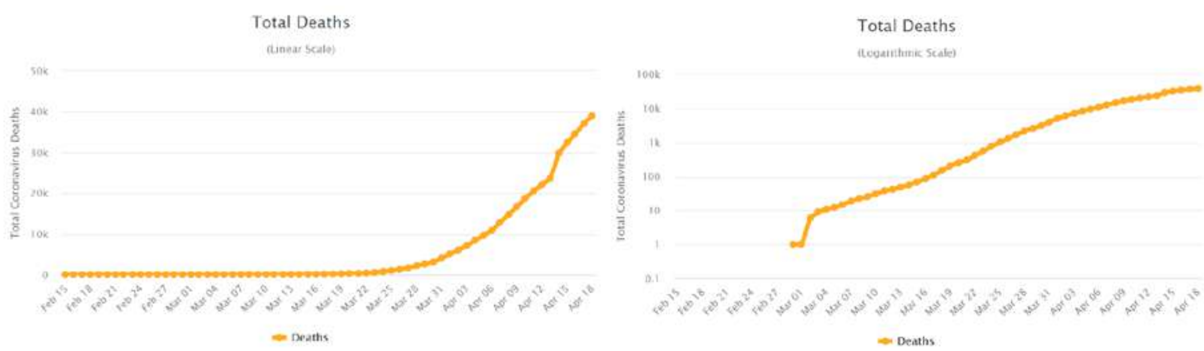
90 Sanderson, Hudson, and Osborn 2020

91 Wikipedia 2020

Box 4 - Log scales and perceptions about the outbreak : an experiment

Romano and colleagues investigated how the presentation in the number of deaths affected public perceptions about the threat posed by the current COVID-19 outbreak. Mass media routinely present data on COVID-19 using log scales, which is a common scale used in research. The team devised a double-blind experiment to test graph comprehension and its effects on attitudes and policy preferences on approximately 2000 participants (residents in the United-States, recruited via Cloud Research). Participants were then randomised in two groups and shown identical data on COVID-19 related deaths on a linear scale or a log scale as below.

Figures shown to participants to the study



People shown the linear scale understood the graph better and made 'better predictions' (or guesswork) compared to those shown the log scale. Moreover, those shown the linear scale also indicated they were more worried about the crisis and supportive of plans to closing non-essential businesses for longer. However, it is worth noting that those shown results on a linear scale were less supportive of the idea of closing non-essential business in the first place. Researchers explain that the linear scale gives the impression of 'a growing pandemic, without any signs of improvements' while 'the logarithmic scale looks flatter and reassuring'.

The authors of the study recommend using a linear scale in this outbreak since they seem to be better understood by the public, which could be considered by modellers working with the CMCC.

Source : Romano et al. (2020)

When plotting model results against time, researchers should reflect on what timelines may be more useful to decision-makers.

Representing uncertainty

As discussed in this report, there is no model devoid of uncertainty. As a result, decision-makers should be fully aware of the extent of the uncertainty and its implications for policy. This is particularly challenging to show on graphs since they tend to be clearer when using point estimates. Report authors should communicate uncertainty by using error bars (standard deviation, standard error, or confidence intervals) or confidence bands or shaded areas (for chart lines). A number of survey respondents highlighted concerns around the presentation of uncertainty, including examples of when it was absent altogether or when uncertainty bands were included, it remained unclear what they referred to. Not highlighting uncertainty, or not doing it clearly “may be misleading for action” as one survey respondent put it. The Winston Centre for Risk Communication and Evaluation also suggests using simple visual depictions (e.g. 1-5 rating scale) to represent uncertainty or quality of evidence[92].

Issues of uncertainty should be explored throughout the reporting, and any conclusions drawn from the results should be framed in such a way to reflect this inherent characteristic of the analyses in all communication format. Risk communication practices emphasise the need to articulate uncertainty, using equivocal expressions such as ‘likely’ or ‘possible’, perhaps even adding a mention of a numerical probability when possible[93]. Educating the audience on the possible sources of uncertainty (e.g. expert disagreement, lack of information) is also a good means to manage the audience’s expectations about the model forecasts. In addition, it could also help communicate on which areas/parameters present the most uncertainty, thereby encouraging data collection efforts.

D. How do you choose the right communication channel ?

One final consideration relates to the format and communication outlets used by modellers and report authors. For entirely understandable reasons, many modelling groups typically disseminate their work through peer reviewed journal publications. Given the possible uses for policymaking and for communication with other stakeholders, peer reviewed journal publications will not be sufficient to achieve policy impact. Combining different approaches will be important to reach all relevant stakeholders.

During this outbreak, we have seen model results presented in the following formats :

- **Long form reports :** those reports provide very extensive information which is very useful for those interested in the modelling methods and data, although they may be less accessible for time pressured decision-makers. Moreover, long form reports take time to update, which may be problematic in this outbreak given the constant refining and updating of models.

92 Winton Centre for Risk and Evidence Communication 2020a

93 Zhang et al. 2020

- **Short country reports :** this was an interesting initiative from the groups at LHSTM and ICL. LSHTM reports produced country snapshots of model results, combining a mix of graphs and data tables. ICL also produces reports (either accessible in html or downloadable as PDFs)[94] with updates done on a daily basis (updating is automated to make it less time consuming). Such reports seem to be helpful for decision-makers. Moreover, their format (PDF) means they are accessible to most users with access computers or phones, can be printed and annotated by decision-makers, and the data and charts can easily be copy pasted to feature in official documents.

- **Interactive websites :** IHME and the ICL have also developed interactive interfaces that allow users to input data themselves or to select particular dates, countries (for multi country comparisons) and outcomes. Those websites empower users to create data representations and download data suited to their needs. Tracking website features can also be helpful to track how users are interacting with the data and can inform future communication efforts (e.g., access stats, identifying the top data queried). Such tracking information should be harvested and can be published to research communities to improve communication.

- **Online events such as webinars :** those activities seem particularly important in the context of this outbreak given travel restrictions in place in most countries. Online events also give an opportunity to a wider audience to ask questions to modellers and to direct queries (one aspect of communication which we will discuss under the accountability section). Actively promoting webinars in many platforms (websites, social media, etc.) is important to ensure adequate reach of participants.

- **Other published material** (online or physical): include newspapers, blogs, websites, videos and podcasts.

Finally, the timing of communication is important. Research into risk communication emphasises the need to maintain communication activities throughout the pandemic, either to reinforce initial messaging or update on new evidence or in the case of modelling, updating of results.

94 MRC Centre for Global Infectious Disease Analysis 2020

SECTION HIGHLIGHTS

- Effective communication between modellers and policymakers is critical to empower policymakers in making evidence-informed decisions to counter pandemics.
- There should be special attention to the language employed: online tools help identify professional jargon, and call out boxes should be included to ensure that reporting is accessible to a wider audience.
- Graphical representations are a powerful tool for conveying messages; however, care should be taken in their use and design. Avoid the use of multiple axes (with multiple scales), overlaying too much information. Special attention is needed when labelling graphs and data clearly.
- Surveyed respondents highlighted the need for modelling groups to communicate uncertainty clearly to support effective risk communication.
- Clear messaging, perhaps included in highlights or call out boxes, can substantially improve the interpretation of the data, especially for time-pressured decision-makers.
- Different communication streams and formats should be employed to meet the needs of different audiences.

6. BRINGING IT TOGETHER : IMPROVING ACCOUNTABILITY IN MODEL INFORMED POLICY RESPONSES

A. Defining accountability in the context of the outbreak

As the word suggests, accountability refers to the principle that individuals, organisations and the community are responsible for providing 'an account' of their actions[95]. Accountability is very often equated with responsibility, but those are not synonyms.

In public health crises, accountability is often discussed in the context of policy decisions (at the local, national, and global level – including development partners). Because decision-makers have a duty to employ their resources towards minimising the harm of the outbreak and safeguarding the health of its constituencies, it is often seen as their responsibility (moral and pragmatic) to rely on the best evidence to inform policies and actions. Accountability there would mean that decision-makers (as well as their advisors) should be able to explain why they have implemented specific policies, and as a result, what the evidence underpinning their decisions is (as is shown in Figure 7).

Figure 7 - Headline article demanding the UK government to publish the evidence behind its COVID policies

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Coronavirus outbreak

Letters
Fri 13 Mar 2020 16.48 GMT
2057

This government must show us the evidence behind its Covid-19 policies

The prime minister must share the data behind his decision making, writes **Dr Michael Sheard**, while **Neil Martinson** says that such decisions must be subject to challenge. **Dr Milan Dagli** fears the government's inaction will worsen the epidemic and **Roger Hunter** is worried the over-60s are being written off

Source : The Guardian, March 13, 2020

95 Gregory 1995

Less often discussed but equally important in the context of this outbreak is the accountability of four other actors: private citizens, other government bodies responsible for implementing policies, researchers, and funders (of research) and/or development partners.

Private citizens are accountable for their actions, in particular following the guidelines as set out by public health agencies or other parts of the government. They are held accountable for their actions either by law or regulation. Government bodies (e.g., local authorities, hospitals, schools) are also accountable to decision-makers for following policy direction, although this may different between countries depending on how those relate to decision-makers.

The accountability of researchers, especially in this context, has not been widely discussed, although a literature on research integrity, a closely related concept but which also includes misconduct or misrepresentation, has emerged in recent years. Because research outputs during a pandemic are used for decision-making, it would seem axiomatic that such evidence be as robust as reasonably possible. If framed solely in narrow technical terms, robustness is difficult to assess in the context of this outbreak, because COVID-19 is so novel, and there are many data gaps and sources of uncertainty that complicate modelling. In addition, the context of a pandemic emergency also raises issues around research ethics, including public benefit (to which extent it informs decisions that matter for different constituencies), accountability to research participants and the consideration of uncertainty. Recognising those constraints, a national research integrity office has been created in Luxembourg to promote good research practices and a code of conduct during the COVID-19 outbreak[96]. It is worth noting that the concept of accountability in research is applied very strongly in some fields, such as practical engineering[97].

Funders of research often require that research funded by them conforms to professional standards as set out in a research institute or academic group's code of conduct, and in accordance to an individual country's regulations. However, it is not clear how else researchers are accountable to their funders.

We summarise those relationships in the following table (although it is worth noting those are not comprehensive descriptions).

96 Bramstedt 2020

97 Madhavan 2020

Table 5: Summary accountability relationships (during disease outbreaks)

Who	To whom?	For what?
Decision-makers	General public (e.g. their constituencies)	Give an account on how decisions were taken, and what evidence has been used
Researchers	General public, funders	Conduct their research using robust and unbiased methods and data, conforming to professional standards, and that supports decision-making
Implementing government bodies	Decision-makers	To action and implement policies at the local level
Funders	Boards and to the general public when public funds are used	To ensure that research that is funded conforms to professional standards and supports decision-makers
General public	To each other, held accountable by regulation or law	For their actions, in particular to follow government advice to safeguard health

To increase accountability, we consider the following steps to be essential.

B. Definition of clear roles and lines of accountability

In many countries, the relationships between the different stakeholders in the pandemic are not well-defined. Stakeholders have been defined as "individuals, organisations or communities that have a direct interest in the process and outcomes of a project, research or policy-endeavour"[98]. Rajan et al (2020) researched this issue during this current outbreak and identified the following problems with the current decision-making architecture: (i) not all countries have made their COVID-19 task force membership public; (ii) confusion/lack of transparency over who is consulted to provide advice to decision-makers; (iii) overrepresentation of some types of experts (including epidemiologists) and underrepresentation of others (experts on non-COVID-19 health or on the societal consequences of COVID); (iv) lack of involvement in civil society.

This lack of clarity, which partly reflects problems in the process of generating and translating evidence into policy, has predictably led to implementation challenges. For example, lockdowns have been contested in the courts in many countries. In Malawi, the

98 Boaz, Hanney, Borst, O'Shea, and Kok, 2018

High Court suspended the implementation of a very stringent lockdown (including closure of central markets and no support policy for the provision of essential goods and services) one day before the start of the lockdown[99]. In the same manner, courts also challenged the extension of the lockdown in South Africa[100].

Without a clear definition of accountability lines, and an articulation of a fair process to support accountability by different stakeholder groups, the decision-making process may be captured by selected voices and vested interests. Nor would there be a guarantee that it functions adequately to formulate suitable policy options and to select those on the basis of the outcomes they produce.

C. The benefits of stakeholder engagement

Improving the understanding of models (their objectives, strengths, and limitations), as well as better two-way communication between developers and end-users, could create ownership and enhance the accountability and trust in the estimates produced by those models. Of the key principles Behrend et al[101] identified for modelling efforts, engagement with stakeholders from the "formulation of questions to discussions on the implications of findings" is especially important. Engagement can be defined as "an iterative process of actively soliciting the knowledge, experience, judgment and values of individuals selected to represent a broad range of direct interest in a particular issue, for the dual purposes of: creating a shared understanding; making relevant, transparent and effective decisions"[102]. Stakeholders in Behrend et al. were mostly decision-makers, although it is worth noting that other stakeholders such as patients (and their representatives) or the non-governmental sector could also be involved.

In our survey, several respondents referenced the need for a more participatory approach to modelling. However, stakeholder engagement takes time and resources (two scarce resources during an outbreak), and is not without challenges. For instance, a respondent to our survey commented that in their experience of collaborative modelling "decision-makers may try to influence the modellers to get an output that fits what they have in mind or support their priors". Capacity of different stakeholders also may need to be built for successful engagement[103]. Moreover, decision-makers may be directing a significant time and attention to planning the practicalities of the outbreak response and may not be available for such engagement.

99 Goitom, 2020

100 Coetzer, 2020

101 Boaz, Hanney, Borst, O'Shea, and Kok 2018

102 Boaz, Hanney, Borst, O'Shea, and Kok 2018

103 Li, Ruiz, Culyer, Chalkidou, and Hofman 2017

However, engagement has the following benefits:

- Managing expectations both on the part of end-users (often policy makers) and modellers about what models can achieve.
- Making sure that models correspond to policy options which are culturally relevant and socially acceptable (Behrend et al 2020).
- Decision-makers can also bring in expertise given their knowledge of the policy needs and local context: they may be able to support researchers in making initial decisions pertaining to the analytical perspective, the objectives, time horizon; as well as advising on data gaps or assumptions; this last point is particular important in instances where models are not locally developed such as some of the COVID-19 models we have seen.
- Engagement also ensures that decision-makers are aware of models in the first place. In many instances, decision-makers and other end-users may not have a full knowledge of availability of evidence and may not have the time or resources to query search engines. This is especially true in the context of COVID-19, given the fast-paced nature of evidence publication.

In the CMCC survey, we asked decision-makers and modellers to reflect on their experiences of collaborative modelling[104]. Selected lessons learned and challenges are listed in Box 5.

104 The question asked was "Can you think of an example of successful collaborative modelling efforts where decision-makers and modelers worked together to best address a policy question (from definition of decision problem to implementation of research findings)? Please describe."

Box 5 - Collaborative modelling: experiences from the field

- *Detailed and shared understanding of the problem space and the policy options is essential at the onset of such collaborations. One respondent describes it as "the single most valuable part of the entire process". However, this often requires multiple meetings and is time intensive.*
- *Involvement of stakeholders requires modellers to articulate complex concepts (assumptions, methods, etc.) in lay terms, which is very difficult to do. Without this step, involved stakeholders will not be able to contribute fully.*
- *Modellers seek input from the general public and policymakers during the initial stages (decision problem definition), but such participation can also be very valuable during model development and to inform communication.*
- *Decision-makers are sometimes faced with more than one demand from local research groups. It is often difficult to understand which one to engage with or whether they should engage with more than one.*
- *Researchers grapple with funding problems when working on an outbreak. They are sometimes not able to respond flexibility to readjust their program of work if their funders do not allow it.*
- *Capacity and collaboration between decision-makers and local research groups should be maintained at all times, not just during crises. In Australia, a respondent has highlighted the importance of a decade long relationship between the two stakeholders that has led to a collaborative effort on COVID-19 modelling.*

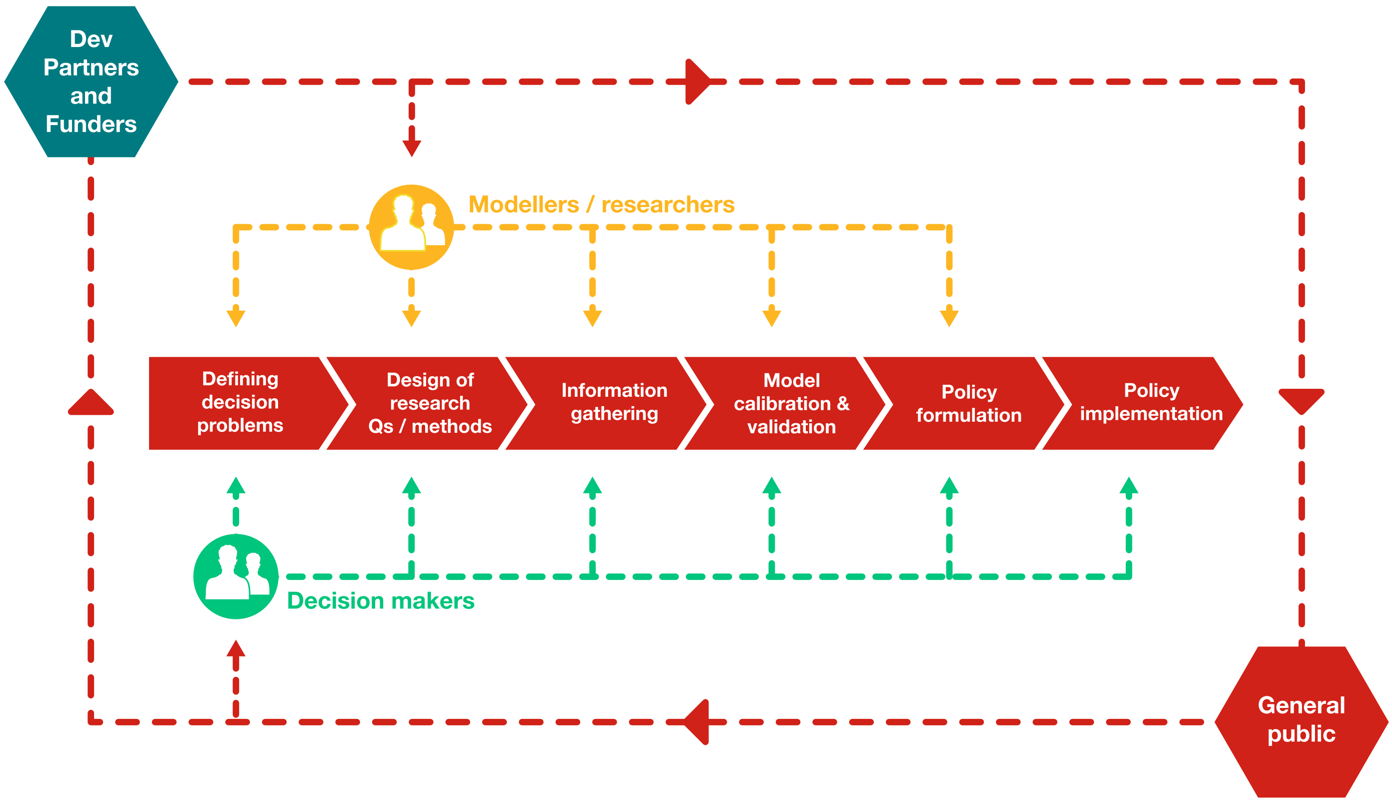
The manner in which stakeholders will be engaged will be important. Planning and sufficiently resourcing this engagement is important to avoid that (i) stakeholders are selected in an informed manner, (ii) the risks of relying entirely on a single source of expertise are minimised, and (iii) the dominating effects of 'loud voices' are mitigated. Broader participation can also help address the problems of relying on early thinking that may receive disproportionate attention and weighting, at the expense of ideas generated through a clear consultative process (Shea et al. 2020). Shea et al. (2020) recommend a formal expert elicitation method that places decision-makers (e.g. public health authorities) at the centre of the process to ensure risk- and evidence-based decision-making.

D. Collaborative efforts

Our engagement with different stakeholders (i.e. decision-makers, modellers/researchers, and funders, development partners) within the CMCC has highlighted the importance of defining a collaborative framework for modelling to maximise its policy impact.

We build on the framework from Behrend et al. (2020) to illustrate how different stakeholders can work together, not only at the research stage, but adding considerations around policy formulation and implementation stage. We also discuss the role of the general public and development partners and funders in this framework. We acknowledge that such collaborations will be very difficult to implement in an emergency context, because of capacity and resource constraints from all stakeholders shown on the graph, not only researchers. However at the same time, because of the emergency context (that creates pressures and high stakes), a collaborative engagement framework is all the more important to consider from the onset.

Figure 8 - Collaborative modelling and implementation



It is important to point to what is perceived as a tension between research independence and stakeholder involvement. Too much contact with stakeholders can be seen as an interference and risk to the integrity and quality of the research, which can also impair the trust that the general public puts on the research process. For instance, in the context of global health research, researchers have shared experience of censorship or interference from funders, especially when it comes to evaluating large scale, donor funded health interventions.[105] For this reason, it is important to define how different stakeholders should be involved, when in the process (e.g. for which the steps as set out in Figure 8), what their role is, and for how long. In addition, conflict of interest declarations also helps reducing the risk of undue interference. In brief, a set of norms and rules need to be established within some form of governance structure.

105 Storeng and Palmer 2019

As described above, collaboration between modellers/researchers and decision-makers throughout the entire life cycle can be very beneficial to ensure that models are fit-for-purpose and appropriately translated into policy. Modellers/researchers should involve decision-makers from the onset to articulate problems clearly: researchers have the knowledge and skills to translate such problems into research questions and develop corresponding methods that will allow their investigation in a robust manner. As discussed earlier, decision-makers contribute to this process by bringing knowledge and experience about policy-making and about a country's particular context (policy or wider context), as well as relationships and contacts that can support research teams in information gathering or model calibration and validation where appropriate. Moreover, through this engagement, researchers can also help shape decision-makers' perspectives of the decision-problem by pointing to relevant literature or international experience. It is important to note that such engagement is demanding on the time and capacity of both parties: researchers and decision-makers. For those reasons, it important to raise this process early to ensure appropriate planning for such engagement.

For this relationship to function, both decision-makers and modellers should be working under the scrutiny of the general public and development partners/funders. Funders should pay particular attention to the ***process*** that surrounds how research is being conducted, especially in an emergency setting, to ensure adequate levels of collaboration. Again, because of concerns about interference, funders should not interfere with the design of methods, data collection, and more importantly, analysis and results[106]. However, funders will play an important role when it comes to shaping (i) the process underpinning the research (e.g. stakeholder involvement), as well as (ii) reporting standards trajectory that could be pre-agreed (as seen in the previous section). All stakeholders are also accountable to the general public, who are, down the line, the stakeholders who are most impacted by successes or failure of policy implementation.

E. Setting up a communication line between end-users and modellers.

In the context of an outbreak, models are often refined and updated in light of new information and data; and giving end-users the possibility to raise questions, as well as to comment and provide feedback to modellers can improve future iterations. In South Africa, models were made public after an initial period of development and a process for commenting was set up. On this point, one survey participant from South Africa highlighted that "the comments from the public have been useful and surprisingly perceptive of weaknesses of the models". However, a 2019 review of the influenza response in the US showed that only one in five influenza public health practitioners (working in three public health organisations) had had a direct communication with modellers[107].

106 Storeng et al. 2019

107 Rivers et al. 2019

The opportunity to provide feedback and comment on the modelling work was mentioned as important by a number of survey participants when discussing accountability. One survey respondent noted: "I found an error in one of the models (a specific country's number of cases far exceeded the country's population) and emailed the organisational email (there was no author email listed) but never heard back. There should be clear process for submitting errors to the authors themselves and an agreed timeline for when a response from the authors would be provided"[108]. Given the workload of modellers, not all comments may be addressed. However, a practical solution to this could be the inclusion of a clause or instructions for gathering comments, especially in pre-print versions, and for modelling groups to set up a process and plan for resources ahead for addressing queries (especially in the case of factual errors as pointed by our respondent). Online events can also be organised to present the work and include a Q&A session. An interesting initiative was the organisation of a 'ask me anything' webinar, which aimed to link end-users of survey and modellers to ask questions about results and future work.

Given restrictions on travels and public events in this outbreak, online events and the creation of a process to submit comments are important mechanisms to sustain a link between study authors and end users.

SECTION HIGHLIGHTS

- There is need for collaboration among stakeholders to enhance the usefulness of any modelling.
- To support such collaboration, a process framework that articulates the roles and responsibilities of various actors to enhance accountability, needs to be developed.

108 Italics/emphasis were added by the authors of this report

CONCLUSION

The COVID-19 pandemic has mobilised the national and global health communities in an unprecedented manner. The production of evidence and decision-support tools, including models, has already saved many lives by informing decision-makers on the most appropriate course of action. While we, the contributors to this work, recognise this potential for models, we also observed important gaps in the existing efforts that limit their potential usefulness. Our intention is to inform future modelling work and to bring together different communities (modellers, implementing agencies, funders, decision-makers) around the needs of those working on the ground.

This report has built on our engagement with the CMCC Policy Group, Technical Group and Modelling Group and our online surveys to provide rapid and practical recommendations to decision-makers and modellers on the way forward. To our knowledge this report represents, at this point in the outbreak, the most comprehensive and inclusive documentation of different stakeholder views, despite the limitations we have set out earlier. We intended to articulate the experience of LMICs in their use of models, and to provide practical guidance on how to select models that are fit-for-purpose to inform local policy needs (in Section 2 and 3 – in particular the flow chart). In Section 4, we also sought to develop reporting practices that could enhance the use and quality of any modelling exercise. The reporting trajectory developed will support both decision-makers and researchers, but also funders when considering resourcing modelling groups. In Section 5, we provide advice on more effective communication of the methods and findings of models to ensure that results are communicated impactfully. We end this report by bringing those elements together and suggesting an inclusive framework for collaborative modelling that sets out processes (definition of roles and accountability lines) for successful engagement. We believe these elements are all important to guide all countries across the world in their current or future efforts against COVID-19.

We want to end this report with the belief reflected by all partners and contributors of the CMCC of the importance and desirability of pursuing a collective, multi-stakeholder (modellers, policy makers, funders and the public) response as part of a process of evidence generation through to policy implementation. Only through such collaboration, which we acknowledge will take time and resources (and may be fraught with some additional risks), will the COVID-19 outbreak (and other future outbreaks) be effectively tackled.

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