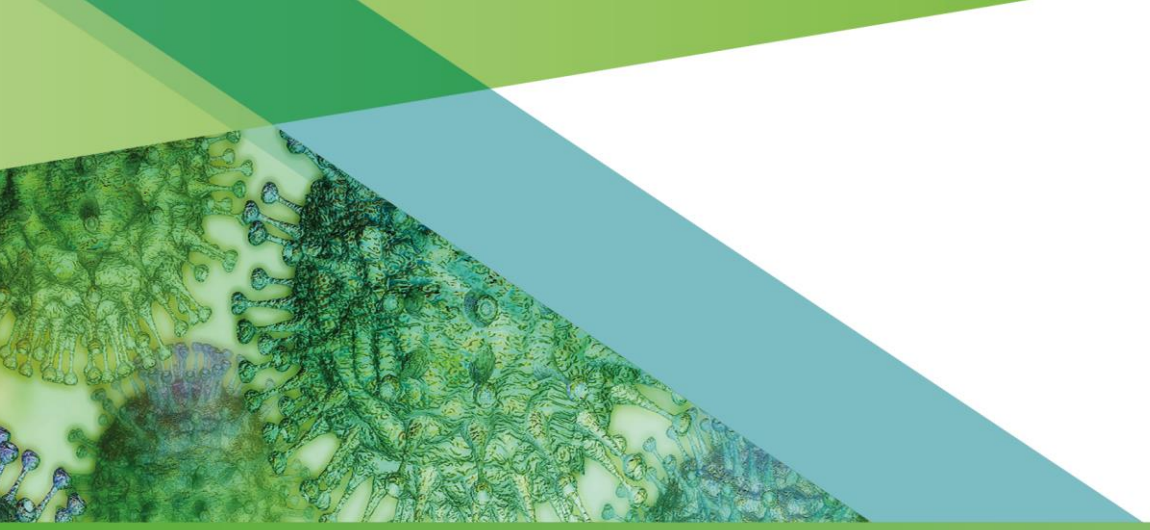


Preliminary forecasts of COVID-19 in the EU/EEA and UK

Version 18 May 2020 [**DRAFT for HSC**]

Executive Summary

Following widespread transmission of the SARS-CoV-2 among EU/EEA countries and the UK for several weeks, the majority of countries reached an epidemic peak of COVID-19 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 [2]. Due to this observed decrease in transmission and to improvements in epidemiological surveillance and healthcare capacity, a number of countries have started to release some targeted non-pharmaceutical interventions and to plan a phasing out of 'stay-at-home' policies.

Among the set of options to enhance the monitoring of the epidemic and provide information about expected trends, 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. In particular, mathematical modelling is 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 the quantification of the uncertainty associated with these estimations and forecasts. In this report, a dynamic compartmental model of COVID-19 is presented, which 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. 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 countries of the EU/EEA 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.

In addition to refining model assumptions and structure according to new scientific evidence, future work 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.

Introduction

SARS-CoV-2, a coronavirus, is the causative agent of the current outbreak of COVID-19 disease. 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 the 23 April 2020 [3].

In March 2020, all EU/EEA countries and the UK implemented a range of non-pharmaceutical interventions to respond to the development of the SARS-CoV-2 epidemic in Europe. 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 [3].

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 [4,5]. 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) [6-10]. Additionally, several academic groups have published mathematical models focused on the dynamics of COVID-19 transmission in Europe [11-14].

The current report presents an outline of the mathematical model used, including the 30-day forecasts for countries and confidence intervals 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. These results 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

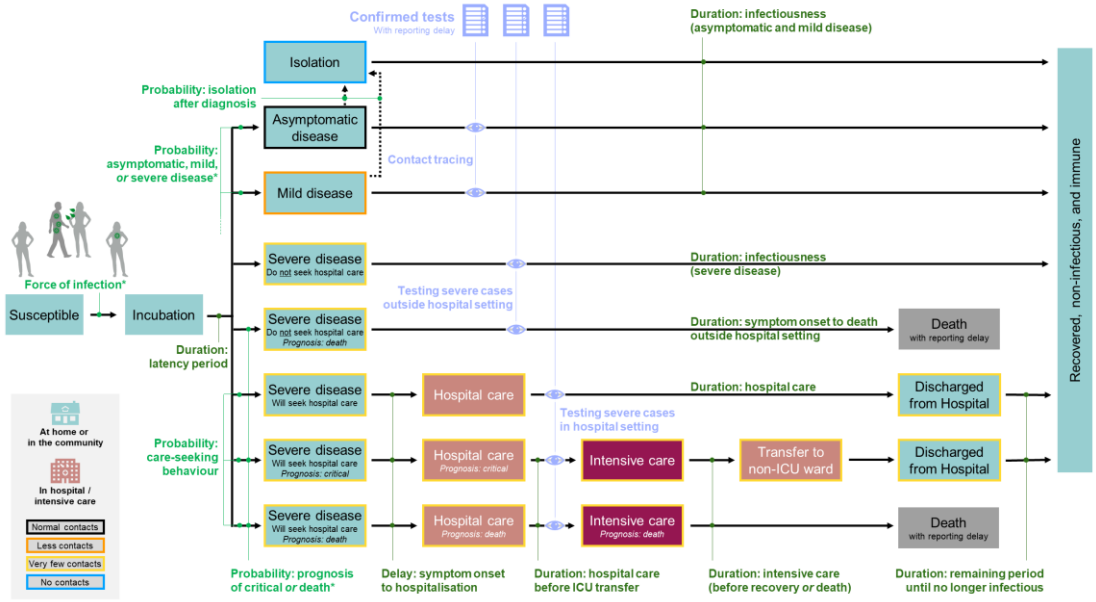
Model structure

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 incorporates the effects of varying proportions of key four non-pharmaceutical interventions. The model is deterministic in nature and simulates discrete time steps of one day.

The natural history of COVID-19 is represented by assuming 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 below). Following infection with SARS-CoV-2, an individual enters an exposed (or incubation or latent) phase where they are assumed to be infected but not yet infectious. Following this exposed phase, the 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. Those developing critical disease whilst 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 i) severe or critical cases presenting at hospital, by severe or critical cases being tested outside of the hospital setting, or ii) 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 number of contacts made by an individual does, however, depend on their age, and can be reduced by non-pharmaceutical interventions (see section on furture development).

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 i) specific social distancing measures for risk groups (e.g elderly population) and ii) closures of educational institutions. Further developments of the model are planned in order to incorporate these intervention measures / closure of educational institutions (as appropriate). The data on response measures is based on information available from official public sources as of 2nd May 2020. Only measures applied at a national-level were included and 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 disctancing 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 also factored in.

More information about current COVID-19 related interventions is available in the latest ECDC Rapid Risk Assessment on Coronavirus disease 2019 (COVID-19) in the EU/EEA and the UK– ninth update published the 23 April 2020 [3].

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 parametres 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) whilst 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 and the UK country based on ECDC epidemic intelligence COVID-19 database, which is updated daily and is publicly available [15]. Where available, daily data on hospitalisation and intensive care unit of COVID-19 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 is very valuable in reducing uncertainty, sustained efforts are on-going to monitor data in the public domain and update the model with the most appropriate data accordingly.

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. 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. Combining such forecasts is termed 'ensemble modelling' and this approach has been found to produce predictions that are more robust.

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 the 2 May 2020 will be continued until the end of the forecast 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 maintened at the same level. As the progressive de-escalations of social distancing measures occur and subsequent contact network between individuals increases, it is possible that disease transmission will further re-increase 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. Indeed, since the combined incubation period and reporting delay estimated around 10 days (with some variation across countries) [16].

We can be reasonably certain that a forecast 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 globally introduced interventions 'en bloc', which makes it statistically challenging to assess which is the most effective at decreasing transmission and, indeed each respective effect on mortality and morbidity reduction. To overcome this issue, a short expert-based survey was conducted among experts involved in COVID-19 public health response at ECDC to assess 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.

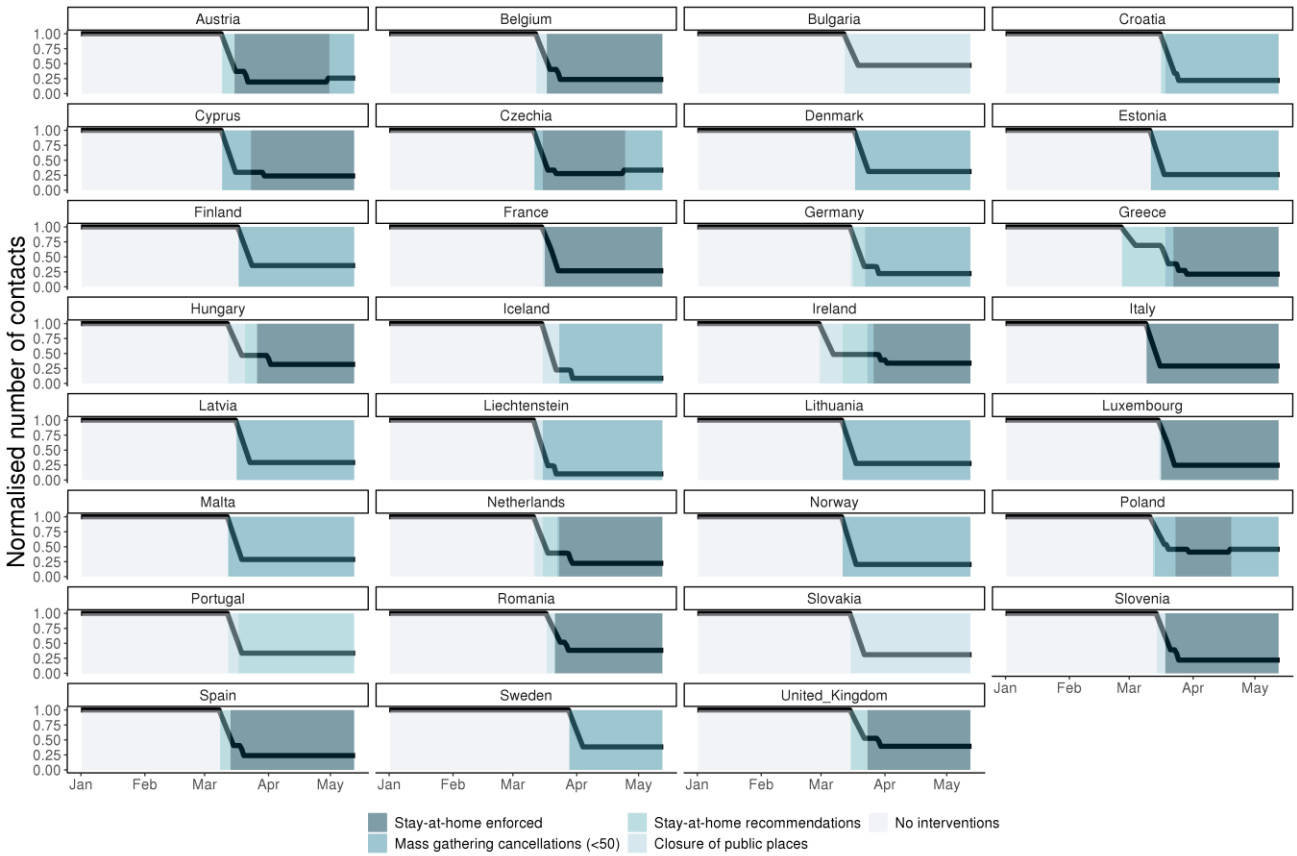
Based on this panel of 16 experts, the median effectiveness of enforced stay-at-home orders was considered the highest, followed by mass gathering cancellations with slightly lower overall effectiveness. Closure of public places and stay-at-home recommendations were ranked as third and fourth with similar median effectiveness, slightly lower than the other two measures (Appendix 4). Each response measure included in the model was normalized 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 furture by epidemiological information about the observed conditions of transmission form contact tracing survey (e.g. role of super-spreader event, community-based transmission in household, during mass gathering ...).

Effect of the non-pharmaceutical interventions

Effect of the 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, and the decrease of the contacts after implementing these measures varies between countries and between the measures.

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

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



Note: Only the strongest non-pharmaceutical intervention at each day taken into account, for the prior estimation of the effect of the interventions please see appendix 4.

Projections of COVID-19 cases and deaths

Status quo forecasts

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

The majority of the EU/EEA countries and the UK are showing a decreasing trend both in cases and deaths for the short-term projections at a 30-day time horizon. In some countries the projection is showing a moderately increasing or flattening trend, most notably seen for those with an absence of marked epidemic peak (e.g. Bulgaria, Hungary, Poland, Romania, Sweden and 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 can show some time lag with the epidemic peak which can be explained, in part, by the multi-source of the data used for the fitting. Overall, the model is able to fit in simultaneous manner the input time-series on new overall number of cases and deaths as well as the available hospital-based data. In these graphics, it should be noted that when time series of hospitalized and ICU are not avalaible in a country, the predictions are computed using the model paramaters based on European averages and represent an approximation of the number of based under this assumption.

It should be noted that daily time-series data from public sources, data on hospital and ICU daily counts, as well as new daily admission of confirmed COVID-19 cases in the hospital and in the ICU, are not publicly available from all EU/EEA countries. These data are of utmost importance to allow model calibration in an optimal manner (more information about data sources in Appendix 3). In order to improve the fitting and the forecast quality, additional time-series on number of hospitalized and ICU COVID-19 cases are required. ECDC is regularly monitoring available data on public domain and liaising with EU/EEA countries and UK to extend the data coverage.

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 specific sub-communities.

Note: The data on non-pharmaceutical interventions are based on information available from official public sources as of Wednesday 29 April at 18:00 and may not capture measures being taken by countries that are not reported on publicly available websites. The situation is evolving rapidly and this represents a snapshot of the measures that countries in the EU/EEA and the UK have reported to date. The response measures displayed are national measures, reported on official public websites.
The data on response measures has 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 outbreak 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 are no longer available on official websites concerning measures that are no longer in force, which may result in the data for more recent measures being more acurate.

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

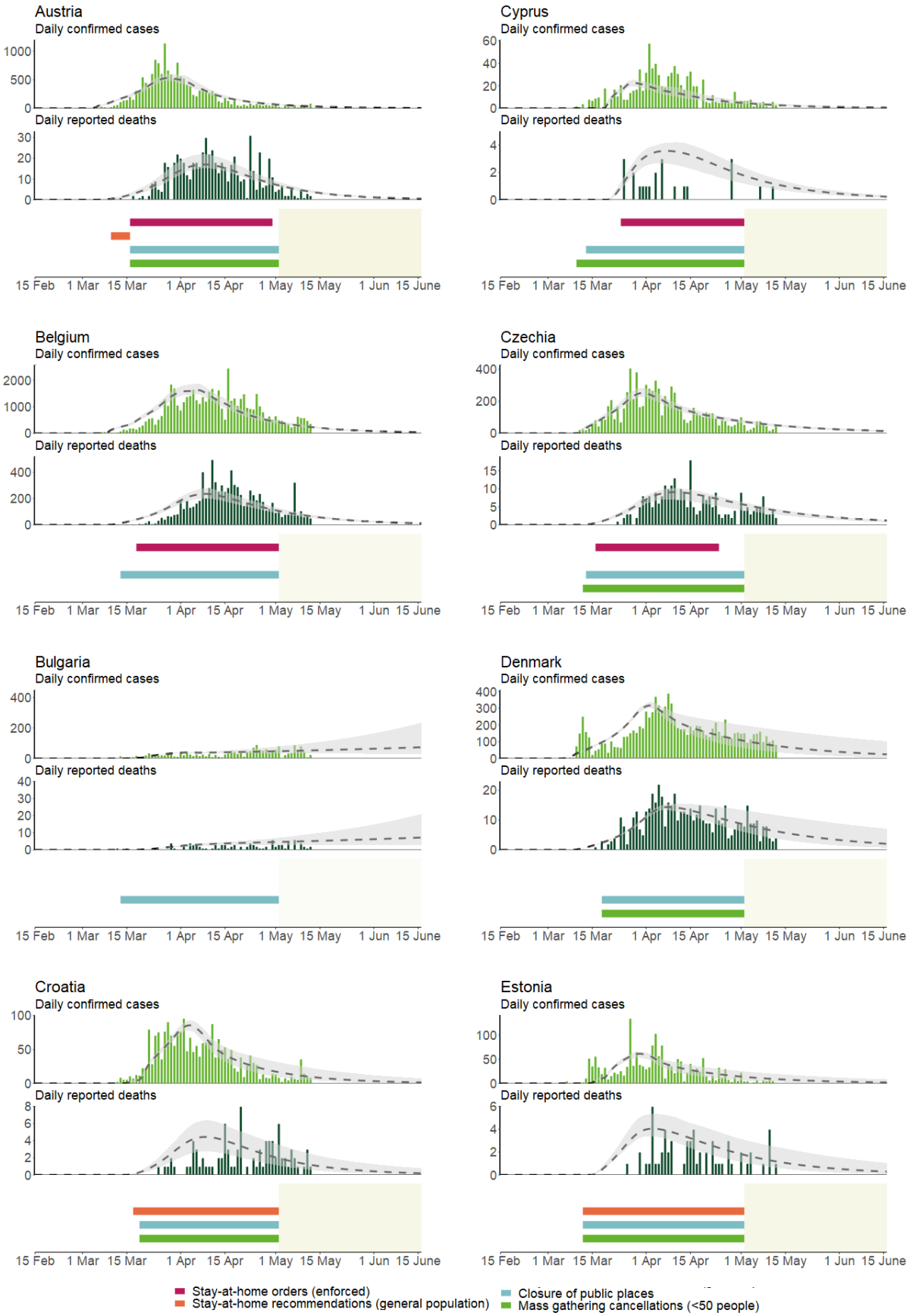


Figure 3 b: Number of observed and predicted newly reported COVID-19 cases and deaths, and non-pharmaceutical interventions in the EU/EEA + UK countries in the period up until 12th June 2020.

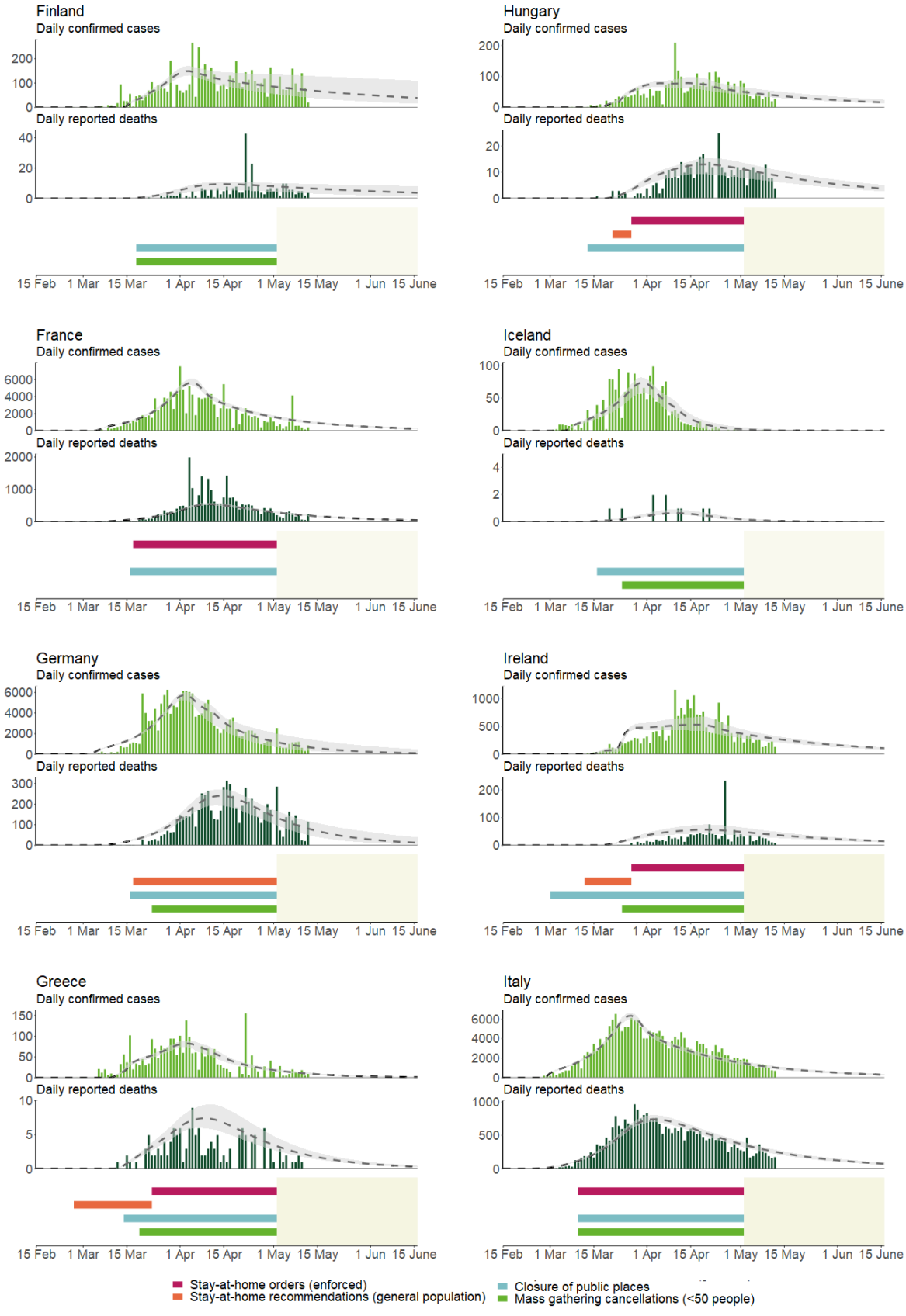


Figure 3 c: Number of observed and predicted newly reported COVID-19 cases and deaths, and non-pharmaceutical interventions in the EU/EEA + UK countries in the period up until 12th June 2020.

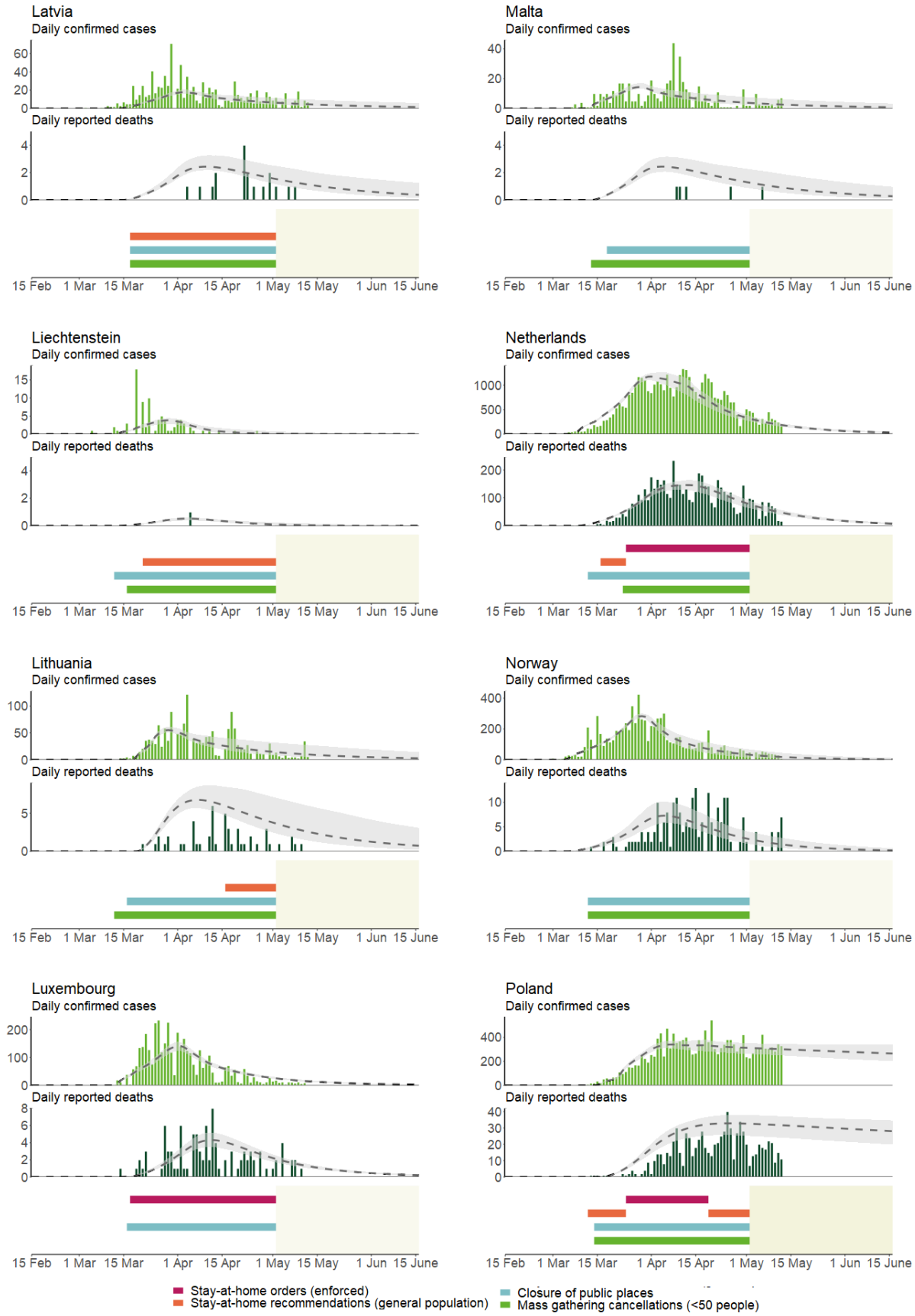
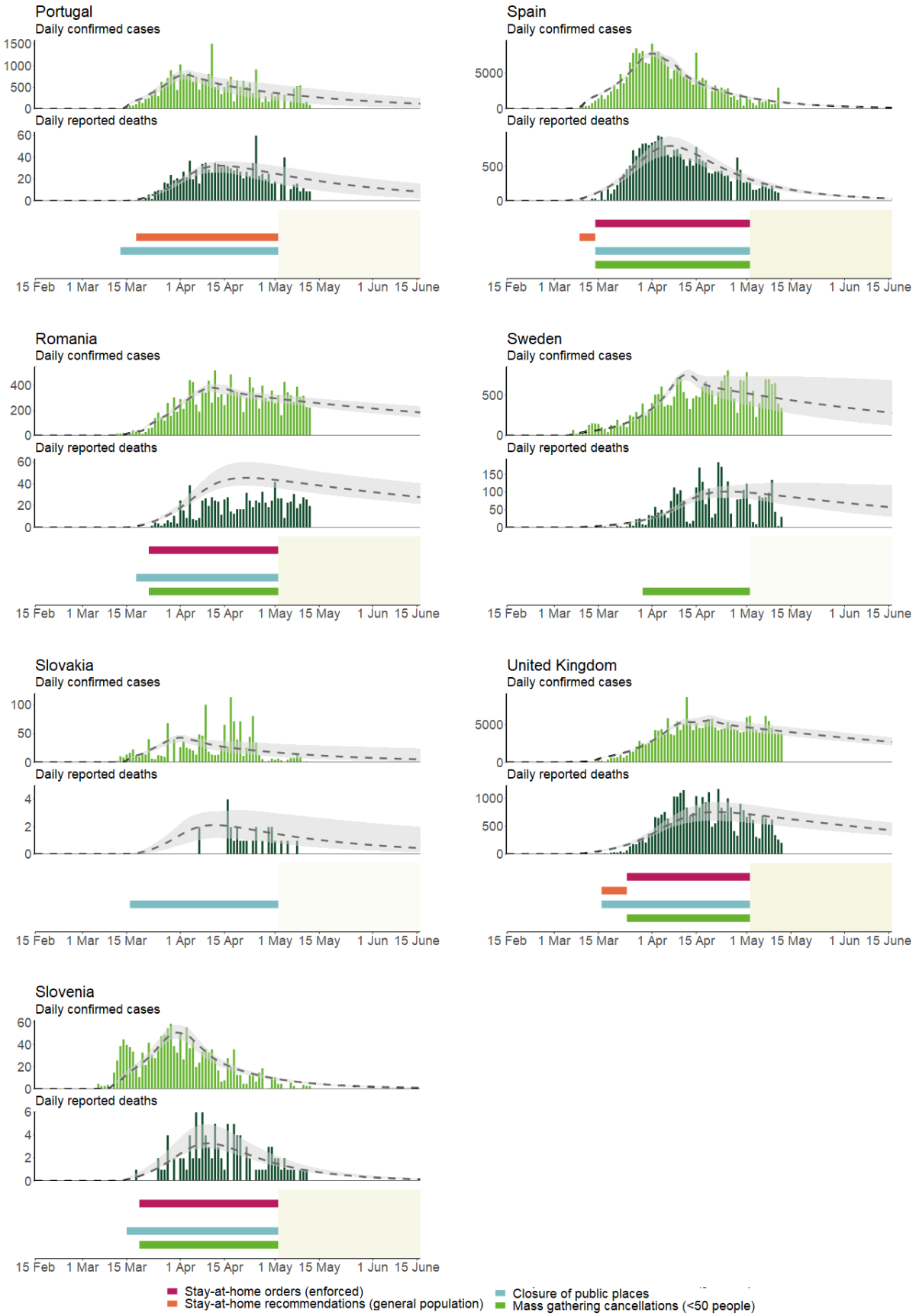


Figure 3 d: Number of observed and predicted newly reported COVID-19 cases and deaths, and non-pharmaceutical interventions in the EU/EEA + UK countries in the period up until 12th June 2020.



Summary and future development

We present a dynamic compartmental model of SARS-CoV-2 transmission and associated progression to COVID-19 disease 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 forecasts 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.

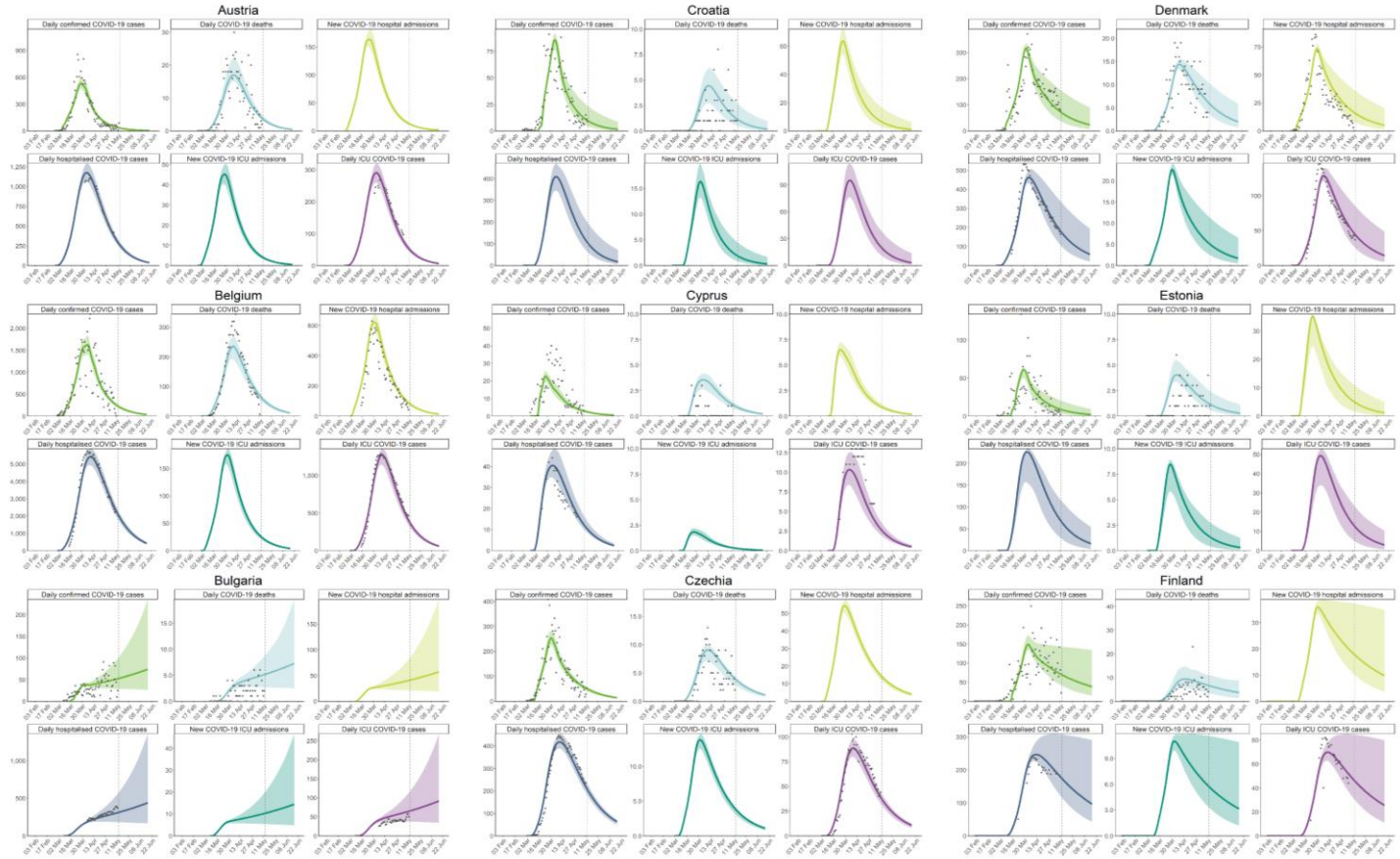
These forecasts illustrate the number of newly reported cases that could be anticipated in countries under the baseline scenario that the currently implemented response measures are maintained for the coming 30 days. Overall, the projected trends show a sustained decrease of cases under a conservative status quo scenario. However, for countries without a marked epidemic peak, the forecasts 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 forecasts 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 time series included in the model. In particular, the new admissions to hospital and to intensive care which 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 forecasts in the case of future increase in transmission. In addition, estimation of model's parameters will be refined as new evidence is provided through scientific literature and case-based surveillance data. Monitoring of model performance and dynamic integration of new available epidemiological data as they become available is planned to continue.
- the structural uncertainty by adding new features in the model structure such as an age-dependant contact matrix. This would allow the development of modelled scenarios through the integration of additional non-pharmaceutical interventions, such closure of educational institutions. Further integration of mobility data and survey on contact is also envisaged which can be incrememtally performed using first google or apple mobility public reports, and more detailled mobility data from mobile operator or EU research funded projects [17-19].
- in addition, such mathematical modelling would benefit from integration in an 'ensemble' forecasts framework. This framework would gather forecasts 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 this document (Appendix 2) the comparison of the ECDC model output with projections from the Institute of Health Metrics and Evaluation (IHME) in Seattle, USA. The IHME forecasts were selected for this exercise since they also simulate the outbreak in EU/EEA countries and the UK, over a 30-day time horizon, and have comparable target indicators 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 the model calibration and as a target indicator for assessing healthcare burden.
- the scenario related uncertainty by considering alternative scenarios of refinement of response measures as well as COVID-19 laboratory testing policies. We advocate for the importance of comparing projections of scenarios with different interventions developed by EU/EEA countries and the UK together with mobility data trends which can be considered as proxy of contact at population level.

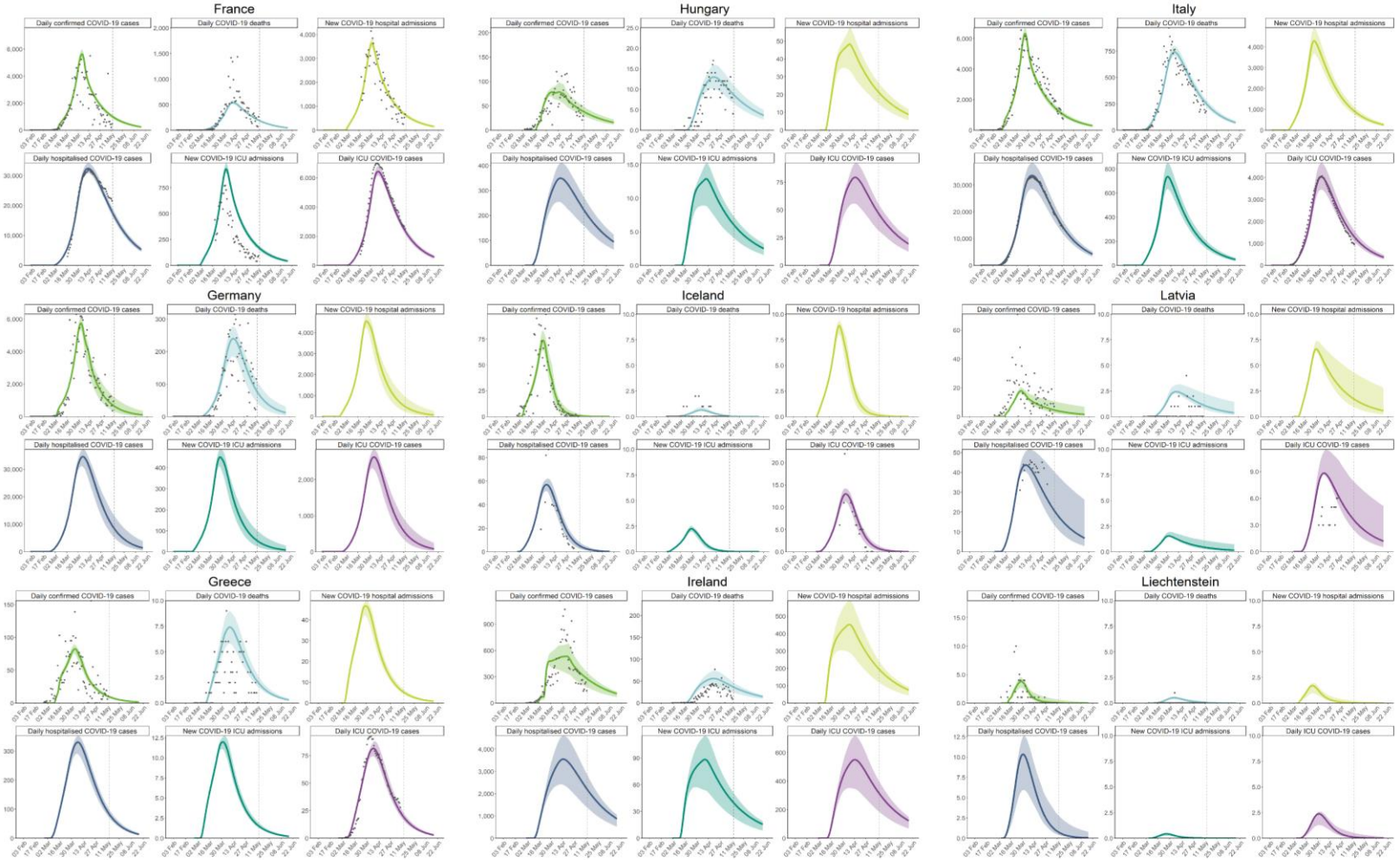
Appendix 1: 30-day projections of COVID-19 cases, deaths, and hospital requirements in EU/EEA countries and the UK

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



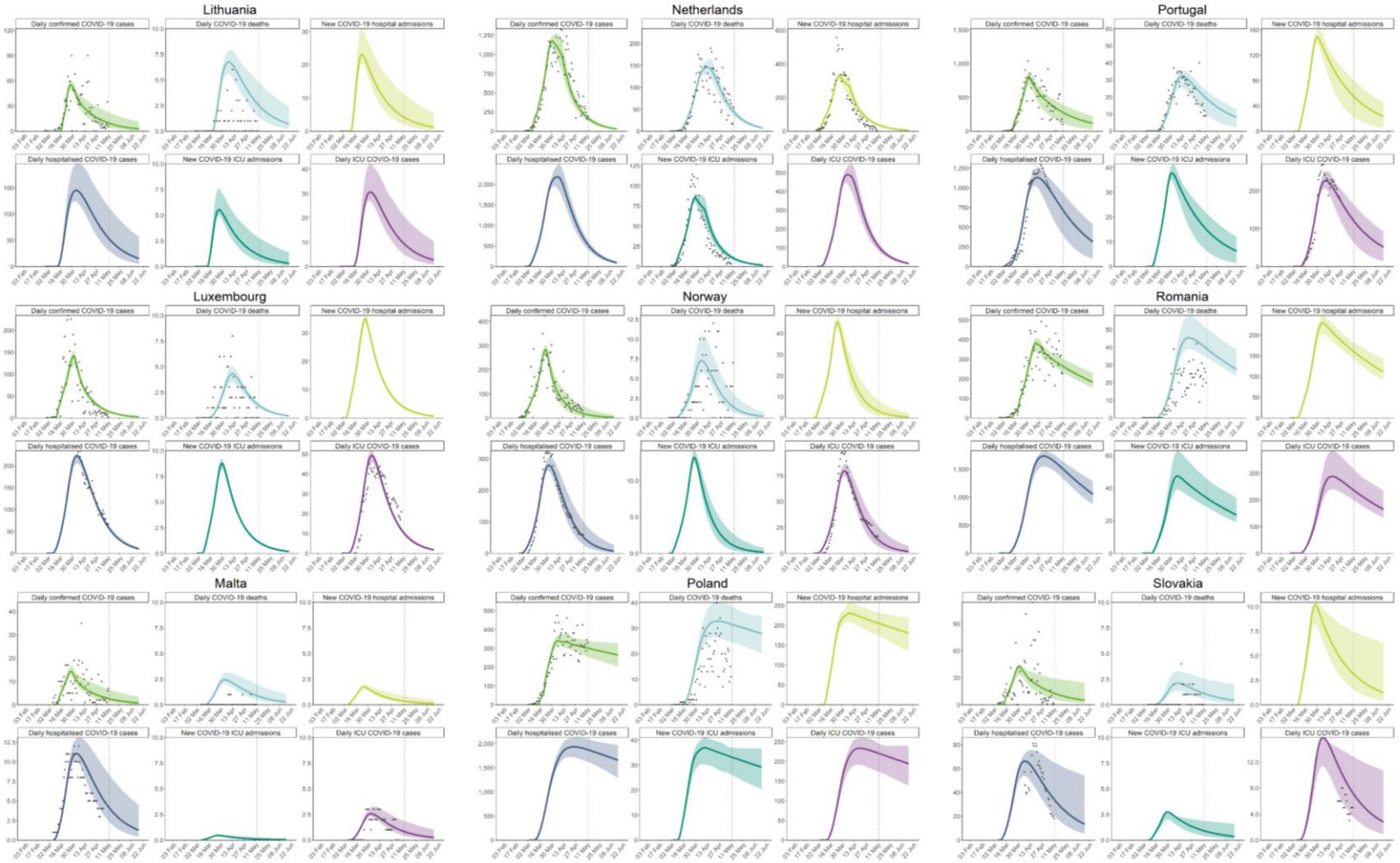
Note: * time series of hospitalized and ICU not avalaible. Due to missing specific countries values of those indicators to inform the curves, the predictions are computed using the model paramaters based on European averages and represent an approximation of the number of based under this assumption.

Figure 4 b: Number of observed and predicted COVID-19 by time series type (new daily case, new daily deaths, new daily admission at hospital, daily number of hospitalized case, daily new admission in intensive care unit and daily number of case hospitalized in intensive care unit) in the EU/EEA + UK countries in the period up until 12th June 2020.



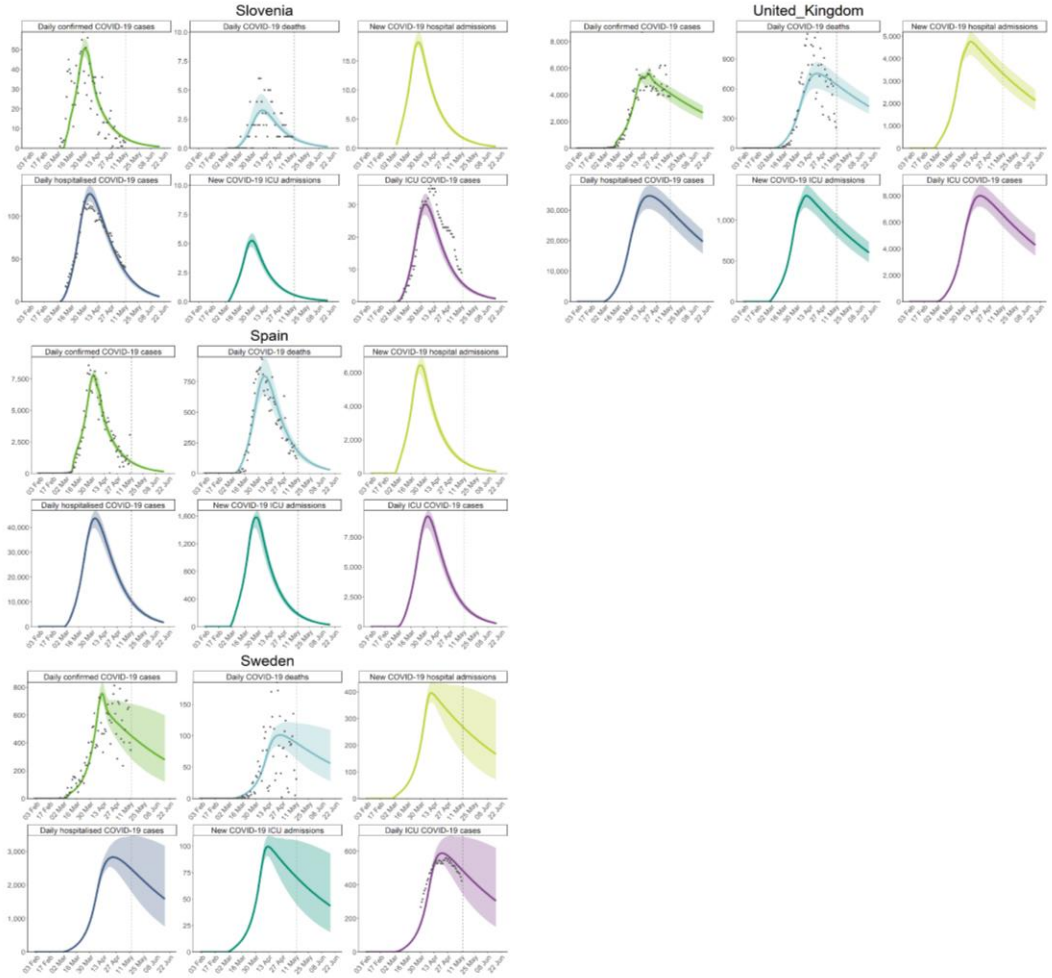
Note: * time series of hospitalized and ICU not avalaible. Due to missing specific countries values of those indicators to inform the curves, the predictions are computed using the model paramaters based on European averages and represent an approximation of the number of based under this assumption.

Figure 4 c: Number of observed and predicted COVID-19 by time series type (new daily case, new daily deaths, new daily admission at hospital, daily number of hospitalized case, daily new admission in intensive care unit and daily number of case hospitalized in intensive care unit) in the EU/EEA + UK countries in the period up until 7th June 2020.



Note: * time series of hospitalized and ICU not avalaible. Due to missing specific countries values of those indicators to inform the curves, the predictions are computed using the model paramaters based on European averages and represent an approximation of the number of based under this assumption.

Figure 4 d: Number of observed and predicted COVID-19 by time series type (new daily case, new daily deaths, new daily admission at hospital, daily number of hospitalized case, daily new admission in intensive care unit and daily number of case hospitalized in intensive care unit) in the EU/EEA + UK countries in the period up until 7th June 2020.

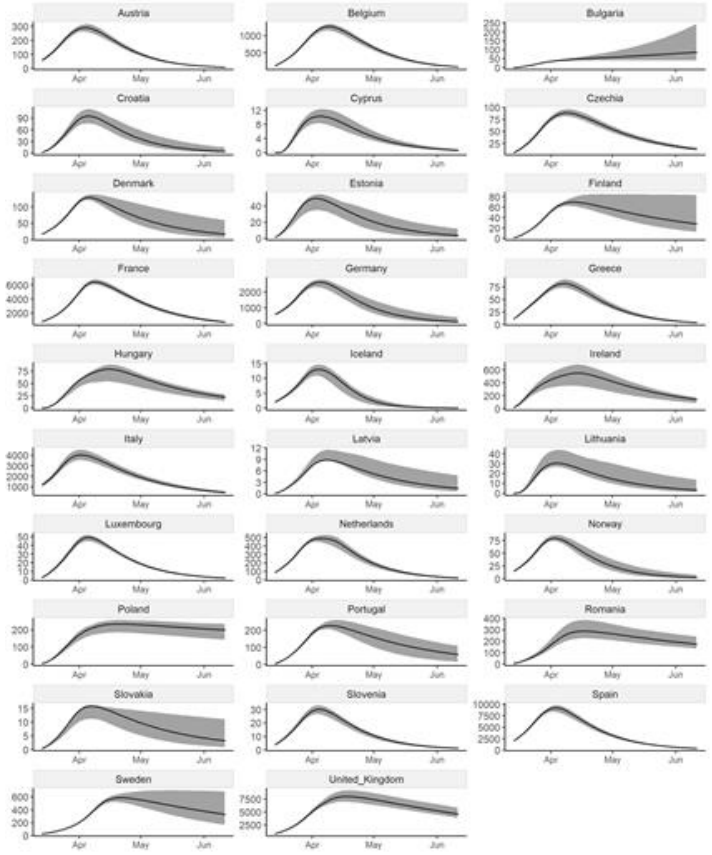


Note: * time series of hospitalized and ICU not avalaible. Due to missing specific countries values of those indicators to inform the curves, the predictions are computed using the model paramaters based on European averages and represent an approximation of the number of based under this assumption.

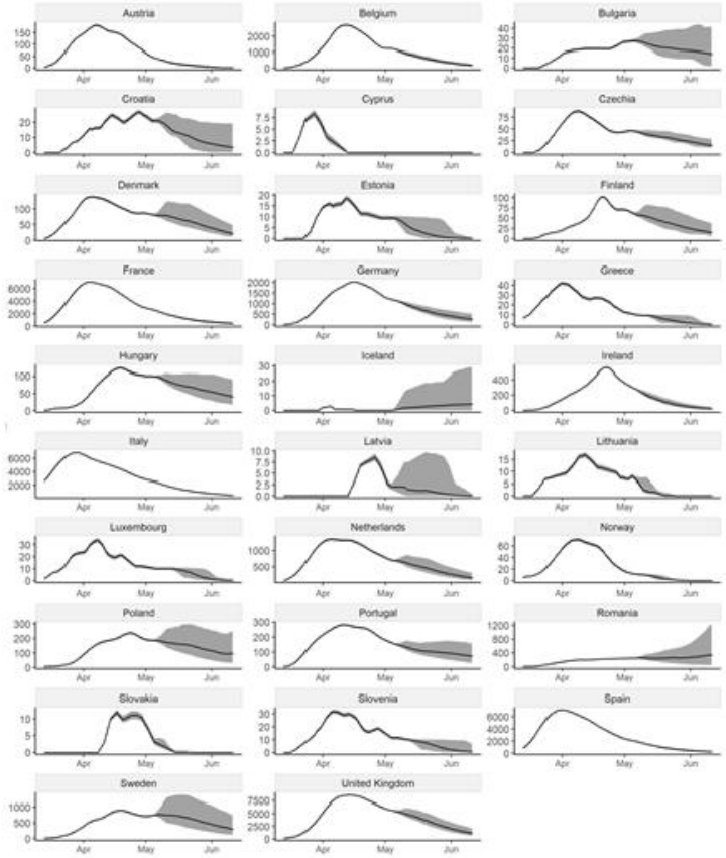
Appendix 2: Comparison of projections from the ECDC model and the nonlinear mixed effects model of Institute of Health Metrics and Evaluation (IHME)

Figure 5: ECDC 30-day projections of mean ICU beds needed by day for COVID-19 patients for EU-EEA countries and United-Kingdom (extraction 10 May 2020) and IHME 30-day projections of mean ICU beds needed by day for COVID-19 patients for EU- EEA countries (except Liechtenstein and Malta) and United-Kingdom.

Panel A



Panel B



Note: Institute of Health Metrics and Evaluation (IHME) model description
The figures below represents the data acquired from The Institute for Health Metrics and Evaluation, Seattle, University of Washington (IHME) on COVID-19 projections (available at: https://covid19.healthdata.org/, [1]).
The model used by IHME is a nonlinear mixed effects model with the main application being COVID-19 forecasting (see for more details: IHME model overview). The IHME model is based on the main assumption that physical distancing stays in place until the pandemic, in its current phase, reaches the point when deaths are less than 0.3 per million people. From this point, physical distancing measures are expected to be in place through the end of May 2020.
Figure adapted from: https://covid19.healthdata.org/united-states-of-america. Projection as of 10/05/2020; [1].

Table 1: Summary of ECDC and IHME 30-day projections between 13/05/2020 and 12/06/2020, EU- EEA countries (except Liechtenstein and Malta) and 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)

Note: [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 [1,20]

Note: * time series of hospitalized and ICU not avalaible. Due to missing specific countries values of those indicators for countries without data to inform the curves, the predictions are computed using the model paramaters based on European averages and represent an approximation of the number of based under this assumption.

Appendix 3: Description of ECDC dynamic transmission model (difference equations, prognosis probabilities, model calibration)

Computing platform

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

Difference equations

The following table describes the different equations that calculate the number of people in each disease state over time, and further provides a brief description of the parameters required in the equations. See the 'calibration' section for details of 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 [21]. 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 require intensive care) given that they have severe disease is also defined to be age dependent and is quantified as per Ferguson et al [21]. 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 additional, we model a further 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 a: Variable description

Variable	Variable description	Difference equation (t represents time, defined in one day time steps)	Parameter descriptions
$\boldsymbol{Z_g}$	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.
$\boldsymbol{E_g}$	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.
$\boldsymbol{A_g}$	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.
$\boldsymbol{M_g}$	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.
$\boldsymbol{Q_g}$	Isolation state (asymptomatic and mild cases)	$Q_g(t+1) = \left(1 - \frac{1}{\gamma_M}\right) Q_g(t) + \sigma(t)\left(A_g(t) + M_g(t)\right)$	
$\boldsymbol{S_g^R}$	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.
$\boldsymbol{S_g^C}$	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.
$\boldsymbol{S_g^D}$	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 $\rho_{\hat{S}_g^D}$.
$\boldsymbol{\hat{S}_g^R}$	Severe disease Will not 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.
$\boldsymbol{\hat{S}_g^D}$	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.

Table 2 b: Variable description

Variable	Variable description	Difference equation	Parameter descriptions

		(t represents time, defined in one day time steps)	
H_g^R	Hospitalised case Prognosis: recover	$H_g^R(t+1) = \left(1 - \frac{1}{\delta_H}\right) H_g^R(t) + \frac{S_g^R(t)}{\delta_S}$	$\delta_H :=$ 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	$H_g^C(t+1) = \left(1 - \frac{1}{\delta_{T_I}}\right) H_g^C(t) + \frac{S_g^C(t)}{\delta_S}$	$\delta_{T_I} :=$ 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	$I_g^C(t+1) = \left(1 - \frac{1}{\delta_I}\right) I_g^C(t) + \frac{H_g^C(t)}{\delta_{T_I}}$	$\delta_I :=$ 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	$I_g^D(t+1) = \left(1 - \frac{1}{\mu}\right) I_g^D(t) + \frac{H_g^D(t)}{\delta_{T_I}}$	$\mu :=$ Mean number of days spent in ICU before death.
T_g	Transferred back to non-ICU ward after intensive care	$T_g(t+1) = \left(1 - \frac{1}{\delta_{T_H}}\right) T_g(t) + \frac{I_g^C(t)}{\delta_I}$	$\delta_{T_H} :=$ Mean number of days in a non-ICU hospital ward following transfer from ICU.
D_g^H	Discharged from hospital (no intensive care)	$D_g^H(t+1) = \left(1 - \frac{1}{\gamma_H}\right) D_g^H(t) + \frac{H_g^R(t)}{\delta_H}$	$\gamma_H :=$ 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)	$D_g^I(t+1) = \left(1 - \frac{1}{\gamma_I}\right) D_g^I(t) + \frac{T_g(t)}{\delta_{T_H}}$	$\gamma_I :=$ 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	$X_g(t+1) = X_g(t) + \frac{\hat{S}_g^D(t)}{\hat{\mu}} + \frac{I_g^D(t)}{\mu}$	
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 resulst results of a survey conducted amongst ECDC expets, we assume *stay-at-home orders* is 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, should multiple measures be implemented at any one time in a country (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

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

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:

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

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 homomgenuos 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:

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

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

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

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

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 ECDC data on confirmed cases, hospitalisation, ICU patients and mortality (where available) from 31 European Union and European Economic Area countries. By default, heavier weighting was given to mortality, hospitalisation, and ICU data in the calibration process. See below table for country-specific variations of indicator weightings used in the calibration process.

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

Country	New daily case	New daily deaths	Daily number of hospitalized case	Daily number of case hospitalized in intensive care unit	Daily number of case hospitalized in intensive care unit	Daily new admission in intensive care unit
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

An ECDC database reporting national and regional-level response measure implementation was used to inform the timing of responses in each country model [3]. 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) whilst behavioural parameters – including response measure efficacy – are assumed to vary by country. Informative varying effect hyper-parameters are used to penalize 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.

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:

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

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

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

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

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-depending 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 estimnates (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 a: Model parameters

Parameter	Description	Prior mean[1]	Lower bound	Upper bound	Global parameter[2]	Selection of countries with specific calibration	Ref.
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	Calibrated: all countries. Fixed: none.	[5,22,23]
Beta	Probability of transmission in one contact between fully susceptible and fully infectious individual	0.05	0.01	0.1	Yes	Calibrated: no. Fixed: yes.	
Beta reduction	Reduction in infectiousness of asymptomatic/mild cases relative to severe/critical cases	0			Yes	Calibrated: no. Fixed: yes.	
Contacts reduction	Reduction in contacts of severe/critical cases relative to asymptomatic/mild cases due to assumed hospitalization or isolation	0.9	0.5	0.99	Yes	Calibrated: no. Fixed: yes.	
Susceptibility	Exponential decay in susceptibility for younger age groups relative to oldest age group	0			Yes	Calibrated: no. Fixed: yes.	
Proportion asymptomatic	Proportion of all cases that are asymptomatic	0			Yes	Calibrated: no. Fixed: yes.	
Latency days	Number of days in latency (infected but not infectious) state	4.6	3	7	Yes	Calibrated: no. Fixed: yes.	[4,24,25]
Infectious days mild	Number of days for which mild and asymptomatic cases are infectious	6	3	10	Yes	Calibrated: no. Fixed: yes.	[4]
Infectious days severe	Number of days for which severe and critical cases are infectious	22	14	35	Yes	Calibrated: no. Fixed: yes.	
Isolation probability	Proportion of mild and asymptomatic cases that isolate after diagnosis	0			No	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	Calibrated: all countries. Fixed: none.	
Onset to hospital days*	Number of days between severe onset of symptoms and hospitalization	5.9	1	14	No	Calibrated: Belgium, Cyprus, Czechia, Denmark, France, Italy, Latvia, Netherlands, Norway, Romania Fixed: all other countries.	[26]
Confirmation delay hospital*	Number of days delay between onset of symptoms and diagnosis for those seeking hospital care	11.46	0.01	14	No	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.	[26]
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	Calibrated: none. Fixed: all countries.	[26]
Home testing rate	Proportion of severe cases not seeking hospital care that get tested	0.7	0.05	0.99	No	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	Calibrated: Austria, Belgium, Czechia, Denmark, Finland, France, Italy, Netherlands, Norway, Portugal, Slovenia. Fixed: all other countries.	
Hospital to icu days	Number of days between hospital admission and ICU admission for cases that will become critical	2	1	10	No	Calibrated: none. Fixed: all countries.	
Icu stay days	Number of days a critical case spends in ICU before discharge	7	1	10	No	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	Calibrated: no. Fixed: yes.	[27]

Table 4 b: Model parameters

Parameter	Description	Prior mean[1]	Lower bound	Upper bound	Global parameter[2]	Selection of countries with specific calibration	Ref.
Home death days	Number of days between symptom onset and death for those not seeking hospital care	10	7	14	Yes	Calibrated: no. Fixed: yes.	
Death reporting delay*	Number of days dealy between a COVID-19 death and that death being reported in the data	1.92	1	14	No	Calibrated: Belgium, Finland, France, Norway, Slovenia. Fixed: all other countries.	[26]
Severe factor	Calibration factor for proportion of symptomatic cases that are severe	1	0.2	3	No	Calibrated: none. Fixed: all countries.	
Critical factor	Calibration factor for proportion of severe cases requiring critical care in ICU	1	0.2	3	No	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	Calibrated: none. Fixed: all countries.	
Critical death non icu	Proportion of critical cases that die when ICU not available or not seeked	0.95	0.8	0.99	No	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	10			Yes	Calibrated: no. Fixed: yes.	
Number import	Number of people initiated with infection at time first importation	100	0	1000	No	Calibrated: none. Fixed: all countries.	
Test per index case	Mean number of contacts to test casesper confirmed index case	0			No	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	Calibrated: all countries. Fixed: none.	
Rel eff 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	Calibrated: no. Fixed: yes.	
Rel eff closure public places any	Contact reduction efficacy of 'closing public spaces' response relative to 'stay home enforced'	0.78	0.01	0.99	Yes	Calibrated: no. Fixed: yes.	
Rel eff stay home recommend	Contact reduction efficacy of 'stay home recommended' response relative to 'stay home enforced'	0.78	0.01	0.99	No	Calibrated: Greece, Ireland. Fixed: all other countries.	
Response delay	Time in days before full efficacy of response is realized following implementation - assumed to be consistent for all interventions	7	1	14	No	Calibrated: none. Fixed: all countries.	

Note:

[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 analaysis or simulations.

[2] If "yes", the paraneters is not a country-specific parameter. Global parameters may or may not be calibrated.

[3] Selection of countries for which the associated parameter is calibrated.

(*) Ref to Tessy [26]

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

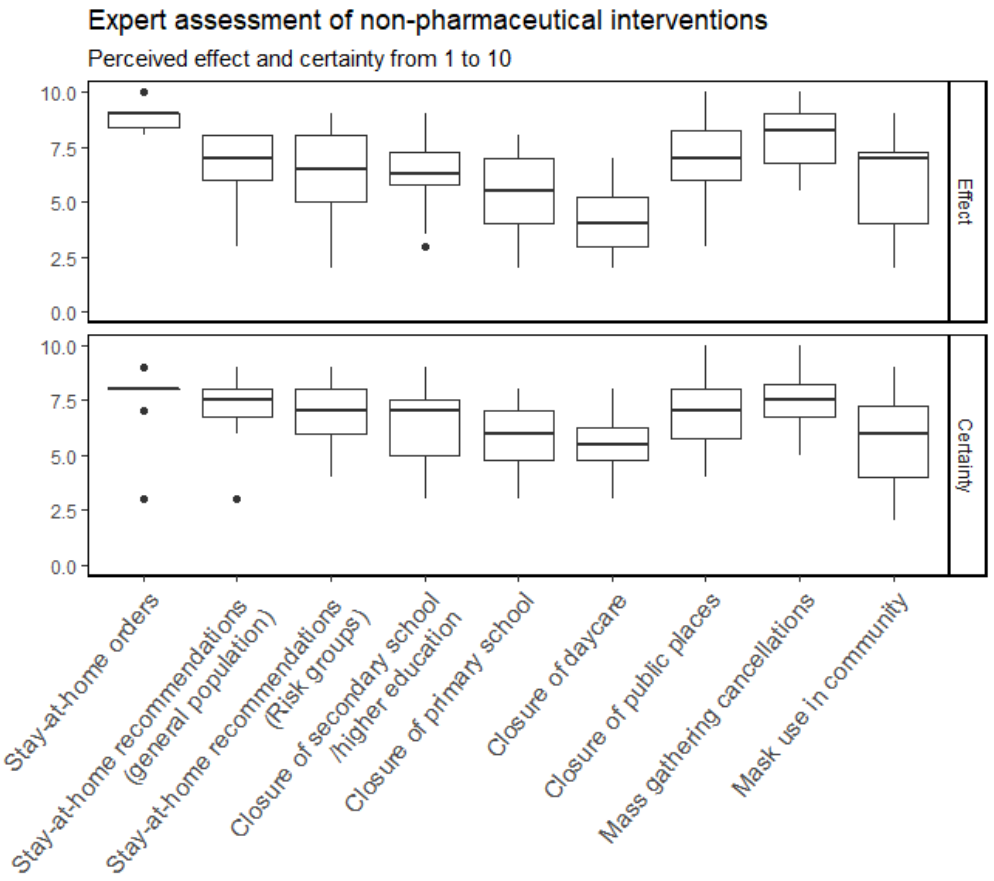
All data on the daily number of new cases and deaths in EU/EEA countries and the UK were obtained from the ECDC's Epidemic Intelligence database (ECDC's E.I. database), which is publicly available and can be accessed here: https://www.ecdc.europa.eu/en/publications-data/download-todays-data-geographic-distribution-covid-19-cases-worldwide.

Country	Source number of case	Source number of death	Source for hospitalised cases	Source for ICU cases
Austria	ECDC's E.I.	ECDC's E.I.	New hospitalised cases from country-specific data source [28]	New ICU cases from country-specific data source [28]
Belgium	Country-specific data source [29]	Country-specific data source [29]	Current hospitalised cases from country-specific data source [29]	Current ICU cases from country-specific data source [29]
Bulgaria	ECDC's E.I.	ECDC's E.I.	Current hospitalised cases from country-specific data source [30]	Current ICU cases from country-specific data source [30]
Croatia	ECDC's E.I.	ECDC's E.I.	NA	NA
Cyprus	ECDC's E.I.	ECDC's E.I.	Current hospitalised cases from country-specific data source [31]	Current ICU cases from country-specific data source [31]
Czechia	ECDC's E.I.	ECDC's E.I.	Current hospitalised cases from country-specific data source [32]	Current ICU cases from country-specific data source [32]
Denmark	ECDC's E.I.	ECDC's E.I.	New hospitalised cases from country-specific data source [33]	New ICU cases from country-specific data source [33]
Estonia	ECDC's E.I.	ECDC's E.I.	NA	NA
Finland	ECDC's E.I.	ECDC's E.I.	Current hospitalised cases from country-specific data source [34]	Current ICU cases from country-specific data source [34]
France	ECDC's E.I.	ECDC's E.I.	New and current hospitalised cases from country-specific data source [35]	New and current ICU cases from country-specific data source [35]
Germany	ECDC's E.I.	ECDC's E.I.	NA	NA
Greece	ECDC's E.I.	ECDC's E.I.	NA	Current ICU cases from MoH report [36]
Hungary	ECDC's E.I.	ECDC's E.I.	NA	NA
Iceland	ECDC's E.I.	ECDC's E.I.	Current hospitalised cases from country-specific data source [37]	Current ICU cases from country-specific data source [37]
Ireland	ECDC's E.I.	ECDC's E.I.	NA	NA
Italy	ECDC's E.I.	ECDC's E.I.	Current hospitalised from country-specific data source [38]	Current ICU from country-specific data source [38]
Latvia	ECDC's E.I.	ECDC's E.I.	Current hospitalised from country-specific data source [39]	Current ICU from country-specific data source [39]
Liechtenstein	ECDC's E.I.	ECDC's E.I.	NA	NA
Lithuania	ECDC's E.I.	ECDC's E.I.	NA	NA
Luxembourg	ECDC's E.I.	ECDC's E.I.	Current hospitalised cases from JRC [40]	Current ICU cases from country-specific data source [41]
Malta	ECDC's E.I. database	ECDC's E.I.	Current hospitalised cases from country-specific data source [42]*	Current ICU cases from country-specific data source [42]*
Netherlands	ECDC's E.I.	ECDC's E.I.	Current hospitalised from country-specific data source [43]	New ICU cases from country-specific data source [44]
Norway	ECDC's E.I.	ECDC's E.I.	Current hospitalised from country-specific data source [45]	Current ICU cases from country-specific data source [45]
Poland	ECDC's E.I.	ECDC's E.I.	NA	NA
Portugal	ECDC's E.I.	ECDC's E.I.	Current hospitalised from country-specific data source [46]	Current ICU from country-specific data source [46]
Romania	ECDC's E.I.	ECDC's E.I.	NA	NA
Slovakia	ECDC's E.I.	ECDC's E.I.	Current hospitalised cases from JRC [40]	Current ICU from country-specific data source
Slovenia	ECDC's E.I.	ECDC's E.I.	Current hospitalised from country-specific data source [47]	Current ICU from country-specific data source [47]
Spain	ECDC's E.I.	ECDC's E.I.	NA	NA
Sweden	ECDC's E.I.	ECDC's E.I.	NA	Current ICU from country-specific data source [48]
United Kingdom	ECDC's E.I.	ECDC's E.I.	NA	NA

Note: NA: Not available.(*) : Data on new hospitalised and ICU cases in Malta courtesy of the Infectious Disease Control Unit (IDCU) of the Ministry for Health in Malta.

Appendix 4: Survey among experts involved in COVID-19 public health response at ECDC to assess the effectiveness of the non-pharmaceutical interventions

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 requested to assess the effectiveness of the intervention to reduce the transmission within or into the risk group(s).

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Disclaimer

ECDC issues this techncial document based on request Number 64 of the DG SANTE C3 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 forecasts 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.

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