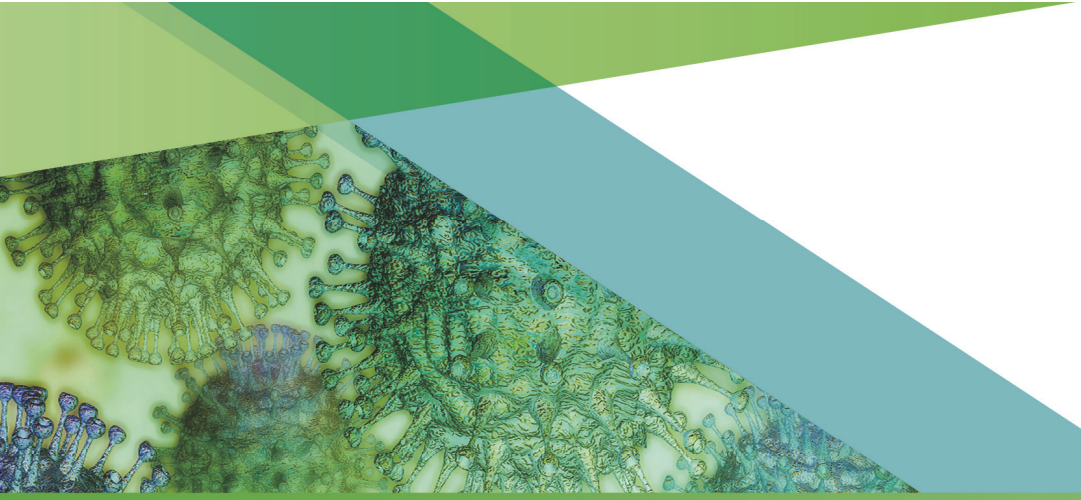


TECHNICAL REPORT

Projected baselines of COVID-19 in the EU/EEA and the UK for assessing the impact of de-escalation of measures

26 May 2020

Executive summary

After widespread transmission of SARS-CoV-2 in EU/EEA countries and the UK over several weeks, the COVID-19 epidemic reached its peak in most countries in April or early May 2020. Some countries have since experienced a sustained decrease in the number of reported cases, progressively reaching the level of transmission reported during the first week of the outbreak. Due to this decrease in transmission and improvements in epidemiological surveillance and healthcare capacity, a number of countries have decided to discontinue several non-pharmaceutical interventions and now plan to gradually phase out their 'stay-at-home' policies.

Mathematical modelling of COVID-19 transmission can be used to better analyse the epidemic development in a population over time, produce projections, and inform public health decision-making on interventions. It is particularly useful for the evaluation of public health measures, notably to understand the expected impact of their implementation or release on disease transmission-related indicators. The mathematical modelling approach also allows for the quantification of the uncertainty associated with these estimations and projections. In this report, a dynamic compartmental model of COVID-19 is presented. It aims to provide a short-term 30-day forecast of the expected number of COVID-19 cases, deaths and hospitalised cases (including general hospital ward and intensive care unit) under a set of assumptions. In this first analysis, the baseline scenario corresponds to a 'status quo' in which all control measures in place on 2 May 2020 will be continued until the end of the projection period (7 June 2020). The model is based on the epidemiological data and scientific evidence available at the time of publication. Further developments are expected as new information and epidemiological data become available.

The model was developed at ECDC and applied at a national level for EU/EEA countries and the UK. When interpreting predictions of mathematical models for emerging diseases, it is essential to keep in mind the underlying assumptions, limitations and uncertainties resulting from gaps in scientific knowledge and in available data. The inherent sources of uncertainty and the limitations of the mathematical modelling approach taken here are discussed and should be considered when interpreting the results and making comparisons with other mathematical models of COVID-19 transmission.

An assessment of the risk associated with the COVID-19 epidemic and the response strategies applied or envisaged should be based on a comprehensive analysis taking in consideration current uncertainties, the specific epidemiological situation in each country, and outputs of models according to new scientific evidences. Future work in this area intends to promote data sharing and operational forecasting through an 'ensemble modelling' approach. This approach combines predictions from different mathematical models to improve on a single-model forecast, offering more accurate predictions of epidemic trends and clarifying the uncertainties associated with these predictions.

Suggested citation: European Centre for Disease Prevention and Control. Projected baselines of COVID-19 in the EU/EEA and the UK for assessing the impact of de-escalation of measures – 26 May 2020. ECDC: Stockholm; 2020.

Introduction

SARS-CoV-2 is the causative agent of the current COVID-19 pandemic. Coronaviruses are transmitted in most instances through large respiratory droplets and direct human-to-human contact transmission, although other modes of transmission (e.g. airborne, faeco-oral and through fomites) have also been proposed. There is currently no specific treatment or vaccine against COVID-19. Severe cases would require treatment in hospital, and critical cases are treated in intensive care, where they most commonly require ventilation. More information on the latest scientific developments are available in the ECDC Rapid Risk Assessment on Coronavirus disease 2019 (COVID-19) in the EU/EEA and the UK (ninth update, published on 23 April 2020) [1].

In March 2020, all EU/EEA countries and the UK implemented a range of non-pharmaceutical interventions to respond to the SARS-CoV-2 epidemic. Following a reduction in virus transmission, several countries have started to progressively ease their public health response measures while other countries have announced the lifting or easing of measures in the near future [1].

To date, mathematical models have been used to investigate many aspects of the COVID-19 pandemic, including basic epidemiological characteristics of the virus (e.g. basic reproduction number (R_0), incubation period, presymptomatic transmission, seasonality), as well as the dynamics of SARS-CoV-2 transmission and the impact of non-pharmaceutical interventions [2,3]. In particular, public health authorities in several EU/EEA countries and the UK have used mathematical modelling to forecast the trajectory of the COVID-19 outbreak in their respective countries and to estimate the time-dependent effective reproduction number, R(t) [4-8]. Additionally, several academic groups have published mathematical models focused on the dynamics of COVID-19 transmission in Europe [9-12].

The current report describes a mathematical model developed by the ECDC and presents 30-day projections for 30 EU/EEA countries and the UK, together with the inherent model assumptions and uncertainties. For this report, the model assumes no changes in the current set of measures adopted in Member States. The model projections and the data to which the model is calibrated should be interpreted with caution; in particular, attention should be given to the specificities of each country's epidemic such as differences between surveillance systems, COVID-19 case definitions, national testing policies applied over the course of the epidemic, and the level of effective implementation of response measures. Due to this heterogeneity, the presented predictions are not suitable for a direct country comparison but instead can be used to inform an understanding of potential future trends in COVID-19 transmission in EU/EEA countries and the UK.

Model description

Model structure

To represent the dynamics of SARS-CoV-2 infection and COVID-19 disease in the EU/EEA and the UK, ECDC has developed an age-stratified compartmental model based on difference equations, which can be applied at country level. The model is deterministic in nature and simulates discrete time steps of one day. The model incorporates the effects of four main non-pharmaceutical interventions.

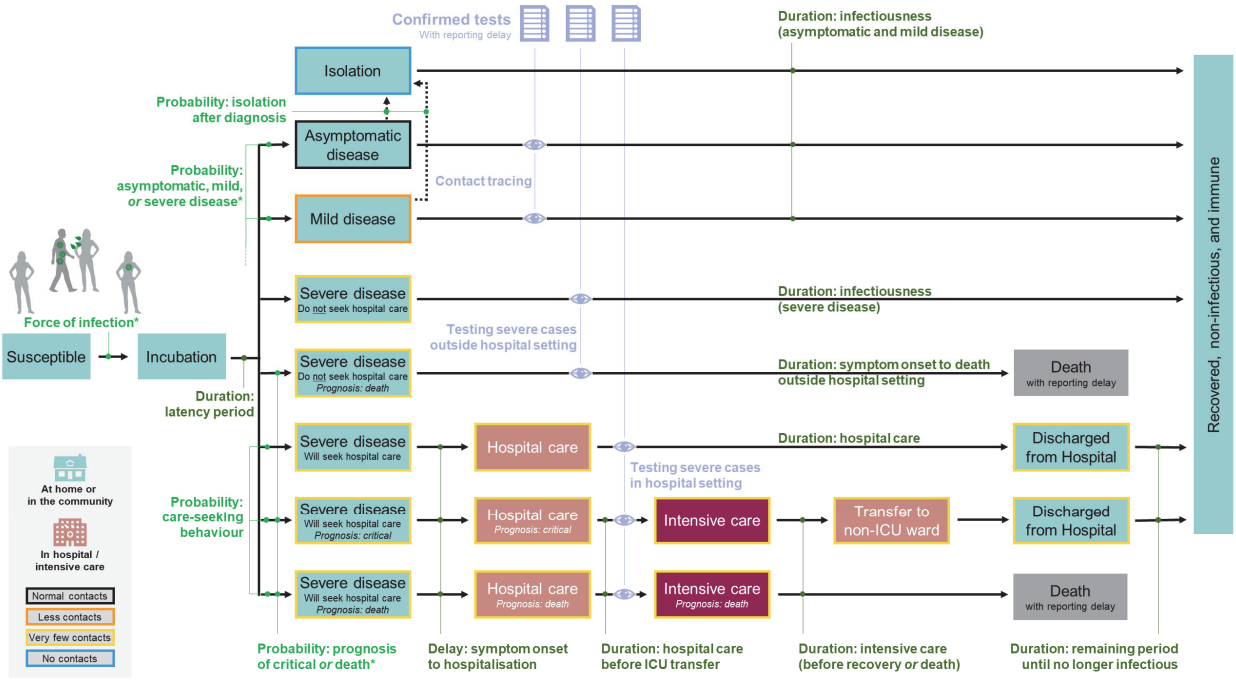
The natural history of COVID-19 is represented by assuming that people can progress through the following mutually exclusive disease states: susceptible to infection, exposed, asymptomatic disease, mild disease, severe disease, critical disease, recovered, and death from COVID-19-related complications (the different compartments of the model are presented in the Figure 1).

Following infection with SARS-CoV-2, individuals enter an exposed (or incubation or latent) phase where they are assumed to be infected but not yet infectious. Following this exposed phase, an infected individual is given a prognosis of either asymptotic, mild, severe, or critical disease, or eventual death from COVID-19-related complications based on age-related probabilities. Asymptomatic and mild cases are assumed to have an identical duration of infection. Those developing severe or critical disease (including those with a prognosis of eventual death) may seek hospital care and be admitted to hospital following a delay from symptom onset, or alternatively not seek care and remain outside of the hospital setting (e.g. in care homes). Those developing critical disease while in hospital care may be admitted to an intensive care unit (ICU), from where they can either fully recover (after being transferred back to a regular hospital ward and subsequently discharged) or die from COVID-19-related complications. Those in the recovered state are assumed to be immune to re-infection; an assumption that can be revisited if further information regarding immunity becomes available. A detailed presentation of the model is available in Appendix 4, which contains a description of the ECDC dynamic transmission model.

Individuals can be tested and diagnosed either through a) severe or critical cases presenting at hospital, b) by severe or critical cases being tested outside of the hospital setting, or c) by mild and asymptomatic cases being discovered via testing or contact tracing. Those with asymptomatic or mild disease can go into an isolation stage after being tested and diagnosed through contract tracing. As well as structuring the population into mutually exclusive disease states, the model structures the population according to age, as several disease-related processes (such as probability of developing severe

and critical disease) are understood to be age-related. For this application, nine age group categories are defined using 10-year bins (0–10 years, 10–20 years … 70–80 years, and 80+ years).

Figure 1. Model compartment overview



The probability of a susceptible individual being infected at a given point in time depends on the intrinsic infectiousness of the virus and on how likely it is that a susceptible individual comes into contact with an infectious individual. We assume that it is less likely that a susceptible individual will come into contact with an individual in a severe or critical state compared to someone in a mild or asymptomatic state but that, given an infectious contact, the susceptibility to infection is not age-dependent. The average number of contacts made by an individual, however, depends on their age, and can be reduced by non-pharmaceutical interventions.

To date, four main non-pharmaceutical interventions on social distancing have been included in the model:

- mass gathering cancellations (ban on gatherings above 50 individuals)
- closure of any public spaces (including restaurants, entertainment venues, non-essential shops, partial or full closure of public transport, etc.)
- stay-at-home recommendations for the general population (which are voluntary or not enforced)
- stay-at-home orders for the general population (which are enforced and can be referred to as 'lockdown').

In this first version of the model, some non-pharmaceutical interventions are not included as the current structure of the model does not include a contact matrix. Excluded interventions were a) specific social distancing measures for risk groups (e.g. elderly population) and b) closures of educational institutions. Further developments of the model are planned in order to incorporate these intervention measures/closures of educational institutions (as appropriate). The data on response measures is based on information available from official public sources as of 2 May 2020. Only measures applied at a national level were included; it should be noted that while dates of introduction and release of measures were verified from official sources, delays in their implementation may have occurred.

The efficacy of social distancing response measures (at reducing human-to-human contacts) that have been implemented in each country are calibrated during the model fitting process. The model assumes that social distancing measures have the same effect across all age groups. For some social distancing measures (stay-at-home recommendations and stay-at-home orders), a delay before they reach the maximum efficacy is reached is also factored in.

More information about current COVID-19-related interventions is available in the latest ECDC rapid risk assessment on coronavirus disease (COVID-19) in the EU/EEA and the UK (ninth update, published on 23 April 2020) [1].

Model uncertainty

The effects of three different sources of uncertainty (parametric, structural and scenario-related uncertainty) are described below. A benefit of mathematical models, built based on data and a set of assumptions, is that they allow the quantification of this uncertainty.

Parametric uncertainty

Parametric uncertainty is the uncertainty about the parameters needed to inform the model. This might include the parameters related to infection (e.g. susceptibility to becoming infected), the natural history of the disease (e.g. how soon individuals display symptoms following infection), and transmission (e.g. behavioural factors) and parameters related to healthcare management (e.g. laboratory capacity for biological diagnostic confirmation). Uncertainty about these parameters can be due to several factors such as their intrinsic variability, survey biases, sampling errors, and measurement errors. In the model, this is addressed by applying specifying ranges for each input parameter based on biological plausibility according to scientific literature or specific studies.

By then 'fitting' the model to empirical data such as COVID-19 confirmed cases, deaths and, where available, number of hospitalised cases (i.e. new admissions at hospital, daily number of patients currently hospitalised, new admissions at ICU and daily number of patients hospitalised in ICU) it is possible to assess which values of the unknown parameters allow the model to give the best representation of how the situation has unfolded up until today. This process is also known as 'model calibration'. As best practice, it is recommended not to choose only one value for each parameter but run the model for a number of different parameter sets. This is termed 'uncertainty analysis' and is illustrated by the shaded ribbons around the model projections. The model is fitted simultaneously to all 31 countries in a Bayesian Markov Chain Monte Carlo (MCMC) framework. In general, biological parameters are assumed to be global (not varying by country) while behavioural parameters – including effectiveness of response measures – are assumed to differ by country.

The current model is calibrated on data on confirmed COVID-19 cases and deaths for each EU/EEA country and the UK based on ECDC's epidemic intelligence COVID-19 database, which is updated daily and also publicly available [13]. Where available, daily COVID-19 data on hospitalisation and intensive care units were included following a systematic review of web resources for all EU/EEA countries and the UK (more details on the data sources are presented in Appendix 3). As data from hospitals are very valuable in reducing uncertainty, sustained efforts are ongoing to monitor data in the public domain and update the model with the most appropriate data.

Structural uncertainty

Model forecasts are influenced by the assumptions made about how infection with a communicable disease affects the population and how the population can be categorised in different disease states (corresponding to compartments in the model), which depend on the natural history of the disease as well as healthcare-seeking behaviour. This is termed the 'structural uncertainty' of the model. To assess the structural uncertainty, several model variants (that vary by compartment structure) of increased complexity have been fitted to the same data. The optimal approach to account for structural uncertainty is to make a formal comparison with other models simulating the same outcomes, i.e. case incidence or mortality.

Scenario uncertainty

One of the uses of models is to support decision makers in assessing various public health options by modelling different scenarios, which contain a range of inherent assumptions and uncertainties. In the case of COVID-19, any scenario contains uncertainty about future policy decisions and public behaviour. Despite this uncertainty, it is still possible to run the model for a number of simple scenarios to support decision makers with a representation of the current knowledge and its limitations by utilising all the key information available.

In this first analysis, the baseline scenario corresponds to a 'status quo' in which all the control measures in place on 2 May 2020 will be continued until the end of the projection period (7 June 2020). In fact, this is a limiting assumption since many EU/EEA countries and the UK are currently discussing, or have decided, to lift some control measures over the forecasting period. These projections under a status quo scenario therefore suggest that the reduction of transmission observed since the peak of the national outbreak will be maintained at the same level. As the progressive de-escalations of social distancing measures occur, and contacts between individuals increase, it is possible that disease transmission will increase again, thus making this scenario the best possible baseline. It should be noted that the shorter the time horizon of projections, the lesser the impact of this uncertainty [14].

We assume that a projection over a shorter timescale would not be largely affected by changes in policy, even if implemented within a short timeframe after the production of the projection.

To date, the effectiveness of each individual type of control measure is unknown. Many countries introduced similar interventions simultaneously, which makes it statistically challenging to assess which was the most effective at decreasing transmission and which effect it had on mortality and morbidity. To overcome this issue, a short survey was conducted among experts involved in the COVID-19 public health response at ECDC. The survey explored the expected effectiveness of the main non-pharmaceutical interventions related to social distancing and the associated uncertainty of the expert judgement for each of the measures.

Based on this initial panel of experts, the median effectiveness of enforced stay-at-home orders was considered the highest, followed by mass gathering cancellations with slightly lower overall effectiveness. Closure of public places and stay-at-home recommendations were ranked as third and fourth with similar median effectiveness, slightly lower than the other two measures (Appendix 4). Each response measure included in the model was normalised and rescaled according

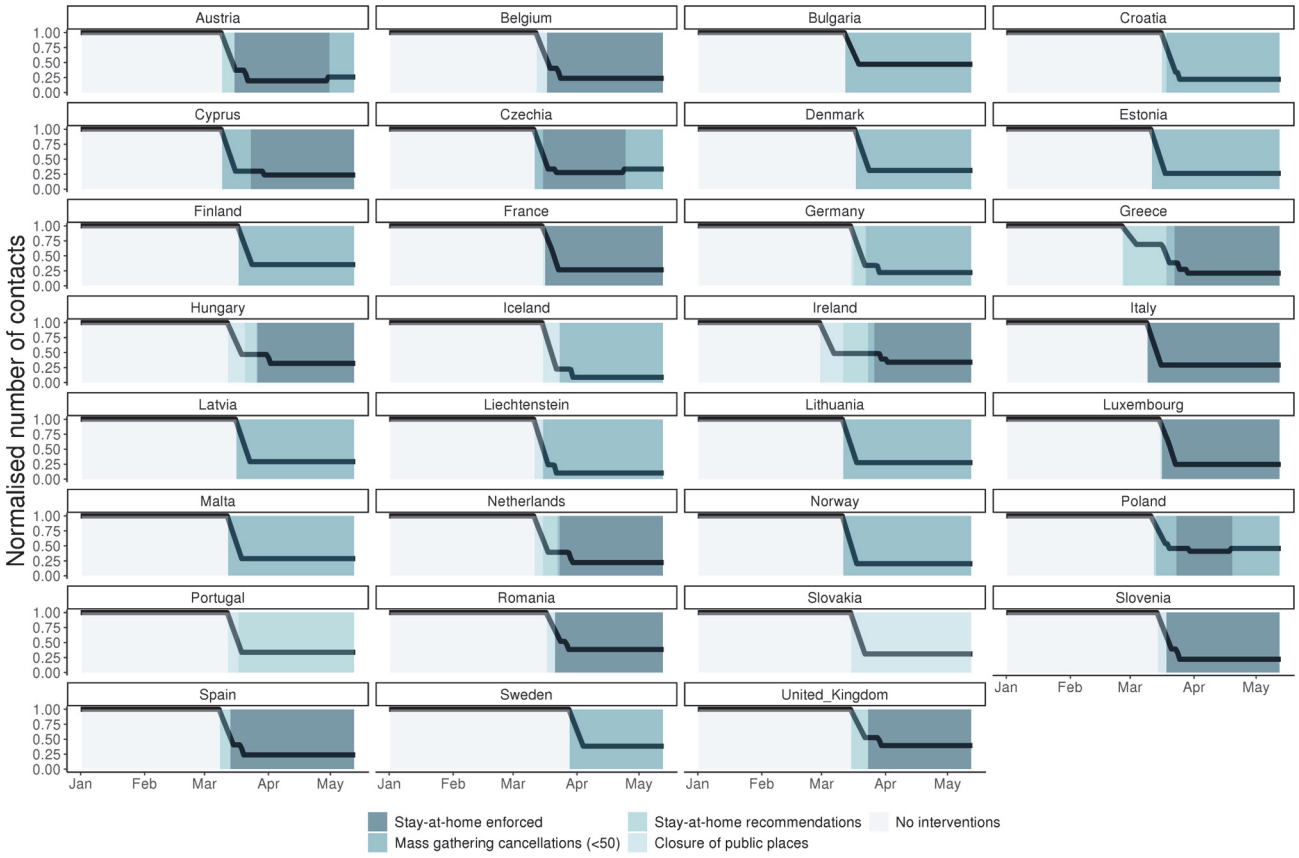
to their relative efficacy to the strongest measure, enforced stay-at-home orders. This knowledge-based approach should be extended in the future by epidemiological information about the observed conditions of transmission. For example, transmission modalities could be recorded through a contact tracing survey (e.g. role of super-spreader events, community-based transmission in households, mass gatherings). A new survey has been launched to enlarge the expert panel and results would be used in updated version of the model in the future.

Effect of the non-pharmaceutical interventions

Effects of non-pharmaceutical interventions on the normalised number of contacts between individuals are shown in Figure 2. To date, all EU/EEA countries and the UK have implemented at least one of the interventions included in the model. The decrease in the number of contacts after implementing these measures varies between countries and measures.

The number of contacts were reduced from baseline 1.00 to 0.28 (median) for the period with the strongest applied intervention measures, varying from 0.09 to 0.47 between the countries. Countries implementing or lifting their interventions at different times show a gradual decrease or increase in the number of normalised contacts.

Figure 2. Effect of non-pharmaceutical interventions on the number of contacts between individuals in the EU/EEA and the UK in the period up until 13 May 2020



Note: Only the strongest non-pharmaceutical intervention on a given day was taken into account; for a prior estimation of the effect of the interventions, see Appendix 4.

Projections of COVID-19 cases and deaths

Status quo projections

Figures 3a–3d show multiple observed time series (cases, deaths, hospitalised, ICU cases) and predicted indicators for the EU/EEA and the UK (15 February–12 June 2020). The non-pharmaceutical interventions included in the model are shown in horizontal bars (15 February–2 May 2020).

The majority of countries show a decreasing trend, both in cases and deaths for the short-term projections within a 30-day time horizon. Most notably in countries without a pronounced epidemic peak, the projection shows a moderately increasing or flattening trend (e.g. Bulgaria, Poland) and for some countries moderate downward trends (Hungary, Romania, Sweden and the United Kingdom).

The results of the model for each time series are presented in Appendix 1 (30-day projections of confirmed COVID-19 cases, deaths, and hospital requirements in EU/EEA countries and the UK). The model curves may show some time lag regarding the epidemic peak.

This can be explained, in part, by the various data sources used for the fitting. Overall, the model is able to simultaneously accommodate inputs from different time series such as the new overall number of cases/deaths and available hospital-based data. When no time series of hospitalised and ICU cases was available for a country, numbers based on European averages were used to produce an approximation of the time-series numbers.

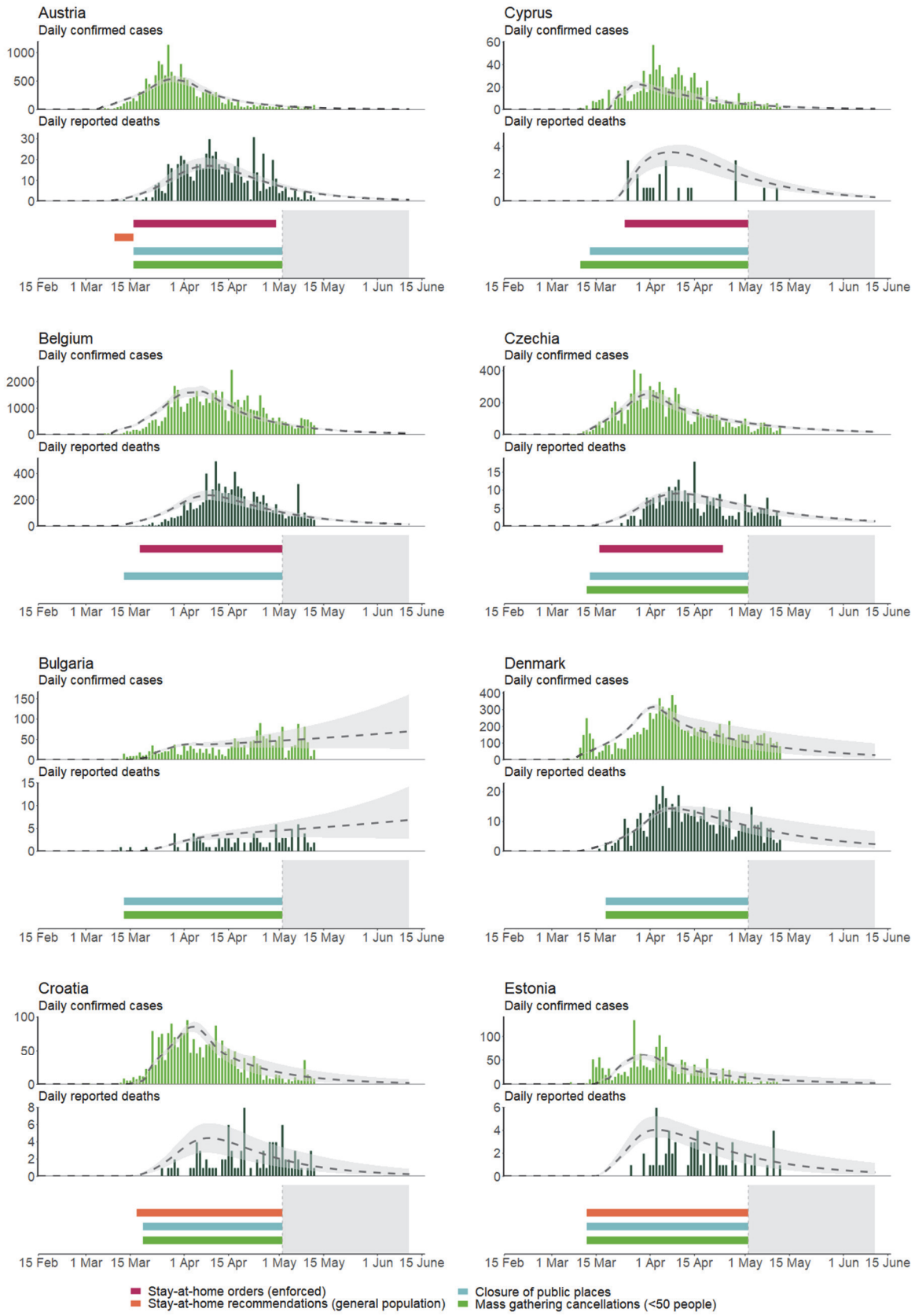
It should be noted that daily time-series data, daily hospital/ICU data, and data on new daily hospital/ICU admissions due to confirmed COVID-19 are not always publicly available. These data, however, are essential when calibrating a mathematical model (for more information on data sources, see Appendix 3). In order to improve the fitting and the projection quality, additional time series on the number of COVID-19 cases are required. ECDC is regularly monitoring data in the public domain and liaises with EU/EEA countries and the UK to extend its data coverage in future analysis.

For some countries, the model has certain limitations: if the observed number of active cases remains relatively small, the model might not be able to capture small local events in the absence of obvious community spread (e.g. local spread within specific locations or communities). The compartmental model does capture transmission in community and disease flows through and outside hospital settings, but not within all possible sub-communities.

Note: The data on non-pharmaceutical interventions used for this report are based on information available from official public sources as of Wednesday 29 April at 18.00 and may not capture measures that are not reported on publicly available websites. Consequently, this approach should be seen as a snapshot of the response measures reported in the EU/EEA and the UK.

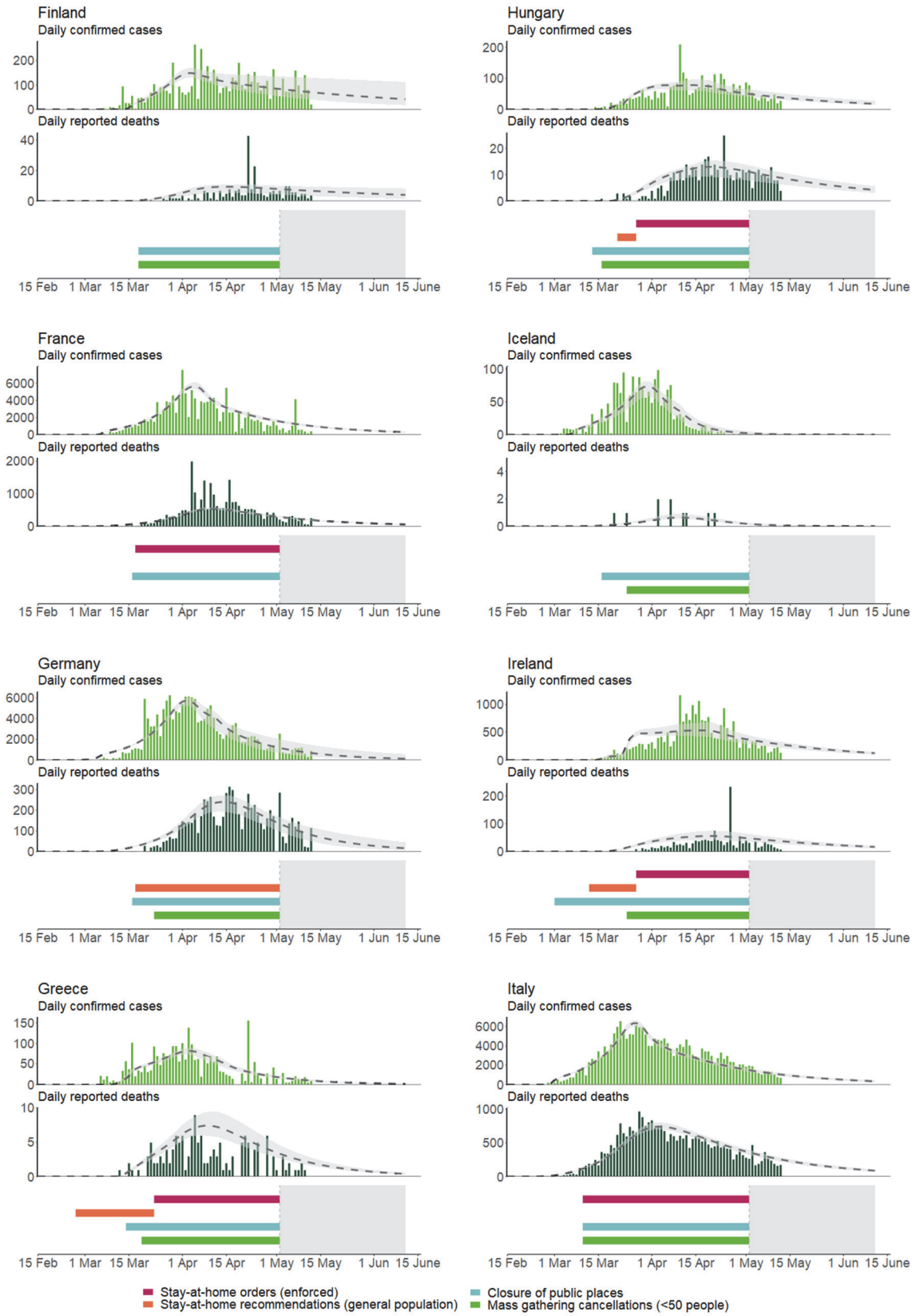
The data on response measures have several limitations. Firstly, there is substantial heterogeneity in physical distancing policies and their implementation between countries. For instance, the level of implementation of measures may vary between countries and there may be specific rules and exceptions to the measures, making interpretation of the data challenging. The measures displayed in these figures are reported at national level, and it should be noted that due to the evolution of the epidemic in certain regions, regional or local measures often preceded national ones. The exact dates of introduction were often available from official sources but delays in their implementation may have occurred. Additionally, availability of public data from official government sources varies among countries. For some countries, data concerning discontinued measures are no longer available on official websites, which may result in the data for more recent measures being more accurate.

Figure 3 a. Number of observed and predicted newly reported COVID-19 cases and deaths, and non-pharmaceutical interventions in the EU/EEA and the UK in the period up until 12 June 2020



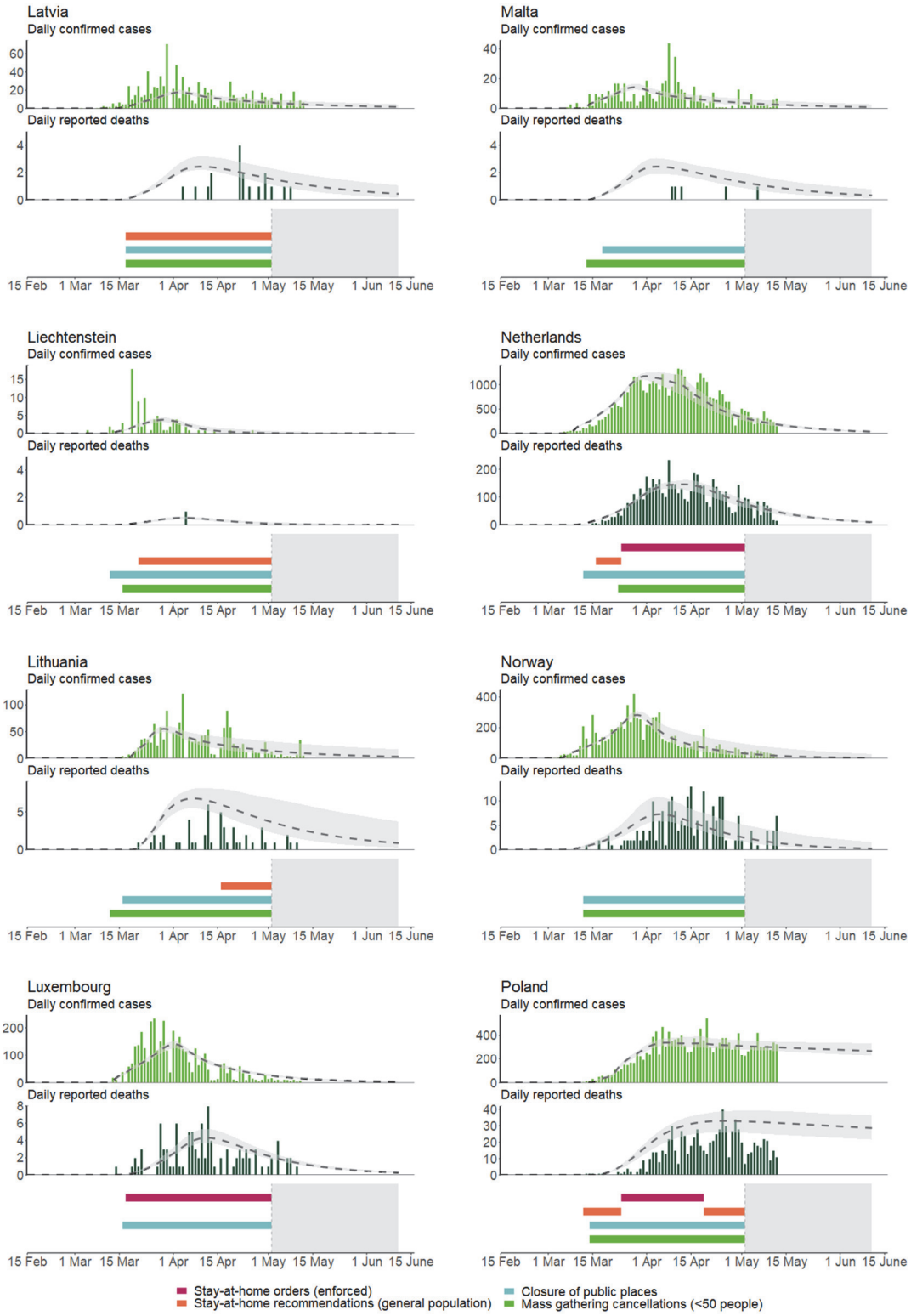
Note: The projections presented here are not suitable for a direct country comparison but instead can be used to inform an understanding of non-pharmaceutical interventions and potential future trends in COVID-19 transmission in EU/EEA countries and the UK.

Figure 3 b. Number of observed and predicted newly reported COVID-19 cases and deaths, and non-pharmaceutical interventions in the EU/EEA and the UK in the period up until 12 June 2020.



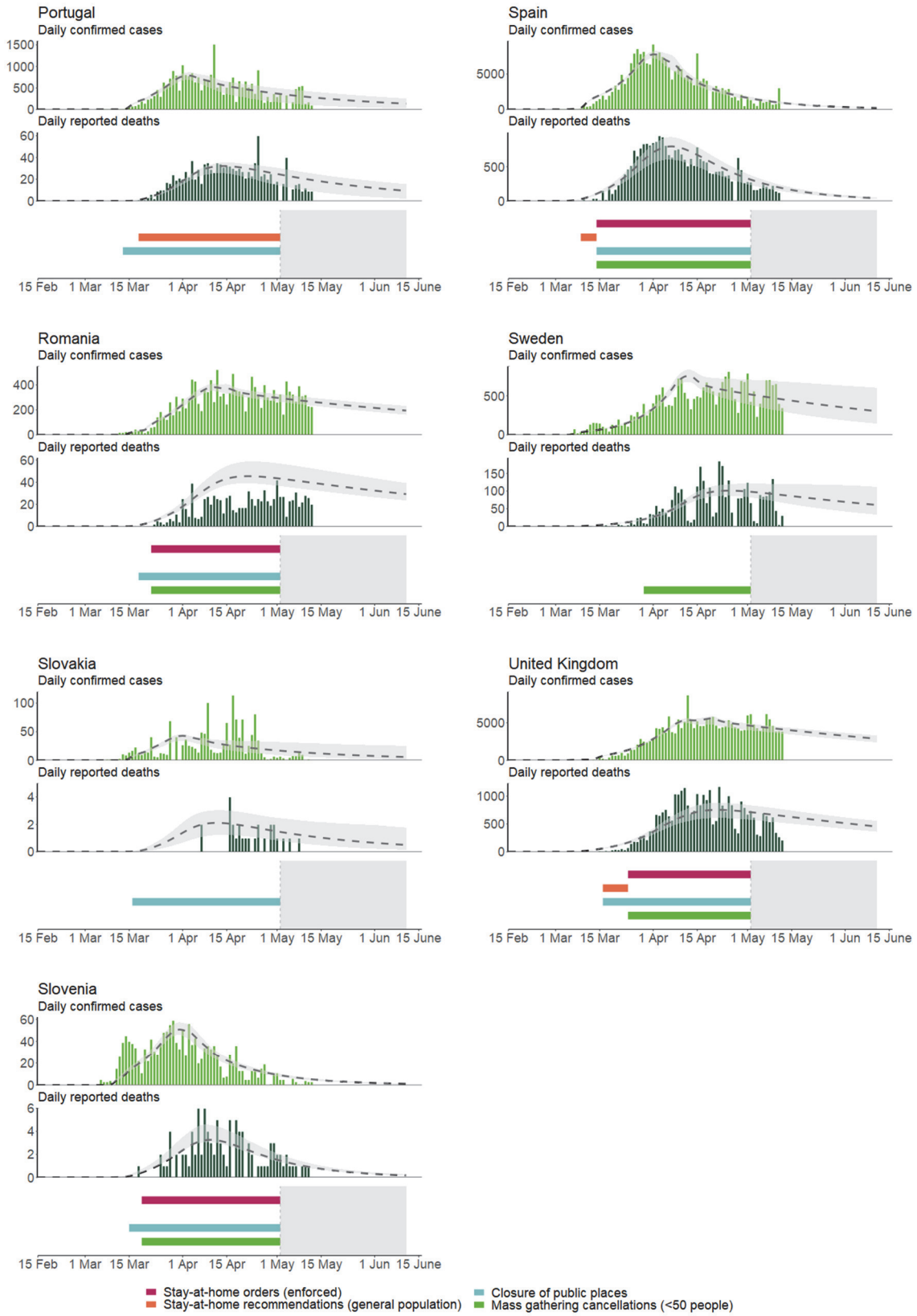
Note: The projections presented here are not suitable for a direct country comparison but instead can be used to inform an understanding of non-pharmaceutical interventions and potential future trends in COVID-19 transmission in EU/EEA countries and the UK.

Figure 3 c. Number of observed and predicted newly reported COVID-19 cases and deaths, and non-pharmaceutical interventions in the EU/EEA and the UK in the period up until 12 June 2020



Note: The projections presented here are not suitable for a direct country comparison but instead can be used to inform an understanding of non-pharmaceutical interventions and potential future trends in COVID-19 transmission in EU/EEA countries and the UK.

Figure 3 d. Number of observed and predicted newly reported COVID-19 cases and deaths, and non-pharmaceutical interventions in the EU/EEA and the UK in the period up until 12 June 2020



Note: The projections presented here are not suitable for a direct country comparison but instead can be used to inform an understanding of non-pharmaceutical interventions and potential future trends in COVID-19 transmission in EU/EEA countries and the UK.

Summary and future development

We present a dynamic compartmental model of SARS-CoV-2 transmission and associated progression to COVID-19 of increasing severity developed at ECDC. The model is calibrated against epidemiological data from all EU/EEA countries and the UK, including multiple community and hospital COVID-19 case time-series. The model provides 30-day projections of the number of reported cases and deaths, together with the expected requirement for hospital and intensive care (ICU) beds for EU/EEA countries and the UK.

These projections illustrate the number of newly reported cases that could be anticipated in countries under the baseline scenario that the currently implemented response measures are maintained for the coming 30 days. In this first analysis, the baseline scenario corresponds to a 'status quo' in which all control measures in place on 2 May 2020 will be continued until the end of the projection period (7 June 2020).

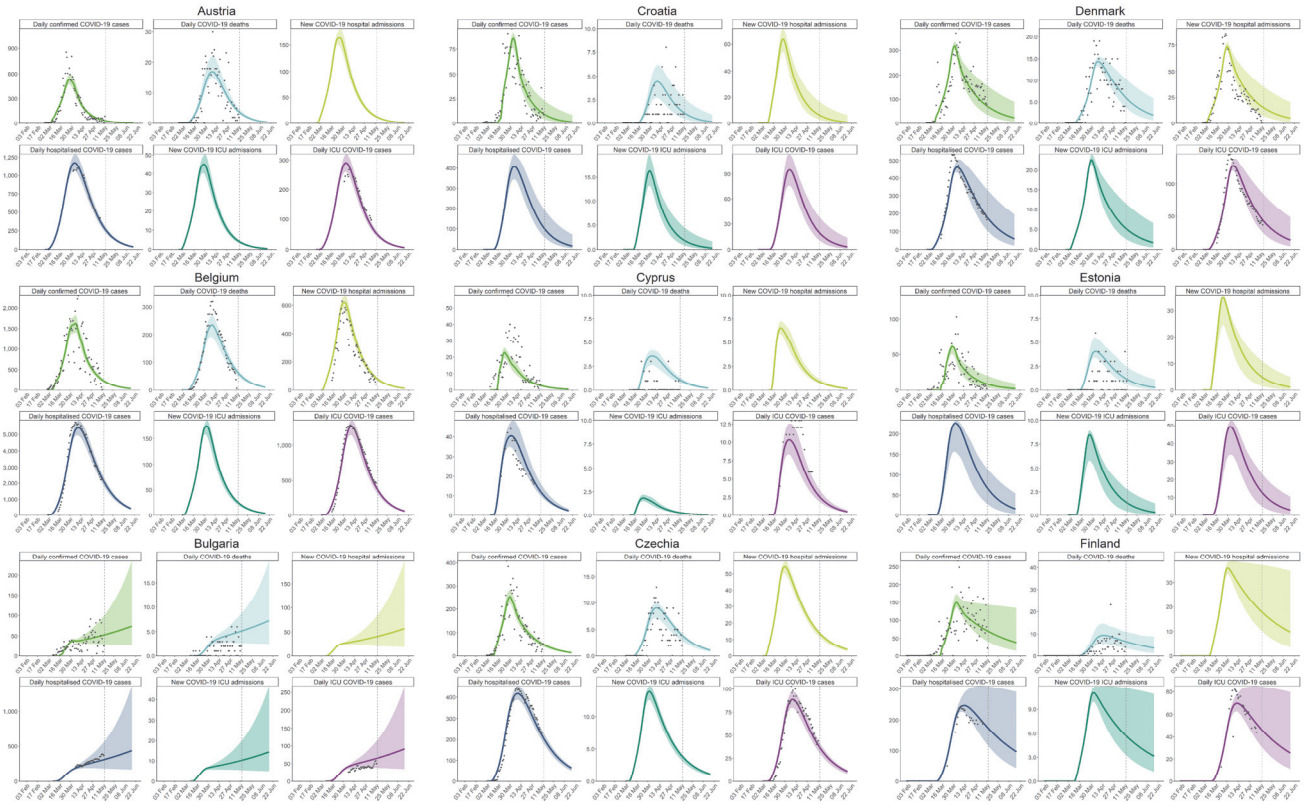
Overall, the projected trends show a sustained decrease of cases under a conservative status quo scenario. However, for countries without a marked epidemic peak, the projections show a moderately increasing trend or a flattened decreasing trend that could continue to place a significant burden on the healthcare system. We also present alongside of the projections the inherent sources of uncertainty associated with a mathematical modelling approach.

Further model developments are envisaged, most notably to:

- address the parametric uncertainty by increasing the number of data time series included in the model. In particular, the new admissions to hospital and intensive care that are both known to be a more accurate proxy of transmission dynamics than the overall number of community cases, which are influenced by testing policies in the community and the availability of resources for testing. A considerable effort has been made by all EU/EEA countries and the UK to make available such data in a timely manner through public websites and epidemiological platforms. We support these initiatives and advocate for wider data sharing of daily time series of new admissions (hospital and ICU) and weekly number of COVID-19 tests performed. This epidemiological information would be particularly valuable to support more accurate projections in the case of future increases in transmission. In addition, the parameters of the model will be refined as new evidence is provided through scientific literature and from case-based surveillance data. Monitoring of model performance and dynamic integration of new available epidemiological data as they become available is planned to continue.
- enhance model structure by adding new features such as an age-dependant contact matrix. This would allow the development of modelled scenarios through the integration of additional non-pharmaceutical interventions, such as closure of educational institutions. Further integration of trend in COVID laboratory testing, mobility data and survey on contact might be considered. On mobility aspects, this can be performed incrementally by using public Google or Apple mobility reports, and, later, more detailed mobility data from mobile operators or research-funded EU projects [15-17].
- in addition, such mathematical modelling would benefit from an 'ensemble' forecast framework. This framework would gather projections produced by modelling initiatives from various sources, such as international institutions, national public health institutes across Europe and academia. Such an initiative would promote knowledge sharing across all EU/EEA countries and the UK. To illustrate this approach, we present in Appendix 2 a comparison of the ECDC model output with projections from the Institute of Health Metrics and Evaluation (IHME, Seattle, USA). The IHME forecasts were selected for this exercise because they also simulate the outbreak in EU/EEA countries and the UK, over a 30-day time horizon, and use target indicators comparable with the ECDC model. For this comparison, daily use of intensive care beds for COVID-19 was selected as one of the most important metrics, both for model calibration and as target indicator for assessing healthcare burden.
- the scenario-related uncertainty by considering alternative scenarios of refined response measures as well as COVID-19 laboratory testing policies. We would like to stress the importance of comparing scenarios that take different interventions into account and assess them against mobility data (which can be considered a proxy of contact at the population level).

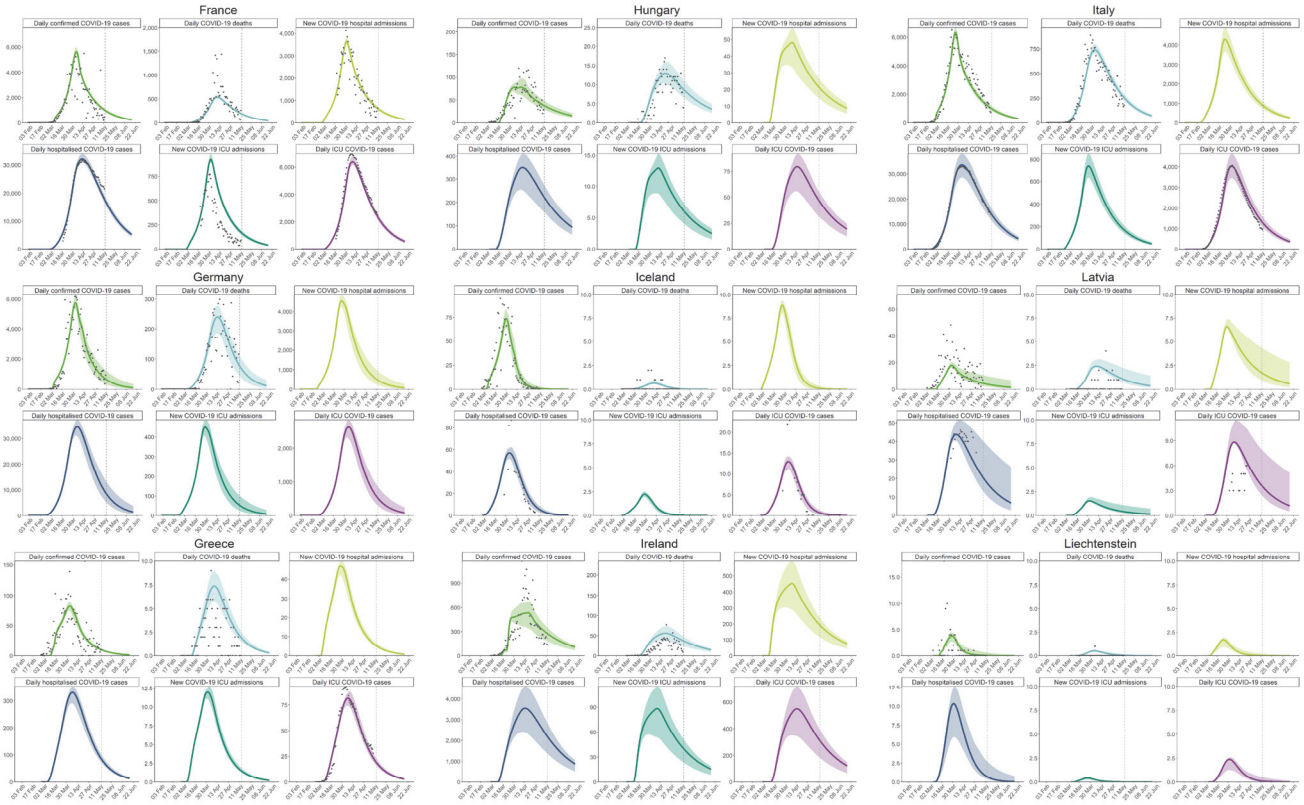
Appendix 1. 30-day projections of COVID-19 cases, deaths, and hospital requirements in EU/EEA countries and the UK

Figure 4 a. Number of observed and predicted COVID-19 cases by time-series type (new daily cases, new daily deaths, new daily admissions at hospital, daily number of hospitalised cases, daily new admission in intensive care units and daily number of cases hospitalised in intensive care units) in the EU/EEA and the UK in the period up until 12 June 2020



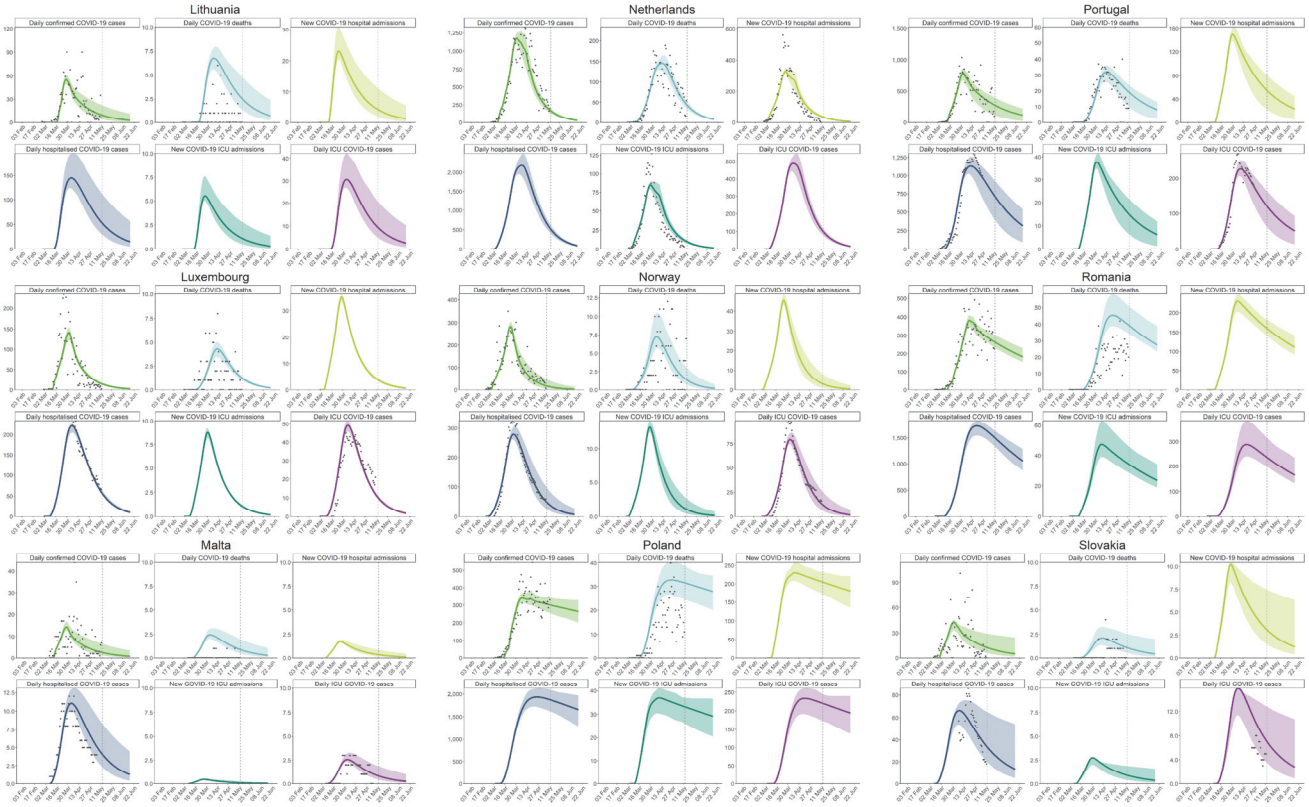
** No time series for hospitalised and ICU cases available. Due to missing country-specific values for indicators informing the graphs, predictions are computed with model parameters based on European averages as an approximation of the actual values.*

Figure 4 b. Number of observed and predicted COVID-19 cases by time-series type (new daily cases, new daily deaths, new daily admissions at hospital, daily number of hospitalised cases, daily new admission in intensive care units and daily number of cases hospitalised in intensive care units) in the EU/EEA and the UK in the period up until 12 June 2020



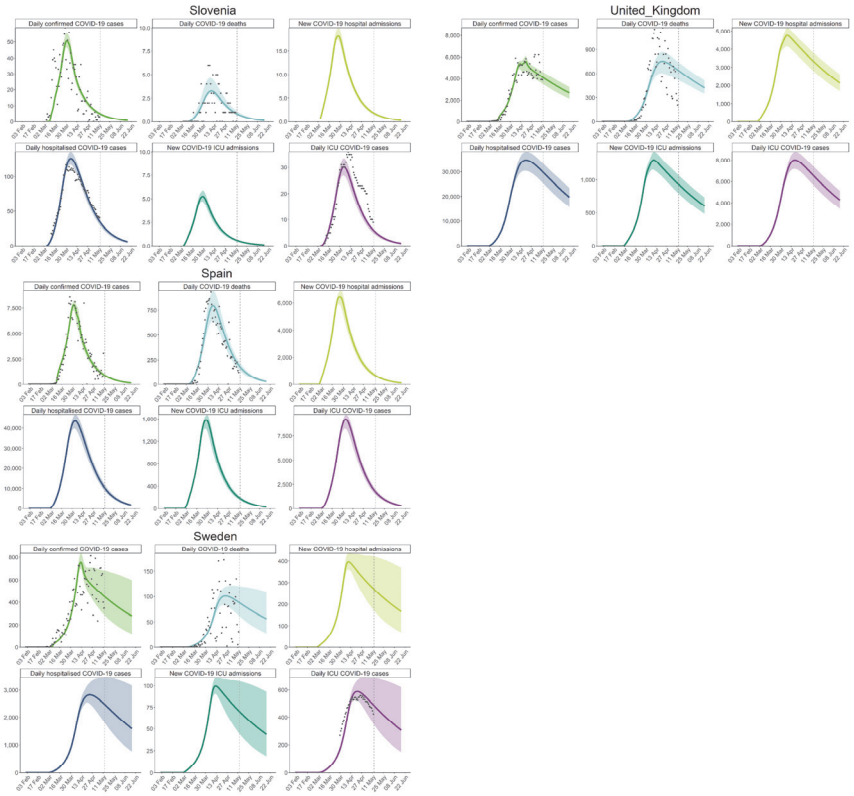
** No time series for hospitalised and ICU cases available. Due to missing country-specific values for indicators informing the graphs, predictions are computed with model parameters based on European averages as an approximation of the actual values.*

Figure 4 c. Number of observed and predicted COVID-19 cases by time-series type (new daily cases, new daily deaths, new daily admissions at hospital, daily number of hospitalised cases, daily new admission in intensive care units and daily number of cases hospitalised in intensive care units) in the EU/EEA and the UK in the period up until 12 June 2020



Note: No time series for hospitalised and ICU cases available. Due to missing country-specific values for indicators informing the graphs, predictions are computed with model parameters based on European averages as an approximation of the actual values.

Figure 4 d. Number of observed and predicted COVID-19 cases by time-series type (new daily cases, new daily deaths, new daily admissions at hospital, daily number of hospitalised cases, daily new admission in intensive care units and daily number of cases hospitalised in intensive care units) in the EU/EEA and the UK in the period up until 12 June 2020

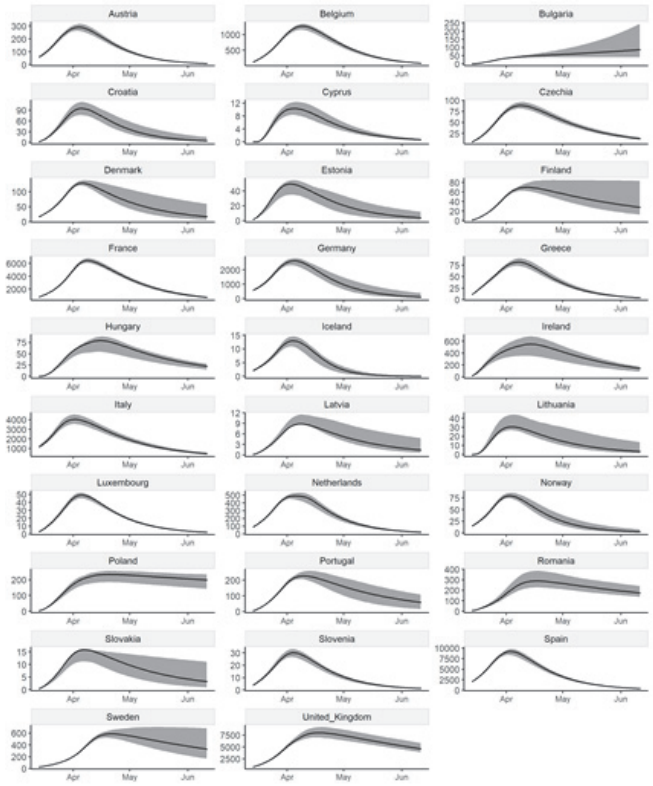


** No time series for hospitalised and ICU cases available. Due to missing country-specific values for indicators informing the graphs, predictions are computed with model parameters based on European averages as an approximation of the actual values.*

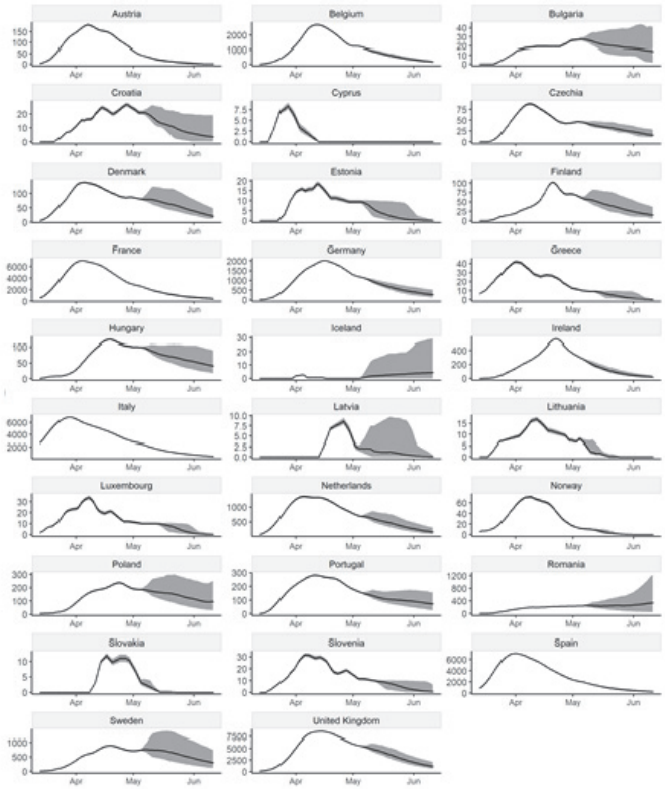
Appendix 2. Comparison of projections from the ECDC model and the nonlinear mixed effects model of the Institute of Health Metrics and Evaluation (IHME, Seattle)

Figure 5. ECDC 30-day projection (Panel A) of mean ICU beds needed by day for COVID-19 patients for EU/EEA countries and the United-Kingdom (data extraction 10 May 2020) and IHME 30-day projection (Panel B) of mean ICU beds needed by day for COVID-19 patients for EU/EEA countries (except Liechtenstein and Malta) and the United Kingdom

Panel A



Panel B



Figures adapted from: https://covid19.healthdata.org/united-states-of-america. Projection as of 10/05/2020 [18].
The figures above are based on data acquired from the Institute for Health Metrics and Evaluation (IHME), Seattle, University of Washington, on COVID-19 projections (available from: https://covid19.healthdata.org/ [18]). The IHME model is a nonlinear mixed-effects model for COVID-19 forecasting (see IHME model overview for more details). The IHME model is based on the main assumption that physical distancing stays in place until deaths are below 0.3 per million people. For the model, physical distancing measures are expected to be in place until the end of May 2020. According to IHME, shaded areas indicate uncertainty defined as 'the range of values that is likely to include the correct projected estimate for a given data category. Larger uncertainty intervals can result from limited data availability, small studies, and conflicting data, while smaller uncertainty intervals can result from extensive data availability, large studies, and data that are consistent across sources.'

Table 1. Summary of ECDC and IHME 30-day projection (13 May 2020–12 June 2020), EU/EEA countries (except Liechtenstein and Malta) and the United Kingdom

Country	ECDC	IHME
	Maximum of daily ICU beds needed (95% uncertainty intervals)[1]	Maximum of daily ICU beds needed (95% uncertainty intervals)[2]
Austria	50 (40–60)	20 (20–30)
Belgium	370 (310–400)	850 (770–1010)
Bulgaria	90 (40–240)	20 (20–40)
Croatia*	20 (10–40)	20 (10–30)
Cyprus	0 (0)	0 (0)
Czechia	40 (30–40)	40 (30–50)
Denmark	40 (20–90)	80 (60–120)
Estonia*	10 (0–20)	0 (0–10)
Finland	50 (30–80)	50 (40–80)
France	2280 (2040–2490)	1730 (1630–1860)
Germany*	520 (280–1010)	880 (780–1040)
Greece	20 (20–20)	10 (10–10)
Hungary*	50 (30–50)	80 (70–110)
Iceland	0 (0)	0 (0–30)
Ireland*	310 (190–390)	180 (150–230)
Italy	1260 (1100–1490)	1740 (1680–1800)
Latvia	0 (0–10)	0 (0–10)
Lithuania*	10 (0–20)	0 (0–10)
Luxembourg	10 (10–10)	10 (10–10)
Netherlands	100 (80–120)	580 (460–840)
Norway	10 (10–20)	10 (10–10)
Poland*	220 (170–250)	170 (120–270)
Portugal	120 (60–180)	120 (100–170)
Romania*	240 (180–310)	340 (40–1250)
Slovakia	10 (0–10)	0 (0)
Slovenia	10 (0–10)	10 (10–10)
Spain*	1760 (1540–1950)	1380 (1290–1500)
Sweden	480 (350–700)	740 (480–1340)
United Kingdom*	6540 (5650–7820)	4660 (3990–5970)

(1) Maximum ICU beds needed is defined as the maximum ICU COVID-19 beds needed on a single day over the selected period; detailed information about IHME indicator and methodology available in: 'Forecasting COVID-19 impact on hospital bed-days, ICU-days, ventilatordays and deaths by US state in the next 4 months', IHME COVID-19 health service utilization forecasting team [18,19]

*Note: * No time series for hospitalised and ICU cases available. Due to missing country-specific values for indicators informing the graphs, predictions are computed with model parameters based on European averages as an approximation of the actual values.*

Appendix 3. Description of ECDC dynamic transmission model: difference equations, prognosis probabilities, and model calibration

Computing platform

The model has been developed using the R software environment for statistical computing and graphics (R version 3.6.3). The calibration process makes use of the *lazymcmc* package for R (version 1.0.0).

Difference equations

The following table describes the difference equations that calculate the number of people in each disease state over time and provides a brief description of the parameters required in the equations. See the 'calibration' section for details on how these parameters are quantified.

Prognosis probabilities

Following an incubation period, an infected individual develops either asymptomatic, mild, or severe disease. We define the probability of developing severe disease to be age-dependent (denoted ρ_{S_g} for age group g) and quantify these age-dependent probabilities in 10-year age bins as per Ferguson et al [20]. Individuals that develop severe disease may, after some time, either seek hospital care or remain outside of the hospital setting. We model three distinct prognosis tracks for those that will seek hospital care: 1) the patient will eventually recover without intensive care, 2) the patient will require intensive care but will eventually recover, 3) the patient will require intensive care and will ultimately die from COVID-19-related complications. The probability of an individual developing into a critical case (and thus requiring intensive care), given that they have severe disease, is also defined to be age-dependent and quantified as per Ferguson et al. [20]. We denote this probability ρ_{C_g} for age group g. The probability of an infected individual being in any one of these three hospital prognosis tracks, respectively, is given by:

$$\rho_{S_g^R} = \rho_{S_g} \cdot \pi \cdot \left(1 - \rho_{C_g}\right)$$
$$\rho_{S_g^C} = \rho_{S_g} \cdot \pi \cdot \rho_{C_g} \cdot (1 - \varphi)$$
$$\rho_{S_g^D} = \rho_{S_g} \cdot \pi \cdot \rho_{C_g} \cdot \varphi$$

where π is the probability that a severe case will seek hospital care, and φ is the probability of death for those in intensive care.

In addition, we model two distinct prognosis tracks for severe cases that do not seek hospital care: 1) eventual recovery and 2) death from COVID-19-related complications. Critical cases are not explicitly tracked outside of the hospital setting. The probability of being in one of these two tracks, respectively, is given by:

$$\rho_{\hat{S}_g^R} = \rho_{S_g} \cdot (1 - \pi) \cdot \left[\left(1 - \rho_{C_g}\right) + \rho_{C_g} \cdot (1 - \hat{\varphi})\right]$$
$$\rho_{\hat{S}_g^D} = \rho_{S_g} \cdot (1 - \pi) \cdot \rho_{C_g} \cdot \hat{\varphi}$$

where $\hat{\varphi}$ is the probability of death for critical cases outside of the hospital setting.

Finally, we define the probability of an infected individual of age group g developing asymptomatic and mild disease to be:

$$\rho_{A_g} = \left(1 - \rho_{S_g}\right)\theta = \left(1 - \rho_{S_g^R} + \rho_{S_g^C} + \rho_{S_g^D} + \rho_{\hat{S}_g^R} + \rho_{\hat{S}_g^D}\right)\theta$$

$$\rho_{M_g} = \left(1 - \rho_{S_g}\right)(1 - \theta) = \left(1 - \rho_{S_g^R} + \rho_{S_g^C} + \rho_{S_g^D} + \rho_{\hat{S}_g^R} + \rho_{\hat{S}_g^D}\right)(1 - \theta)$$

Where θ is the proportion of non-severe COVID-19 cases that are asymptomatic. It then holds that:

$\rho_{A_g} + \rho_{M_g} + \rho_{S_g^R} + \rho_{S_g^C} + \rho_{S_g^D} + \rho_{\hat{S}_g^R} + \rho_{\hat{S}_g^D} = 1$ for all age groups g.

Table 2. Variable description

Variable	Variable description	Difference equation (t represents time, defined in one-day time steps)	Parameter descriptions
Z_g	Susceptible to infection	$Z_g(t+1) = Z_g(t) - \lambda(t)Z_g(t)$	$\lambda(t)$ ≔ Probability of infection for susceptible individuals. Described in detail in 'force of infection' section.
E_g	Incubation phase (infected but not infectious)	$E_g(t+1) = \left(1 - \frac{1}{\delta_E}\right)E_g(t) + \lambda(t)Z_g(t)$	δ_E ≔ Mean number of days in the incubation phase.
A_g	Asymptomatic disease	$A_g(t+1) = \left(1 - \sigma(t) - \frac{1}{\gamma_M}\right)A_g(t) + \frac{\rho_{A_g}}{\delta_E}E_g(t)$	σ(t)≔ Contact tracing intensity and probability of isolation for diagnosed asymptomatic and mild cases. See 'isolation dynamics' section for details. γ_M ≔ Mean infectious period for asymptomatic and mild cases.
M_g	Mild disease	$M_g(t+1) = \left(1 - \sigma(t) - \frac{1}{\gamma_M}\right)M_g(t) + \frac{\rho_{M_g}}{\delta_E}E_g(t)$	ρ_{A_g}, ρ_{M_g} ≔ Probability of asymptomatic or mild disease, respectively, for age group g.
Q_g	Isolation state (asymptomatic and mild cases)	$Q_g(t+1) = \left(1 - \frac{1}{\gamma_M}\right)Q_g(t) + \sigma(t)\left(A_g(t) + M_g(t)\right)$	
S_g^R	Severe disease Will seek hospital care Prognosis: recover	$S_g^R(t+1) = \left(1 - \frac{1}{\delta_S}\right)S_g^R(t) + \frac{\rho_{S_g^R}}{\delta_E}E_g(t)$	δ_S ≔ Mean number of days between severe symptom onset and hospitalisation.
S_g^C	Severe disease Will seek hospital care Prognosis: critical but recover	$S_g^C(t+1) = \left(1 - \frac{1}{\delta_S}\right)S_g^C(t) + \frac{\rho_{S_g^C}}{\delta_E}E_g(t)$	$\rho_{S_g^R}, \rho_{S_g^C}, \rho_{S_g^D}$ ≔ Probability of care-seeking severe disease (prognosis of recover, critical but recover, and death, respectively) for age group g.
S_g^D	Severe disease Will seek hospital care Prognosis: death	$S_g^D(t+1) = \left(1 - \frac{1}{\delta_S}\right)S_g^D(t) + \frac{\rho_{S_g^D}}{\delta_E}E_g(t)$	See 'prognosis probability' section for further details of $\rho_{S_g^R}$, $\rho_{S_g^C}$, $\rho_{S_g^D}$, $\rho_{\hat{S}_g^R}$ and $\rho_{\hat{S}_g^D}$.
$\hat{S}_g^R$	Severe disease Will <u>not</u> seek hospital care Prognosis: recover	$\hat{S}_g^R(t+1) = \left(1 - \frac{1}{\gamma_S}\right)\hat{S}_g^R(t) + \frac{\rho_{\hat{S}_g^R}}{\delta_E}E_g(t)$	$\rho_{\hat{S}_g^R}, \rho_{\hat{S}_g^D}$ ≔ Probability of non-care-seeking severe disease (prognosis of recover / death). γ_S ≔ Mean infectious period for severe cases.

Variable	Variable description	Difference equation (t represents time, defined in one-day time steps)	Parameter descriptions
$\hat{S}_g^D$	Severe disease Will not seek hospital care Prognosis: death	$\hat{S}_g^D(t+1) = \left(1 - \frac{1}{\hat{\mu}}\right)\hat{S}_g^D(t) + \frac{\rho_{\hat{S}_g^D}}{\delta_E}E_g(t)$	$\hat{\mu}$:= Mean number of days between symptom onset and death outside of the hospital setting.
H_g^R	Hospitalised case Prognosis: recover	$H_g^R(t+1) = \left(1 - \frac{1}{\delta_H}\right)H_g^R(t) + \frac{S_g^R(t)}{\delta_S}$	δ_H := Mean number of days in hospital before discharge for cases that do not go through ICU.
H_g^C	Hospitalised case Prognosis: critical but recover	$H_g^C(t+1) = \left(1 - \frac{1}{\delta_{T_I}}\right)H_g^C(t) + \frac{S_g^C(t)}{\delta_S}$	δ_{T_I} := Mean number of days in hospital before transfer to ICU for cases that become critical.
H_g^D	Hospitalised case Prognosis: death	$H_g^D(t+1) = \left(1 - \frac{1}{\delta_{T_I}}\right)H_g^D(t) + \frac{S_g^D(t)}{\delta_S}$	
I_g^C	Intensive care case Prognosis: critical but recover	$I_g^C(t+1) = \left(1 - \frac{1}{\delta_I}\right)I_g^C(t) + \frac{H_g^C(t)}{\delta_{T_I}}$	δ_I := Mean number of days spent in ICU before transfer back to non-ICU ward for critical cases that recover.
I_g^D	Intensive care case Prognosis: death	$I_g^D(t+1) = \left(1 - \frac{1}{\mu}\right)I_g^D(t) + \frac{H_g^D(t)}{\delta_{T_I}}$	μ := Mean number of days spent in ICU before death.
T_g	Transferred back to non-ICU ward after intensive care	$T_g(t+1) = \left(1 - \frac{1}{\delta_{T_H}}\right)T_g(t) + \frac{I_g^C(t)}{\delta_I}$	δ_{T_H} := Mean number of days in a non-ICU hospital ward following transfer from ICU.
D_g^H	Discharged from hospital (no intensive care)	$D_g^H(t+1) = \left(1 - \frac{1}{\gamma_H}\right)D_g^H(t) + \frac{H_g^R(t)}{\delta_H}$	γ_H := Number of remaining days until severe cases are recovered (and no longer infectious) following hospital discharge for non-critical cases.
D_g^I	Discharged from hospital (after intensive care)	$D_g^I(t+1) = \left(1 - \frac{1}{\gamma_I}\right)D_g^I(t) + \frac{T_g(t)}{\delta_{T_H}}$	γ_I := Number of remaining days until severe cases are recovered (and no longer infectious) following ICU and hospital discharge for critical cases.
X_g	Death from COVID-19-related complications	$X_g(t+1) = X_g(t) + \frac{\hat{S}_g^D(t)}{\hat{\mu}} + \frac{I_g^D(t)}{\mu}$	

Variable	Variable description	Difference equation (t represents time, defined in one-day time steps)	Parameter descriptions
R_g	Recovered (with assumed sterile immunity)	$R_g(t+1) = R_g(t) + \frac{A_g(t) + M_g(t) + Q_g(t)}{\gamma_M} + \frac{\hat{S}_g^R(t)}{\gamma_S} + \frac{D_g^H(t)}{\gamma_H} + \frac{D_g^I(t)}{\gamma_I}$	

Effect of response measures

We consider four non-therapeutic social distancing response measures in the model which work to reduce the average number of contacts between people in the population: stay-at-home orders, stay-at-home recommendations, closure of public spaces, and cancellation of mass gatherings. As per the results of a survey conducted amongst ECDC experts, we assume stay-at-home orders are the strongest possible measure in the context of contact reduction and assume that the other three responses have a relative efficacy (relative to stay-at-home orders) that is consistent across European countries. We then apply a scaling factor to proportionately increase or decrease the total efficacy of response measures for each country. This scaling factor for each country is subjected to the calibration process (see 'calibration section' for further information). We quantify the relative efficacies of response measures relative to stay-at-home orders, using an internal ECDC survey of expert opinions.

We assume no synergistic effects exist for the implementation of contact reduction response measures. That is, if a country implements several measures simultaneously (for example stay-at-home orders and closure of public spaces), only the highest efficacy across these response measures is used to calculate the effect on contact reduction. Formally, the response efficacy ($r_{\text{effective}}$) at a time t is given by:

$$r_{\text{effective}}(t) = \min(r_1(t)\varepsilon_1, r_2(t)\varepsilon_2, r_3(t)\varepsilon_3, r_4(t)\varepsilon_4, 0.99) \cdot \omega_a$$

where ε_k is the relative efficacy of response k in reducing the average number of contacts per person per day (relative to stay-at-home orders, see Appendix 4), ω_a is the calibrated country-specific scaling factor for country a that scales the efficacies of all responses proportionately, and $r_k(t)$ is a binary variable defined as

$$r_k(t) = \begin{cases} 1, & \text{if response } k \textit{ is} \text{ implemented at time } t \\ 0, & \text{if response } k \text{ is not implemented at time } t \end{cases}$$

We assume a value of 0.99 as an upper bound of $r_{\text{effective}}$ for all time points as it is unlikely that any combination of response measures will lead to a 100% reduction in contacts.

We then define the effective average number of per-person per-day contacts with those in infectious disease state $j = \{\text{asymptomatic}, \text{mild}, \text{severe}\}$ at time t to be:

$$c^j_{\text{effective}}(t) = c\delta_j\left(1 - r_{\text{effective}}(t)\right)\frac{I_j(t)}{N}$$

where c is the average number of contacts per-person per-day (in the absence of response measures) and δ_j is a proportion representing a reduction of contacts when in infectious state j relative to 'normal' behaviour (due to sickness, hospitalisation, or otherwise). We note here that we assume homogenous mixing across age groups (that is, contacts are equally likely to occur between any pair of age groups).

We assert the condition that $\delta_S \leq \delta_M \leq \delta_A = 1$. The variable $I_j(t)$ represents the total number of asymptomatic, mild, and severe cases at time t and N is the total number of people in the population. That is:

$$I_A(t) = \sum_g A_g(t)$$

$$I_M(t) = \sum_g M_g(t)$$

$$I_S(t) = \sum_g \begin{pmatrix} S_g^R(t) + S_g^S(t) + S_g^D(t) + \hat{S}_g^R(t) + \hat{S}_g^D(t) + H_g^R(t) + H_g^C(t) + H_g^D(t) \\ + I_g^C(t) + I_g^D(t) + T_g(t) + D_g^H(t) + D_g^I(t) \end{pmatrix}$$

$$N = I_A(t) + I_M(t) + I_S(t) + \left(\sum_g Z_g(t) + E_g(t) + Q_g(t) + X_g(t) + R_g(t)\right)$$

Force of infection

The force of infection (that is, the effective probability of becoming infected) for a susceptible individual at time t is then described by:

$$\lambda(t) = 1 - \prod_j \left(1 - \beta_j\right)^{c^j_{\text{effective}}(t)}$$

where β_j is the probability of transmission between a susceptible and infectious contact in disease state j for $j = \{\text{asymptomatic}, \text{mild}, \text{severe}\}$. For the purpose of this modelling exercise, we have assumed $\beta_A = \beta_M = \beta_S$.

The total number of new infections over all age groups g at time t is then given by:

$$\sum_g \lambda(t) \cdot Z_g(t)$$

Model calibration

The model was calibrated to publicly available data on confirmed cases, hospitalisation, ICU patients and mortality (where available) from 31 EU/EEA countries. By default, heavier weighting was given to mortality, hospitalisation, and ICU data in the calibration process. The table below gives country-specific variations of indicator weightings used in the calibration process.

An ECDC database for national and regional response measure implementation was used to inform the timing of responses in each country model [1]. The fitting procedure uses a Bayesian Markov chain Monte Carlo (MCMC) framework to simultaneously fit all 31 countries. In general, biological parameters were assumed to be global (not varying by country) while behavioural parameters – including response measure efficacy – are assumed to vary by country. Informative varying effect hyper-parameters are used to penalise high variance between country-specific parameters. All priors are informed by quantitative evidence from published literature, and an overview is presented in the table below.

Table 3. Country-specific variations of indicator weightings used in the calibration process

Country	New daily cases	New daily deaths	Daily number of hospitalised cases	Daily number of hospitalised cases in ICU	Daily new admissions in hospital	Daily new admissions in intensive care units
Default	2	4	4	4	8	8
Austria	2	8	8	8	8	8
Cyprus	4	4	8	8	8	8
Estonia	4	8	4	4	8	8
Finland	4	4	4	16	8	8
France	2	4	4	4	8	8
Germany	4	8	4	4	8	8
Greece	4	4	4	8	8	8
Iceland	2	8	8	8	8	8
Italy	4	8	8	8	8	8
Latvia	2	8	4	8	8	8
Luxembourg	2	8	8	8	8	8
Netherlands	4	4	8	8	8	8
Norway	2	4	16	16	8	8
Poland	8	8	4	4	8	8
United Kingdom	4	4	4	4	8	8

Calibrating with R_0

The basic reproduction number, denoted R_0, is the number of secondary infections caused by a single infectious case over the course of that infection in an otherwise fully susceptible population. In our model, we calculate R_0 at the time of initial case importation, τ, using:

$$R_0 = Z(\tau) \cdot \lambda(\tau) \cdot \gamma$$

where γ is the population average period of infectiousness, and $Z(\tau) \approx N$ is the total number of susceptible people in the population at time τ and is approximately equal to N, the total number of people in the population.

As the population is otherwise fully susceptible at time τ (aside from the number of cases initially imported), the force of infection equation at time τ cancels down to:

$$\lambda(\tau) = 1 - (1 - \beta)^{\frac{c}{N}}$$

where $\beta = \beta_A = \beta_M = \beta_S$ (as described in the 'force of infection' section). Rather than calibrating β (for which we have little understanding in the context of SARS-CoV-2 transmission) and c such that we align to empirical epidemiological data, we consider R_0 as a calibration parameter – specific for each country – from which we determine the necessary value of c having fixed β to some sensible value. We do this by solving the R_0 equation for c:

$$R_0 = Z(\tau) \cdot \lambda(\tau) \cdot \gamma \approx N \cdot \left[1 - (1 - \beta)^{\frac{c}{N}}\right] \cdot \gamma$$

$$\Longrightarrow 1 - \frac{R_0}{N \cdot \gamma} \approx (1 - \beta)^{\frac{c}{N}}$$

$$\Longrightarrow \log\left(1 - \frac{R_0}{N \cdot \gamma}\right) \approx \frac{c}{N} \cdot \log(1 - \beta)$$

$$\therefore c \approx N \cdot \frac{\log\left(1 - \frac{R_0}{N \cdot \gamma}\right)}{\log(1 - \beta)}$$

There is a slight complication in that each of β, c, and γ can differ by disease state (asymptomatic, mild, or severe disease). Taking advantage of the 'prognosis structure' of the model, we can accurately compute population averages for all of these parameters by pre-calculating the likely proportions of asymptomatic, mild, severe cases. This considers age-dependent probabilities and population demographics. We stress here that R_0 is a calibrated parameter for each country, noting that the prior used in the calibration process is informed by international literature estimates (see table of model parameters below).

Initial conditions

We initiate model dynamics by importing asymptomatic and mild cases into the population one to two weeks before the estimated 'outbreak date'. For most of the countries modelled, the 'outbreak date' is defined to be the first occurrence of three consecutive days of non-zero confirmed cases. For countries with relatively few cases (selected manually), the 'outbreak date' is classified as the date of the first confirmed case. The number of cases imported is calibrated for each country.

Description of data sources

Table 4. Model parameters

Parameter	Description	Prior mean[1]	Lower bound	Upper bound	Global parameter[2]	Uses hyper parameter[3]	Selection of countries with specific calibration[4]	References
R0	Basic reproduction number defined as the average of the number of new cases from one infected case in a totally susceptible population	3	2	5	No	No	Calibrated: all countries. Fixed: none.	[3,21,22]
Beta	Probability of transmission in one contact between fully susceptible and fully infectious individual	0.05	0.01	0.1	Yes	NA	Calibrated: no. Fixed: yes.	
Beta reduction	Reduction in infectiousness of asymptomatic/mild cases relative to severe/critical cases	0	NA	NA	Yes	NA	Calibrated: no. Fixed: yes.	
Contacts reduction	Reduction in contacts of severe/critical cases relative to asymptomatic/mild cases due to assumed hospitalisation or isolation	0.9	0.5	0.99	Yes	NA	Calibrated: no. Fixed: yes.	

Parameter	Description	Prior mean[1]	Lower bound	Upper bound	Global parameter[2]	Uses hyper parameter[3]	Selection of countries with specific calibration[4]	References
Susceptibility	Exponential decay in susceptibility for younger age groups relative to oldest age group	0	NA	NA	Yes	NA	Calibrated: no. Fixed: yes.	
Proportion asymptomatic	Proportion of all cases that are asymptomatic	0	NA	NA	Yes	NA	Calibrated: no. Fixed: yes.	
Latency days	Number of days in latency (infected but not infectious) state	4.6	3	7	Yes	NA	Calibrated: no. Fixed: yes.	[2,23,24]
Infectious days mild	Number of days for which mild and asymptomatic cases are infectious	6	3	10	Yes	NA	Calibrated: no. Fixed: yes.	[2]
Infectious days severe	Number of days for which severe and critical cases are infectious	22	14	35	Yes	NA	Calibrated: no. Fixed: yes.	
Isolation probability	Proportion of mild and asymptomatic cases that isolate after diagnosis	0	NA	NA	No	Yes	Calibrated: none. Fixed: all countries.	
Seek hospital	Proportion of severe cases that seek hospital care during course of severe disease	0.7	0.5	0.99	No	Yes	Calibrated: all countries. Fixed: none.	
Onset to hospital days*	Number of days between severe onset of symptoms and hospitalisation	5.9	1	14	No	Yes	Calibrated: Belgium, Cyprus, Czechia, Denmark, France, Italy, Latvia, Netherlands, Norway, Romania Fixed: all other countries.	[25]
Confirmation delay hospital*	Number of days delay between onset of symptoms and diagnosis for those seeking hospital care	11.46	0.01	14	No	Yes	Calibrated: Belgium, Cyprus, Czechia, Denmark, Finland, France, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden, United Kingdom. Fixed: all other countries.	[25]
Confirmation delay home*	Number of days delay between onset of symptoms and diagnosis for those outside of the hospital setting	6.75	1	14	No	Yes	Calibrated: none. Fixed: all countries.	[25]
Home testing rate	Proportion of severe cases not seeking hospital care that get tested	0.7	0.05	0.99	No	Yes	Calibrated: none. Fixed: all countries.	
Hospital stay days	Number of days a severe non-critical case spends in hospital before discharge	10	1	14	No	Yes	Calibrated: Austria, Belgium, Czechia, Denmark, Finland, France, Italy, Netherlands, Norway, Portugal, Slovenia. Fixed: all other countries.	

Parameter	Description	Prior mean[1]	Lower bound	Upper bound	Global parameter[2]	Uses hyper parameter[3]	Selection of countries with specific calibration[4]	References
Hospital to ICU days	Number of days between hospital admission and ICU admission for cases that will become critical	2	1	10	No	Yes	Calibrated: none. Fixed: all countries.	
ICU stay days	Number of days a critical case spends in ICU before discharge	7	1	10	No	Yes	Calibrated: Austria, Belgium, Czechia, Denmark, Finland, France, Greece, Italy, Norway, Portugal, Sweden. Fixed: all other countries	
ICU death days	Number of days a critical case spends in ICU before death	6	3	14	Yes	NA	Calibrated: no. Fixed: yes.	[26]
Home death days	Number of days between symptom onset and death for those not seeking hospital care	10	7	14	Yes	NA	Calibrated: no. Fixed: yes.	
Death reporting delay*	Number of days delay between a COVID-19 death and that death being reported in the data	1.92	1	14	No	Yes	Calibrated: Belgium, Finland, France, Norway, Slovenia. Fixed: all other countries.	[25]
Severe factor	Calibration factor for proportion of symptomatic cases that are severe	1	0.2	3	No	Yes	Calibrated: none. Fixed: all countries.	
Critical factor	Calibration factor for proportion of severe cases requiring critical care in ICU	1	0.2	3	No	Yes	Calibrated: all countries. Fixed: none.	
Critical death ICU	Proportion of critical cases that die in ICU care (ventilators assumed to be available)	0.5	0.2	0.75	No	Yes	Calibrated: none. Fixed: all countries.	
Critical death non ICU	Proportion of critical cases that die when ICU not available or not sought	0.95	0.8	0.99	No	Yes	Calibrated: Austria, Belgium, Czechia, Denmark, Finland, France, Iceland, Luxembourg, Netherlands, Norway, Portugal, Slovakia, Slovenia. Fixed: none.	
First import	Number of days delay between first case importation and first confirmed case	7	NA	NA	Yes	NA	Calibrated: no. Fixed: yes.	
Number import	Number of people initiated with infection at time first importation	100	0	1000	No	No	Calibrated: none. Fixed: all countries.	
Test per index case	Mean number of contacts to test cases per confirmed index case	0	NA	NA	No	Yes	Calibrated: none. Fixed: all countries.	
Efficacy contact all	Reduction in average number of contacts among all people when strongest non-targeted response is in place	0.95	0.5	5	No	Yes	Calibrated: all countries. Fixed: none.	
Relative efficacy mass gathering 50	Contact reduction efficacy of 'ban mass gatherings > 50 people' response relative to 'stay home enforced'	0.92	0.01	0.99	Yes	NA	Calibrated: no. Fixed: yes.	
Relative efficacy closure public places any	Contact reduction efficacy of 'closing public spaces' response relative to 'stay home enforced'	0.78	0.01	0.99	Yes	NA	Calibrated: no. Fixed: yes.	

Parameter	Description	Prior mean[1]	Lower bound	Upper bound	Global parameter[2]	Uses hyper parameter[3]	Selection of countries with specific calibration[4]	References
Relative efficacy stay home recommend	Contact reduction efficacy of 'stay home recommended' response relative to 'stay home enforced'	0.78	0.01	0.99	No	No	Calibrated: Greece, Ireland. Fixed: all other countries.	
Response delay	Time in days before full efficacy of response is realised following implementation – assumed to be consistent for all interventions	7	1	14	Yes	NA	Calibrated: none. Fixed: all countries.	

(*) TESSy [25]
NA: not applicable
(1) Prior mean of the parameter is used for all countries. For countries for which the parameter is not calibrated (i.e. fixed), the prior is used in the simulation (that is, the parameter is fixed for those countries). For countries for which the parameter is calibrated, the prior is used in the calibration process but it is the parameter posterior that is used in analyses or simulations.
(2) If 'yes', the parameter is not a country-specific parameter. Global parameters may or may not be calibrated.
(3) If "yes", the parameter uses an informative hyper-prior mean and standard deviation to enable learning across countries during the calibration process. Only applicable for non-global parameters.
(4) Selection of countries for which the associated parameter is calibrated.

All data on the daily number of new cases and deaths in EU/EEA countries and the UK were obtained from ECDC's Epidemic Intelligence (EI) database which is publicly available and can be accessed at: https://www.ecdc.europa.eu/en/publications-data/download-todays-data-geographic-distribution-covid-19-cases-worldwide.

Table 5. Summary of the sources of epidemiological data by countries

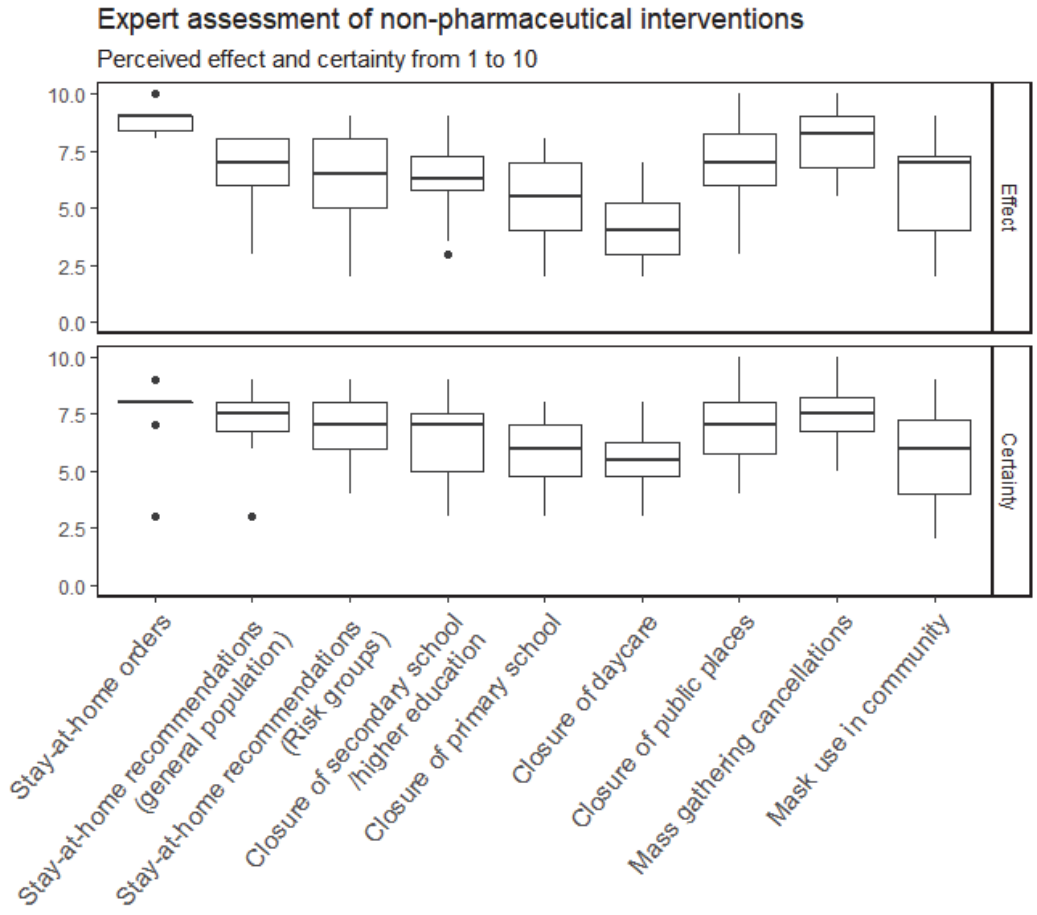
Country	Source number of case	Source number of death	Source for hospitalised cases	Source for ICU cases
Austria	EI database	EI database	New hospitalised cases from country-specific data source [27]	New ICU cases from country-specific data source [27]
Belgium	Country-specific data source [28]	Country-specific data source [28]	Current hospitalised cases from country-specific data source [28]	Current ICU cases from country-specific data source [28]
Bulgaria	EI database	EI database	Current hospitalised cases from country-specific data source [29]	Current ICU cases from country-specific data source [29]
Croatia	EI database	EI database	NA	NA
Cyprus	EI database	EI database	Current hospitalised cases from country-specific data source [30]	Current ICU cases from country-specific data source [30]
Czechia	EI database	EI database	Current hospitalised cases from country-specific data source [31]	Current ICU cases from country-specific data source [31]
Denmark	EI database	EI database	New hospitalised cases from country-specific data source [32]	New ICU cases from country-specific data source [32]
Estonia	EI database	EI database	NA	NA
Finland	EI database	EI database	Current hospitalised cases from country-specific data source [33]	Current ICU cases from country-specific data source [33]
France	EI database	EI database	New and current hospitalised cases from country-specific data source [34]	New and current ICU cases from country-specific data source [34]
Germany	EI database	EI database	NA	NA
Greece	EI database	EI database	NA	Current ICU cases from MoH report [35] *
Hungary	EI database	EI database	NA	NA

Country	Source number of case	Source number of death	Source for hospitalised cases	Source for ICU cases
Iceland	EI database	EI database	Current hospitalised cases from country-specific data source [36]	Current ICU cases from country-specific data source [36]
Ireland	EI database	EI database	NA	NA
Italy	EI database	EI database	Current hospitalised from country-specific data source [37]	Current ICU from country-specific data source [37]
Latvia	EI database	EI database	Current hospitalised from country-specific data source [38]	Current ICU from country-specific data source [38]
Liechtenstein	EI database	EI database	NA	NA
Lithuania	EI database	EI database	NA	NA
Luxembourg	EI database	EI database	Current hospitalised cases from JRC [39]	Current ICU cases from country-specific data source [40]
Malta	EI database	EI database	Current hospitalised cases from country-specific data source [41]†	Current ICU cases from country-specific data source [41]†
Netherlands	EI database	EI database	Current hospitalised from country-specific data source [42]	New ICU cases from country-specific data source [43]
Norway	EI database	EI database	Current hospitalised from country-specific data source [44]	Current ICU cases from country-specific data source [44] *
Poland	EI database	EI database	NA	NA
Portugal	EI database	EI database	Current hospitalised from country-specific data source [45]	Current ICU from country-specific data source [45]
Romania	EI database	EI database	NA	NA
Slovakia	EI database	EI database	Current hospitalised cases from JRC [39]	Current ICU from country-specific data source
Slovenia	EI database	EI database	Current hospitalised from country-specific data source [46]	Current ICU from country-specific data source [46]
Spain	EI database	EI database	NA	NA
Sweden	EI database	EI database	NA	Current ICU from country-specific data source [47,48]
United Kingdom	EI database	EI database	NA	NA

EI database: ECDC's Epidemic Intelligence database [13]
(NA) not available
(*) ICU cases for Greece and Norway refer to patients under mechanical ventilation
(†) Data on new hospitalised and ICU cases in Malta are courtesy of the Infectious Disease Control Unit (IDCU) of the Ministry for Health in Malta.

Appendix 4. Effectiveness of non-pharmaceutical interventions according to a survey among experts involved in the COVID-19 public health response at ECDC

Figure 6. Expert assessment of the perceived effectiveness and uncertainty of non-pharmaceutical interventions to reduce the transmission of SARS-CoV-2 (n=16 public health experts)



Note: For the 'stay-at-home recommendations (risk groups)', participants were asked to assess the effectiveness of interventions aimed at reducing the transmission within or into the risk group(s).

Source of request

Request 64, European Commission, Directorate-General for Health and Food Safety, Crisis Management and Preparedness in Health (SANTE.DDG1.C.3)

Consulted experts

ECDC experts (in alphabetic order): Angelo D'Ambrosio, Mike Catchpole, Bruno Ciancio, Emilie Finch, Helen Johnson, Tommi Karki, Adrian Prodan, Emmanuel Robesyn, Bertrand Sudre.

We would also like to thank all ECDC experts involved in monitoring the non-pharmaceutical measures included in this report.

Modelling experts for the development and fitting of the model:

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Also consulted (arranged alphabetically by country): Austria (Florian Bachner, Health Economics and Systems Analysis, Austrian Public Health Institute, Vienna, Austria); Belgium (Herman Van Oyen, Scientific Institute of Public Health, Brussels; Sophie Quoilin, Scientific Institute of Public Health, Brussels); Denmark (Mathias Luidor Heltberg, Statens Serum Institut, Copenhagen); France (Coignard Bruno, Direction des maladies infectieuses, Santé publique France, Saint-Maurice; Roche Benjamin, MIVEGEC, IRD, CNRS, Université Montpellier, Montpellier); Greece (Theodore Lytras, National Public Health Organization, Athens); Hungary (Zsuzsanna Molnár, Epidemiology and Vaccination Surveillance Department, National Center for Public Health, Hungary; Ágnes Hajdu, National Center for Epidemiology, Budapest); Iceland (Brynjólfur Gauti Jónsson, Statistical Consulting Center at the School of Health Sciences, University of Iceland, Reykjavík); Netherlands (Susan van den Hof, Centre for Infectious Disease Epidemiology and Surveillance, National Institute for Public Health and the Environment (RIVM), Bilthoven); Poland (Rosińska Magdalena, National Institute of Public Health, National Intitute of Hygiene, Warsaw); Portugal (Carlos Dias, National Institute of Health Doutor Ricardo Jorge, Lisbon; Constantino Pereira Caetano, National Institute Of Health Doutor Ricardo Jorge, Lisbon; Baltazar Nunes, National Institute of Health Doutor Ricardo Jorge, Lisbon); Slovakia (Zuzana Chladná, Comenius University in Bratislava, Bratislava; Henrieta Hudečková, Jessenius Faculty of Medicine at Martin, Comenius University, Bratislava; Jana Zibolenová, Jessenius faculty of Medicine at Martin, Comenius University, Bratislava, Slovakia); Spain (Clara Prats, Universitat Politècnica de Catalunya, Barcelona); Sweden (Anders Tegnell, Department of Public Health Analysis and Data Development, Folkhälsomyndigheten, Solna; Lisa Brouwers, Department of Public Health Analysis and Data Development, Folkhälsomyndigheten, Solna; Sharon Kühlmann-Berenzon, Department of Public Health Analysis and Data Development, Folkhälsomyndigheten, Solna); United Kingdom (Paul Birrell, Public Health England, London).

All experts have submitted declarations of interest, and a review of these declarations did not reveal any conflict of interest.

Disclaimer

ECDC issues this technical document based on request No 64 by the European Commission, Directorate-General for Health and Food Safety, Crisis Management and Preparedness in Health (SANTE.DDG1.C.3) and in accordance with Article 10 of Decision No 1082/13/EC and Article 7(1) of Regulation (EC) No 851/2004 establishing a European centre for disease prevention and control (ECDC).

In the framework of ECDC's mandate, the specific purpose of this technical report is to present short-term projections of the COVID-19 epidemic by EU/EEA countries and the UK to inform public health decisions on interventions to control the outbreak. The responsibility on the choice of which option to pursue and which actions to take, including the adoption of mandatory rules or guidelines, lies exclusively with the EU/EEA countries and the UK.

In its activities, ECDC strives to ensure its independence, high scientific quality, transparency and efficiency. This report was written with the coordination and assistance of the COVID-19 support public health emergency group at the European Centre for Disease Prevention and Control. All data published in this report are correct to the best of our knowledge at the time of publication. Maps and figures published do not represent a statement on the part of ECDC or its partners on the legal or border status of the countries and territories shown.

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