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CORONAVIRUS (COVID-19): ANALYSIS

Covid-19: Modelling the epidemic in Scotland

Background

The Scottish Government, like other governments around the world, is responding to the Covid-19 pandemic. A key part of this response is to model the potential spread and level of the virus in Scotland, and to compare the Scottish experience to other parts of the UK and other countries around the world. The results of this work are used to help the Scottish Government and the wider public sector, and in particular the health service, plan and put in place what is needed to keep us safe and treat people who have virus e.g. to decide how many Intensive Care Beds (ICU) we need for Covid patients.

Key Points

- Modelling of the epidemic in Scotland is undertaken to look at the progression of the epidemic and to inform logistical response required.
- This is done over two time periods. Short term, for the next two weeks, and longer term. Both these help to forecast Covid-19 in Scotland.
- A number of different models are used from academic groups across the UK and Scottish Government.
- We use the value of R to talk about Covid-19 in Scotland. On the 8th May R in Scotland was estimated at between 0.7 & 1.0.
- Before the stay at home guidance was put in place in Scotland, the value of R was significantly above 1.
- The modelling shows that the number of cases, hospital and ICT use and deaths are likely to fall slightly over the next two weeks.

Purpose of this publication

This document will describe how Scottish Government's modelling of the Covid epidemic is done, how it is used to estimate the reproduction rate R and what key messages currently are from this work.

How Covid-19 is modelled

There are two types of modelling which are done to help us respond to Covid-19. The first type of modelling is about the Covid-19 epidemic. This is called "epidemiological" modelling. The second type of modelling uses the first type to help plan our response to Covid-19 in Scotland. This is called "logistics" modelling.

Epidemiological Modelling
There are a range of academic groups doing epidemiological modelling of Covid-19. These academic groups feed in their results to a group at a UK level called the "Scientific Pandemic Influenza Group on Modelling (SPI-M)". Scottish Government uses the modelling from this group along with its own modelling (using a publically available Imperial College modelling code) to advise on the potential future progression of the Covid-19 epidemic in Scotland e.g. in terms of the reproduction rate R and what might happen if we ease lockdown.

The SPI-M group feeds its modelling expertise to the UK Scientific Advisory Group for Emergencies (SAGE) which gives advice on Covid-19 to governments across the UK. In Scotland this is through the Scottish Government COVID-19 Advisory Group which considers this advice and potential impacts in Scotland.

There are a number of groups who are modelling the Covid-19 epidemic in the general population in Scotland, including:

- London School of Hygiene and Tropical Medicine
- University of Warwick

- University of Manchester
- Scottish Government (using the publically available Imperial College Modelling Code)

Scottish Government (using the publically available Imperial College Modelling Code)

Scottish Government uses the publically available Imperial model as reported in their Report 13 to help understand the Covid-19 epidemic in Scotland over the longer term and what the reproductive rate at a point in time (R_t) is for Scotland. The model is run with full settings as recommended by Imperial College[1].

The model is modified by removing the UK entry in the list of European countries and replacing with England, Scotland, Wales and Northern Ireland as separate nations. Sensitivity analysis has not been undertaken to assess how this alters the sampling behaviour with the additional countries and data series. It may result to differences in the outputs to the Imperial College model reported values for other countries. Smaller nations which are similar to Scotland are included in the model (for example Denmark or Norway), and although sampling will likely be driven by larger populations, it appears to have not skewed the results for these nations.

The intervention dates (e.g. when lockdown started) used are those relevant to the country in question. The infection fatality ratio (IFR), which is the proportion of people infected with Covid-19 that die (based on each countries age structure - Scotland's population for example contains a greater proportion of older people than the UK as a whole), are taken from the IFR value for the UK published by Imperial College London, apportioning population share of each nation and scaling based on the paper from the University of St

[1] https://github.com/ImperialCollegeLondon/covid19model/blob/master/Technical_description_of_Imperial_COVID_19_Model.pdf

Andrews for age corrected IFR for UK nations[2]. Data on cases and deaths come from a range of publically available sources[3].
The model estimates, within intervals of uncertainty, the number of infections, number of deaths and the reproductive rate of the virus at a point in time (R_t) based on the time series of cases, in the same manner as the Imperial report. Imperial College is not involved in running the model. Scottish Government does this as Imperial College runs their models for the UK as a whole, not for individual UK nations. There are, however, other academic groups who model Scotland (see above). Their modelling is also used to help Scotland plan its response to the Covid-19 epidemic.

Short and long term forecasts
There are short term forecasts of Covid-19 (over the next two weeks) and long term modelling of Covid-19 (over the next couple of months). Short term modelling helps us understand what the NHS needs to plan for nationally in the next two week period while longer term modelling helps us to look at what is happening in regard to the progression of the epidemic. As we go further into the future, what might happen becomes less certain.

The modelling is updated every week. Longer term modelling is currently updated over each weekend based on the best data available from the previous week. By comparing the different models we are able to say with more confidence what might happen. For the short term, models from different groups are used together to give a combined two week forecast. For the longer term modelling different models are compared to see if results are similar. The Scottish Government modelling using the Imperial College public code each week is compared to the other models to add confidence in the results.

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[2] Kulu, H, Dorey, P (2020) The Contribution of Age Structure to the Number of Deaths from Covid-19 in the UK by Geographical Units https://doi.org/10.1101/2020.04.16.20067991
[3] European countries. https://opendata.ecdc.europa.eu/covid19/casedistribution/csv
England https://coronavirus.data.gov.uk/
Scotland https://www.gov.scot/publications/trends-in-number-of-people-in-hospital-with-confirmed-or-suspected-covid-19/
Wales https://public.tableau.com/profile/public.health.wales.health.protection#!/vizhome/RapidCOVID-19virology-Public/Headlinesummary
Northern Ireland: https://app.powerbi.com/view?r=eyJrIjoiZGYxNjYzNmUtOTlmZS00ODAxLWE1YTEtMjA0NjZhMzImN2JmIiwidCI6IjljOWEzMGRlLWQ4ZDctNGFhNC05NjAwLTRiZTc2MjVmZjZjNSIsImMiOjh9

There are also a range of subgroups of SAGE and SPI-M looking at different aspects of Covid-19 e.g. on Covid-19 in care homes and other situations around Covid-19 which also feed information into the different governments of the UK including Scotland.

Logistical Modelling

Logistics modelling is undertaken by each government in the UK for use by their key public sector partners e.g. Health Boards to help plan their response.

Modellers from the four countries governments across the UK meet regularly to talk through their logistics modelling and to share best practice.

Logistics modelling in Scotland produces forecasts for the next few months, using the epidemiological modelling based on the Imperial Modelling Code run by Scottish Government. Amongst other things, it gives the "most likely" number of Covid-19 cases needing hospitalisation or an ICU bed. It also gives upper and lower bounds of confidence. These mark the levels at which the model estimates there is a 2.5% chance of the level being above (upper bound), or below (lower bound). The upper bound is labelled as a "worse" scenario and the lower bound labelled as "better".

What the modelling tells us and how we talk about it

There are two main ways we talk about the epidemic and our short- and long term forecast of Covid-19 cases in Scotland.

The first of these is how many people in Scotland:

- still will be **susceptible** to Covid-19, i.e. they haven't yet got Covid-19.
- are currently **infected** with Covid-19 in Scotland.
- have **recovered** (or died) from Covid-19

at different points in the future based on the current social interventions in place. At the moment this is based on a range of measures, including "stay at home".

The information on infected people helps us to work out what the short term forecast for the number of bed (and ICU) we might need and how many people might get Covid-19 in the future given the transmission from those people to others under a number of scenarios e.g. easing social restrictions by for example opening schools.

What is the reproductive rate R and how it is estimated

This infected pool of people can increase quickly or more slowly depending on the effectiveness of the social and other measures in place in Scotland. This can be described as the effective reproductive rate (rate of transmission of the virus) at a given point in time (R_t). If the R_t is above 1 the growth in the epidemic in Scotland will grow.

The basic reproduction number is affected by several factors

- The underlying infectiousness of the organism
- How long people who have Covid can infect others for
- The number of people in the population that the affected patients are in contact with, and how intense that contact is.
- In addition, R_t should decrease over time: as people become infected in a population there are fewer susceptible people left as they are either infected, have recovered, or have died. So, if 50% of the population have been infected, R is half of what it would have been at the start of the epidemic.
- If policies have the effect of reducing the number of people someone comes into contact with, that would in turn reduce R.

The R value presented in this document and in the Scottish Government's Coronavirus (COVID-19): framework for decision making, is calculated through modelling of the path of the virus, using data on cases and deaths. As such, it is an estimate with a level of uncertainty. Given the levels of uncertainty, we use modelling outputs from a number of different academic groups (mentioned above) to validate our estimate the R value for Scotland. No modelling group use exactly the same approach to modelling $R_{t.}$ As such, their outputs are brought together to give a consensus view.

Importantly, particularly given the uncertainty in the R value, the Scottish Government publishes and uses a number of different pieces of data to understand the current path of the virus. This includes the number of cases, hospital and ICU bed use, and deaths.

Estimating R in different settings

There are at least three different epidemics in Scotland currently in the general population, care homes, and hospitals. R_t is likely to be different in each of these settings. The model currently being used is a "whole population" model, which analyses the spread of the disease across Scotland as a whole. Other types of models are needed to analyse smaller units such as care homes and hospitals. We are working with academic groups from around the UK to develop modelling for these settings.

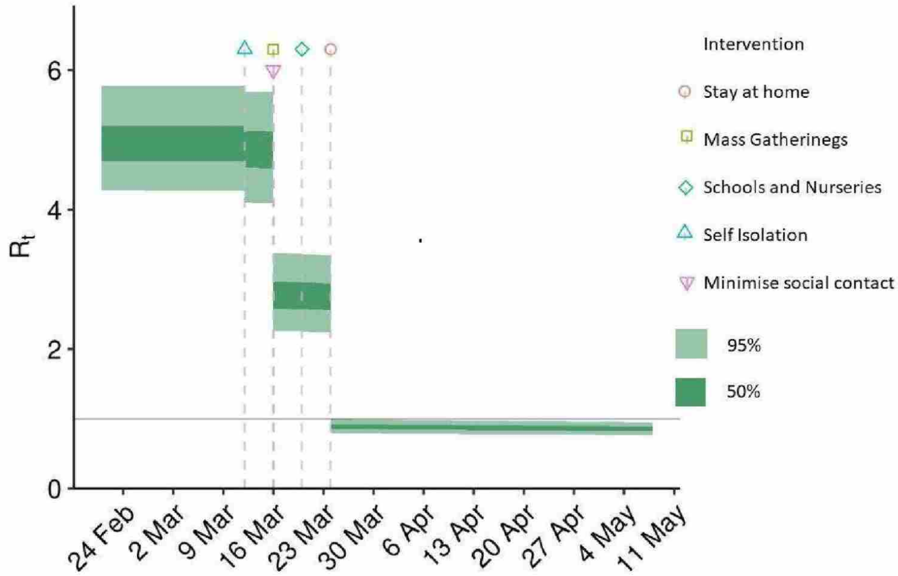
In order to control the epidemic in Scotland, ideally we need a low number of infected people who can pass the virus on to others and a low R_t below 1. We would be achieving this when the reproductive rate is not increasing in any of these locations.

What the modelling tells us

Figure 1 shows the movement of R_t since February. Before the "stay at home" restrictions were put in place R_t was above 1, and likely to have been between 4 and 6 before any interventions were put in place.

The model estimates the R_t value for Friday 8th May to be between 0.7 and 1.0.

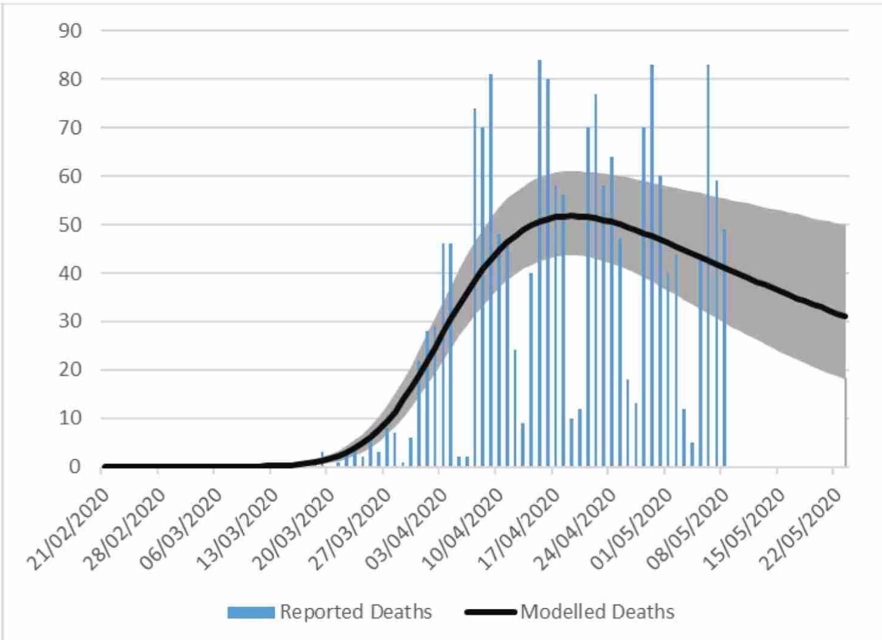
<u>Figure 1: R_t for Scotland, 2020</u>



Source: Scottish Government modelled estimates using Imperial College model code,
Source: Actual data from https://www.gov.scot/publications/coronavirus-covid-19-trends-in-daily-data/

Figure 2 shows the epidemiological model forecasts which suggest that, given the present set of interventions, this epidemic curve shows signs of reducing.

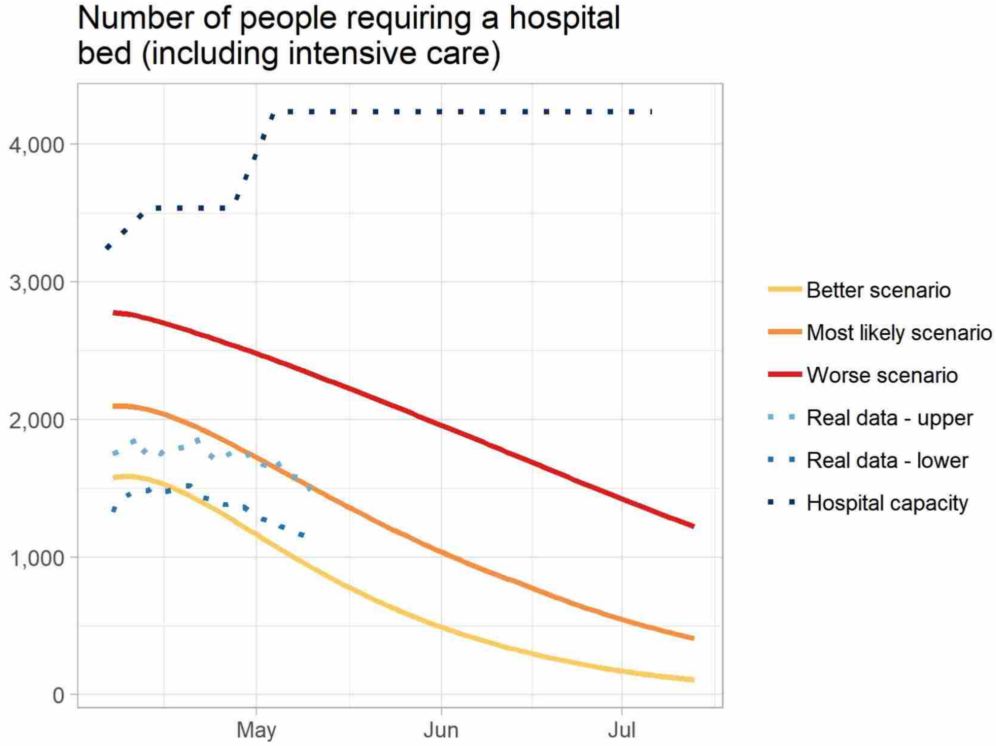
<u>Figure 2: Short term modelled forecast number of deaths from Covid-19 in Scotland, May 2020</u>



Source: Scottish Government modelled estimates using Imperial College model code,
Source: Actual data from https://www.gov.scot/publications/coronavirus-covid-19-trends-in-daily-data/

For the logistics model, short term forecasts for hospital bed occupancy predict a steady decline over the next two weeks, following the end of a plateau of around 1,500 people three to four weeks ago. The medium term forecast (figure 3) shows a similar story over the next few months, with a steady decline, but very little chance of reducing hospital occupancy due to Covid to zero. This assumes that we maintain the current “stay at home” arrangements, and there is no change in adherence to these. If guidance changes, this forecast will no longer apply.

Figure 3: Logistical model medium term forecast of number of people requiring a hospital bed from Covid-19 in Scotland, 2020

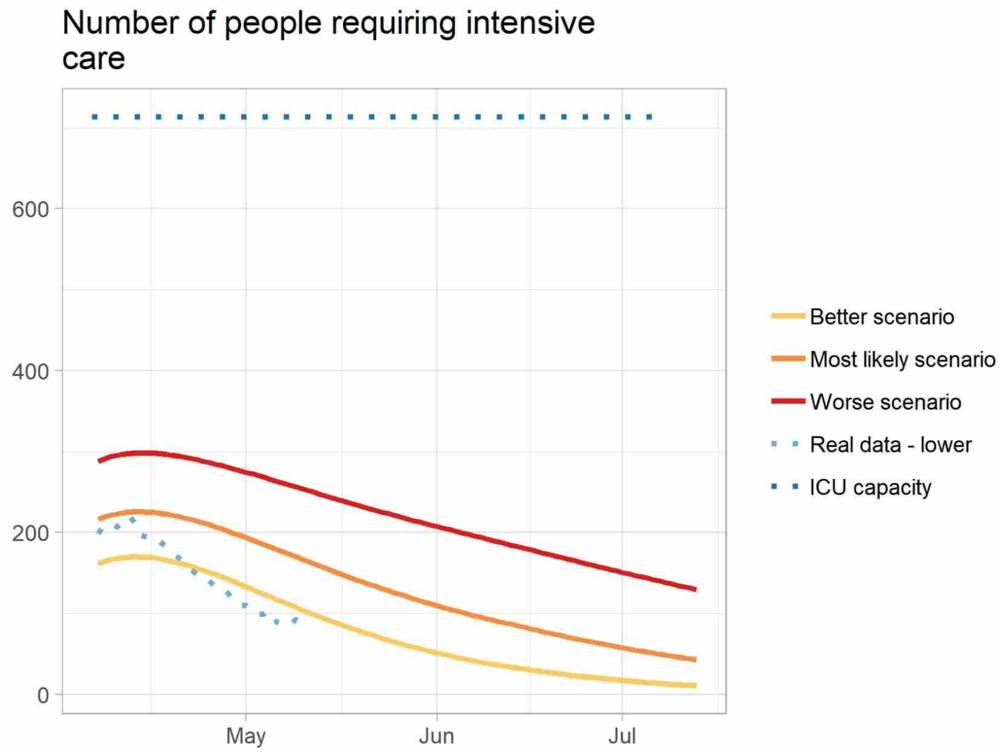


Source: Scottish Government modelled estimates using outputs from the Imperial College model code,
Source: Actual data from https://www.gov.scot/publications/coronavirus-covid-19-trends-in-daily-data/

There is still some uncertainty regarding the actual number of people in hospital with Covid-19, with the chart above comparing a lower bound for this number (based on the number of people in hospital that have tested positive for Covid-19) and an upper bound (additionally including suspected cases that have not tested positive).

The medium term modelling also provides us with the following forecast of the number of ICU beds required (figure 4). In recent weeks, it has looked as if the actual count of people in ICU has been falling faster than the model suggests, although the most recent data seems to show the potential for a second plateau, or even another rise.

Figure 4: Logistical model medium term forecast of number of people requiring an intensive care from Covid-19 in Scotland, 2020



Source: Scottish Government modelled estimates using outputs from the Imperial College model code,
Source: Actual data from https://www.gov.scot/publications/coronavirus-covid-19-trends-in-daily-data/

What's next?

The modelled estimates of hospital and ICU use, and of the reproduction number R_t will be published each week.

Further information can be found at https://www.gov.scot/coronavirus-covid-19

Annex: Scottish Government Modelling using publically available Imperial College Code

One of the models used by the Scottish Government to understand the progression of the epidemic is a modified version of the publically available Imperial College Covid-19 model, which has been adapted to fit the situation in Scotland. We use it to help us to understand the longer term progress of the epidemic, and the influence of the introduced measures. It also offers the potential for exploring the impact of easing restrictions in other countries. This model uses publically available data on daily cases and deaths in Scotland, England, Wales and Northern Ireland, as well as in 13 other European countries. This technical annex should be seen in the context of the Imperial College model description.

The key piece of information the model uses is data on numbers of deaths over time across countries. The expected number of deaths in each country is directly related to the numbers of infections occurring in previous days. In the early stages of an epidemic this can be dominated by infections taking place elsewhere (for example, people returning from overseas), so to avoid bias, the model only starts to include data from a country when a total of 10 deaths has been reached.

A specific relationship between infections and deaths, called the Infection Fatality Rate (IFR), is used for each country. As the likelihood of death as a result of COVID-19 infection is strongly related to a person's age, this IFR rate is a reflection of the age structure of each country. To reflect the varying age structure of the UK population across the nations, an age-adjusted IFR for each has been calculated using the IFR value for the UK published by Imperial College London, apportioning population share of each nation, and the relative IFR values produced by Kulu and Dorey (2020)[4], resulting in slightly higher IFR for Scotland than the overall IFR presented by Imperial College for the UK (Table 1).

[4] Kulu, H, Dorey, P (2020) The Contribution of Age Structure to the Number of Deaths from Covid-19 in the UK by Geographical Units https://doi.org/10.1101/2020.04.16.20067991

Table 1. Relative Infection Fatality Rates used in the model for nations in the UK[4].

Country	Relative IFR
Scotland	1.03
England	1.00
Wales	1.12
Northern Ireland	0.91

The time between infection and death is made up of two periods, a latent period from infection to the start of symptoms, and an onset-to-death period. The number of deaths today is the sum of the past infections weighted by their probability of death, where the probability of death and the probability of showing symptoms depends on the number of days since infection, and the country-specific IFR.

The Imperial College model takes the observed number of deaths on a given day, and back calculates the number of infections required to result in that number of deaths (with given probability of time until death and onset of disease). The reproductive rate on a given day is estimated by calculating the infectious incidence rate required to go from the previous days result to the numbers of incidence on the next day. The R_t for a given day will not be a fixed value, as it will be updated with new information when each additional week of data is added to the model. Comparisons can be made between values in the same model run but should not be attempted between models using different sets of input data.

Estimates of R_t in the future are calculated by using the death data up to today, providing estimates of the infectious incidence occurring in previous days, and then estimating in the future the numbers of those infections resulting in death. This iterative process continues as deaths decrease.

Estimates are produced for the numbers of: infectious people in the population, cases, deaths and Rt (with confidence intervals) both for the historic period where we have data, and forecast into the future to simulate the progression of the epidemic. As this forecasting projects further into the future the level of uncertainty increases.

The model includes 6 interventions, one of which is constructed from the other 5, which are timings of school, and nursery university closures, self-isolating if ill, banning of public events, "any government intervention in place", implementing a partial or complete lockdown and encouraging social distancing. The interventions are applied from the day they are introduced onwards, as in the Imperial College model. The "any government intervention covariate" is applied when any of the interventions are applied. The dates of interventions used for Scotland are shown in table 2.

Table 2. Dates of interventions for Scotland.

Intervention	Date
"Any government intervention"	12 March
Self-isolation	12 March
Mass Gatherings	16 March
Minimise social contact	16 March
Closure of schools and nurseries	20 March
Stay at home	24 March

The model is edited in RStudio Version 1.2.5042 and run using the R statistical computing software, version 3.6.3, on an AMD 64-core Dell Linux system, with 256Gb RAM.

Acronyms

Acronym	Description
IFR	The infection-fatality rate (IFR) is the proportion of deaths from a certain disease compared to the total number of people diagnosed with the disease in a certain period of time. An IFR is conventionally expressed as a percentage and represents a measure of disease severity
COVID-19	Coronavirus disease 2019 (COVID-19) is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). It was first identified in December 2019 in Wuhan, China, and has since spread globally, resulting in an ongoing pandemic.
R_0	The initial reproduction number. The average number of people an infected person transmitted the disease to at the start of the epidemic, before anyone has immunity to it.
R_t	The reproduction number at a point in time; the average number of people an infected person transmitted the disease to at some point in the epidemic.
SAGE	The Scientific Advisory Group for Emergencies (SAGE) provides scientific and technical advice to support government decision makers during emergencies.
SPI-M	The Scientific Pandemic Influenza Group on Modelling (SPI-M) gives expert advice to the Department of Health and Social Care and wider UK government on scientific matters relating to the UK's response to an influenza pandemic (or other emerging human infectious disease threats).

How to access background or source data

The data collected for this research publication:
☐ are available in more detail through Scottish Neighbourhood Statistics

☐ are available via an alternative route

☒ may be made available on request, subject to consideration of legal and ethical factors. Please contact modellingcoronavirus@gov.scot for further information.

☐ cannot be made available by Scottish Government for further analysis as Scottish Government is not the data controller.

The views expressed in this report are those of the researcher and do not necessarily represent those of the Scottish Government or Scottish Ministers.

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