NIPH
Norwegian Institute of Public Health

Situational awareness and forecasting

FHI COVID-19 modelling team

20 May 2020

New highlights today:

- The situation is stable, and there are essentially no difference in the results from the last days.

What this report contains:

This report presents results based on a mathematical model describing the geographical spread of COVID-19 in Norway. The model consists of three layers:

- Population structure in each municipality
- Mobility data for inter-municipality movements (Telenor mobile phone data)
- Infection transmission model

The model produces estimates of the current epidemiological situation at the municipality, county (fylke) and national levels, a forecast of the situation for the next three weeks, and a long term prediction.

How we calibrate the model:
The model is fitted to Norwegian COVID-19 hospital incidence data from March 10 until today. We seed infections imported to Norway into the model from February 26 until March 18.

How you should interpret the results:
The model is stochastic. To predict the probability of various outcomes, we run the model many times in order to represent inherent randomness. We present the results in terms of mean values, 95% confidence intervals, medians, and interquartile ranges. We emphasise that the confidence bands might be broader than what we display, because there are several sources of additional uncertainty which we currently do not fully explore: Firstly, there are uncertainties related to the natural history of SARS-CoV-2, including the importance of asymptomatic and presymptomatic infection. Secondly, there are uncertainties related to the timing of hospitalisation relative to symptom onset, the severity of the COVID-19 infections by age, and the duration of hospitalisation and ventilator treatment in ICU. We will update the model assumptions and parameters in accordance with new evidence and local data as they become available. Results can change also significantly. See more details at the end of this report.

The mobility data are updated until May 19. They account for the changes in the movement patterns between municipalities that have occurred since the start of the epidemic.

Because in this report we calibrate our model using national hospitalisation data, the predictions at county level can only be taken as an indication.

We assume three reproduction numbers for Norway:

- R_0 active until March 14;
- R_1 active from March 15 to April 19;

- R_2 active from April 20 until today.

When we forecast beyond today, we use the last reproduction number for the whole future, if not explicitly said otherwise.

The basic reproductive numbers are calibrated to hospital incidence data until today. Estimates of R_0, R_1, and R_2 are uncertain, and we use their distribution to assure appropriate uncertainty of our predictions. Uncertainties related to the model parameters, as well as the transient period in week 11 and week 17, imply that reported effective reproductive numbers should be interpreted with caution. Because patients admitted to hospital have been infected long before, there is a necessary delay of about two weeks in the estimation of reproductive numbers.

In this report, the term patient in ventilator treatment includes only those patients that require either invasive mechanical ventilation or ECMO (Extracorporeal membrane oxygenation).

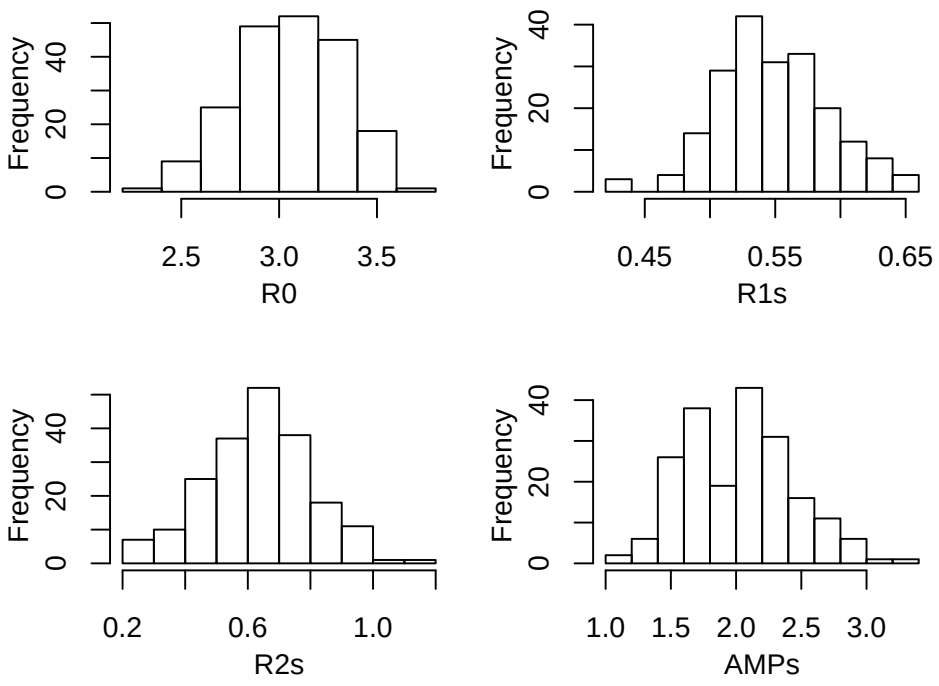
1 Estimated Reproductive Numbers

Calibration of our model with hospitalisation data leads to the following estimates:

Table 1: Calibration results

Parameter	Mean	Median	Confidence interval (95 %)
Amplification factor	2.02	2.03	(1.38-2.91)
Ro	3.06	3.05	(2.56-3.51)
R1	0.55	0.55	(0.48-0.63)
R2	0.64	0.64	(0.3-0.96)

Estimated densities of these four parameters are plotted below:



Our model estimates the number of COVID-19 patients admitted daily to hospitals, plotted below with blue median and interquartile bands, which are compared with the actual true data, in red. The uncertainty captures the uncertainty in the calibrated parameters in addition to the stochastic elements of our model and the variability of other model parameters.

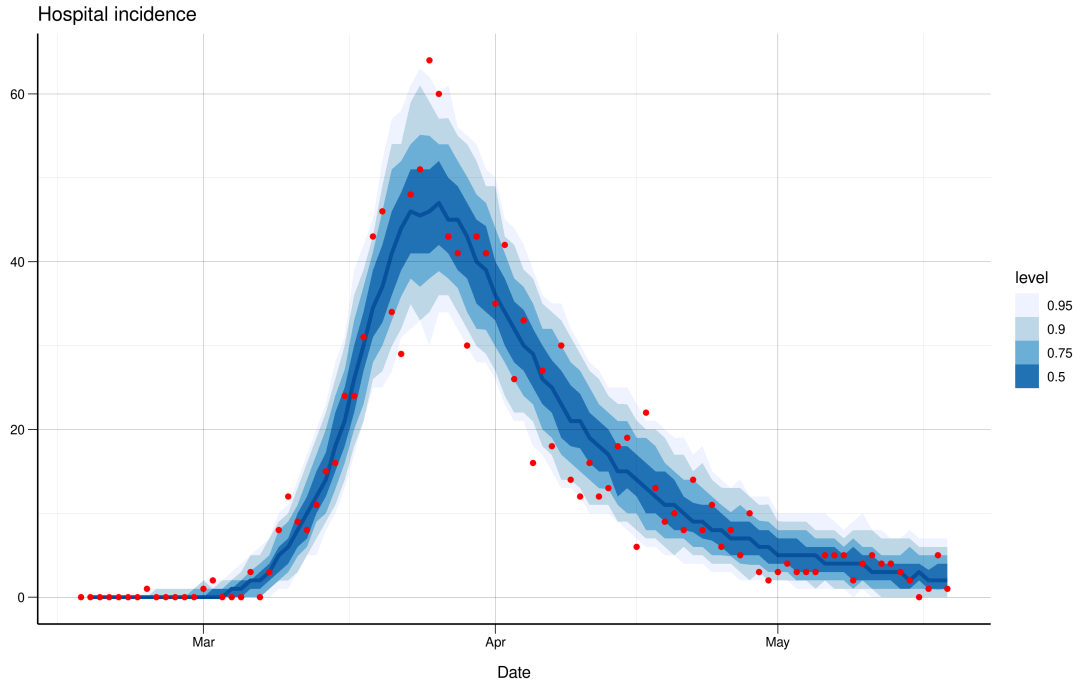


Figure 1: True total number of hospital admissions (red) and predicted values (blue)

Below we show how our model fits to the hospital prevalence data, which are not used to estimate the parameters, and can therefore be seen as a validation of the model assumptions.

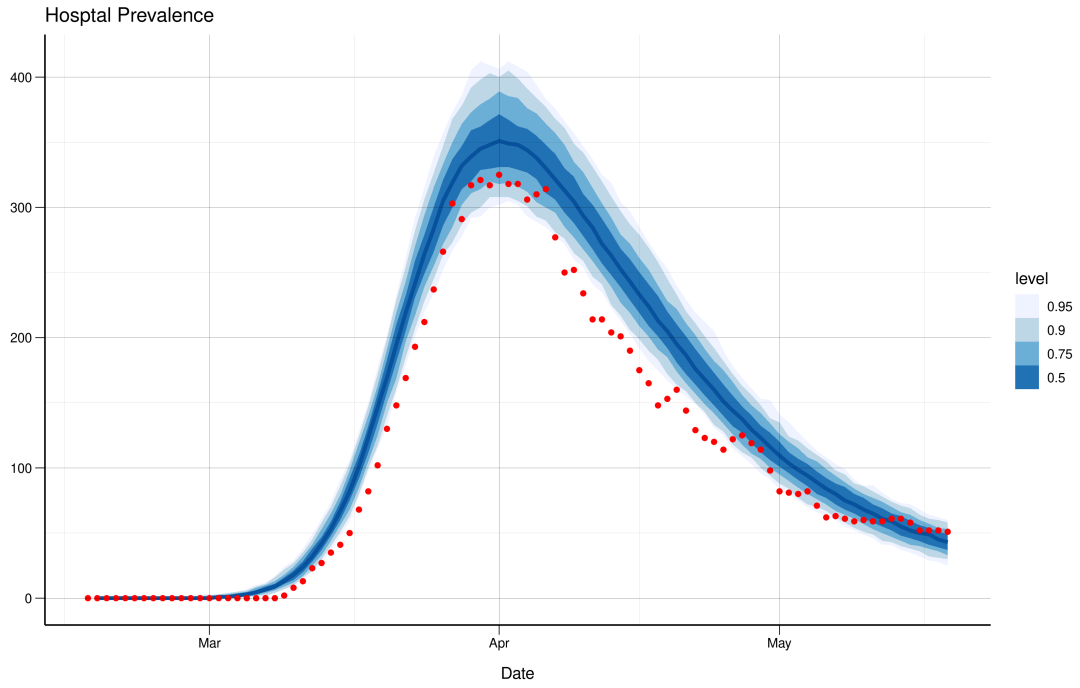


Figure 2: True total number of hospitalizations (red) and predicted values (blue)

Finally, in the figure below we compare the true daily number of patients receiving ventilator treatment (red) with the model estimates (blue).

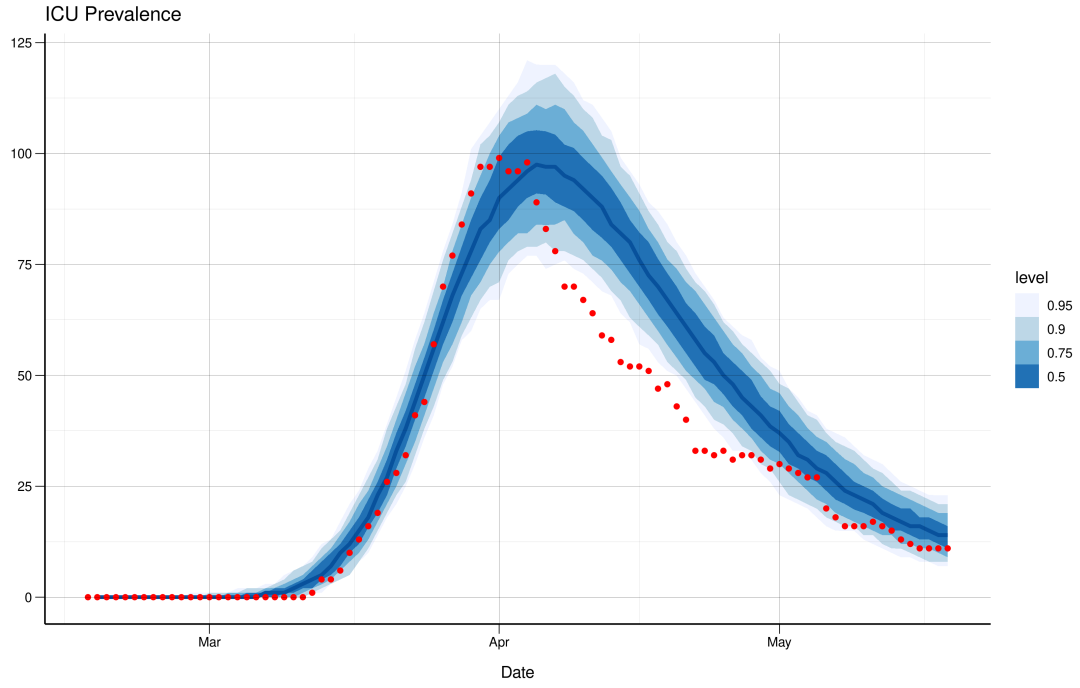


Figure 3: True total number on ventilator (red) and predicted values (blue)

2 Estimated cumulative number of infected individuals

Table 2: Estimated cumulative number of infections, 2020-05-19

Region	Total	Symptomatic	No. confirmed	Fraction reported	Min. fraction
Norway	36302 (31993; 40125)	22443 (19694; 24799)	8257	23%	21%
Agder	2296 (1680; 3156)	1419 (1041; 1940)	338	15%	11%
Innlandet	1855 (1292; 2497)	1134 (782; 1524)	480	26%	19%
Møre og Romsdal	724 (469; 1054)	452 (288; 660)	133	18%	13%
Nordland	591 (318; 894)	366 (196; 565)	117	20%	13%
Oslo	8387 (7009; 9735)	5151 (4310; 5999)	2572	31%	26%
Rogaland	4845 (3871; 5945)	2999 (2386; 3645)	438	9%	7%
Troms og Finnmark	1110 (559; 2097)	678 (340; 1275)	252	23%	12%
Trøndelag	1630 (1106; 2294)	1009 (701; 1392)	530	33%	23%
Vestfold og Telemark	2880 (2187; 3976)	1772 (1329; 2402)	282	10%	7%
Vestland	3894 (2990; 5000)	2397 (1826; 3046)	880	23%	18%
Viken	8090 (6839; 9461)	5066 (4242; 5932)	2235	28%	24%

Fraction reported=Number confirmed/number predicted; Minimal fraction reported=number confirmed/upper CI

3 Predicted incidence of infected individuals, next three weeks

Predicted incidence (asymptomatic and symptomatic) for Norway per day, with confidence intervals.

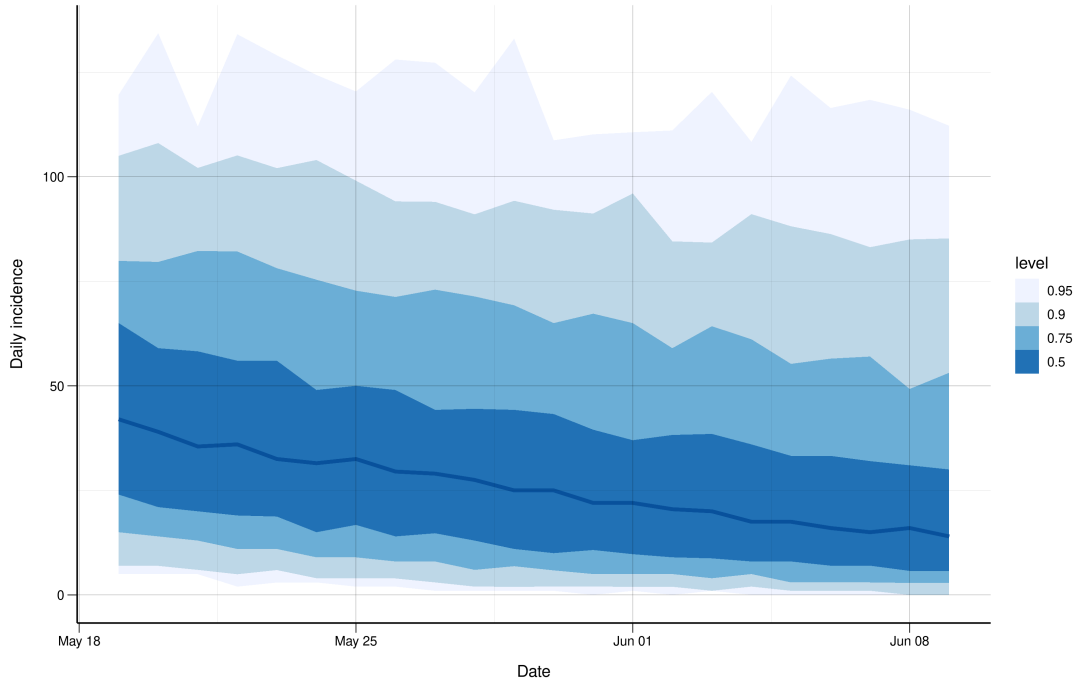


Table 3: Predicted incidence per day.

Region	1 week prediction (26 May)	2 weeks prediction (02 June)	3 weeks prediction (09 June)
Norway	37 (2-128)	30 (0-111)	25 (0-113)
Agder	3 (0-10)	2 (0-9)	2 (0-9)
Innlandet	3 (0-10)	3 (0-10)	3 (0-11)
Møre og Romsdal	2 (0-5)	1 (0-4)	1 (0-5)
Nordland	1 (0-4)	1 (0-4)	1 (0-4)
Oslo	6 (0-21)	5 (0-19)	4 (0-21)
Rogaland	5 (0-18)	4 (0-19)	4 (0-13)
Troms og Finnmark	2 (0-5)	1 (0-4)	1 (0-4)
Trøndelag	2 (0-9)	2 (0-7)	2 (0-7)
Vestfold og Telemark	3 (0-12)	3 (0-11)	3 (0-14)
Vestland	5 (0-16)	4 (0-16)	3 (0-12)
Viken	11 (0-34)	8 (0-38)	7 (0-32)

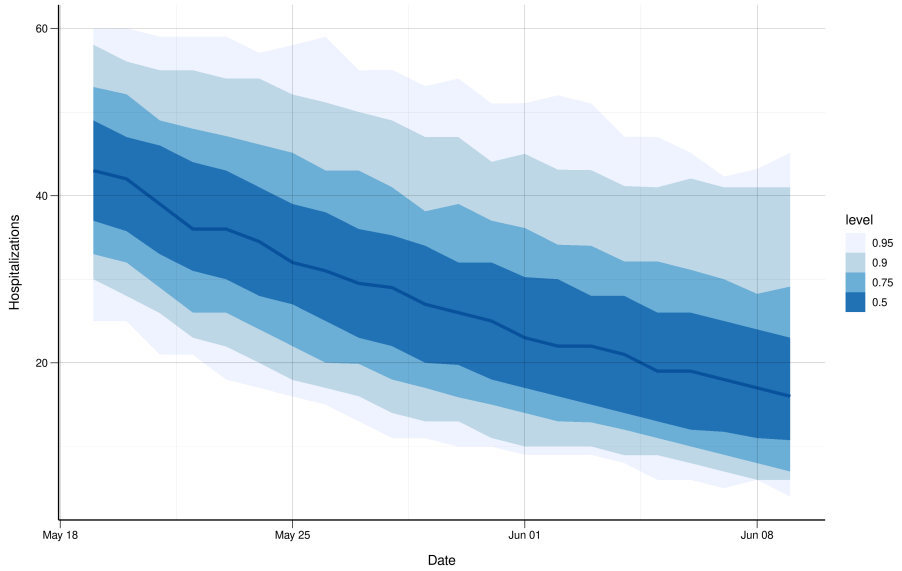
4 Predicted hospitalisation, next three weeks, including patients in ventilator treatment

Table 4: Number of hospitalisation beds occupied by Covid-19 patients.

Region	1 week prediction (26 May)	2 weeks prediction (02 June)	3 weeks prediction (09 June)
Norge	32 (14-60)	24 (7-53)	18 (3-47)
Agder	2 (0-7)	2 (0-6)	1 (0-6)
Innlandet	2 (0-8)	2 (0-8)	2 (0-7)
Møre og Romsdal	1 (0-4)	1 (0-3)	0 (0-3)
Nordland	1 (0-5)	1 (0-5)	0 (0-3)
Oslo	6 (1-14)	4 (0-11)	3 (0-9)
Rogaland	4 (0-11)	2 (0-9)	2 (0-8)
Troms og Finnmark	1 (0-4)	1 (0-3)	1 (0-5)
Trøndelag	2 (0-6)	1 (0-4)	1 (0-4)
Vestfold og Telemark	3 (0-9)	2 (0-8)	2 (0-8)
Vestland	4 (0-10)	3 (0-8)	2 (0-8)
Viken	7 (0-17)	6 (0-16)	5 (0-14)

Yesterday's real value for Norway: 51

Predicted daily number of COVID-19 patients in hospital in Norway (95% confidence intervals and interquartile range), next three weeks, including patients ventilator treatment.



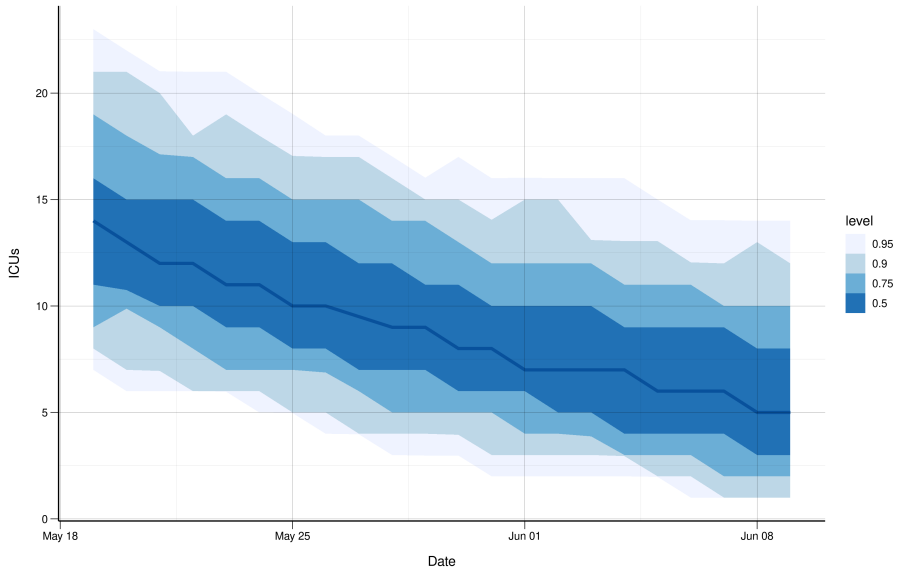
5 Predicted number of patients in ventilator treatment: next three weeks

Table 5: Number of ICU beds occupied by Covid-19 patients.

Region	1 week prediction (26 May)	2 weeks prediction (02 June)	3 weeks prediction (09 June)
Norge	10 (4-18)	8 (2-16)	6 (1-14)
Agder	1 (0-3)	0 (0-2)	0 (0-2)
Innlandet	1 (0-3)	1 (0-3)	0 (0-2)
Møre og Romsdal	0 (0-1)	0 (0-1)	0 (0-1)
Nordland	0 (0-2)	0 (0-2)	0 (0-1)
Oslo	2 (0-5)	1 (0-4)	1 (0-3)
Rogaland	1 (0-4)	1 (0-4)	1 (0-3)
Troms og Finnmark	0 (0-2)	0 (0-1)	0 (0-2)
Trøndelag	0 (0-2)	0 (0-1)	0 (0-1)
Vestfold og Telemark	1 (0-4)	1 (0-3)	1 (0-3)
Vestland	1 (0-3)	1 (0-3)	1 (0-2)
Viken	2 (0-6)	2 (0-6)	1 (0-4)

Yesterday's real value for Norway: 11

Predicted daily number of COVID-19 patients in ventilator treatment in Norway (95% confidence intervals and interquartile range), next three weeks.



6 Predicted prevalence of infectious individuals, next three weeks:

Predicted daily prevalence of asymptomatic, presymptomatic and symptomatic individuals, aggregated, whole Norway, (95% confidence interval).

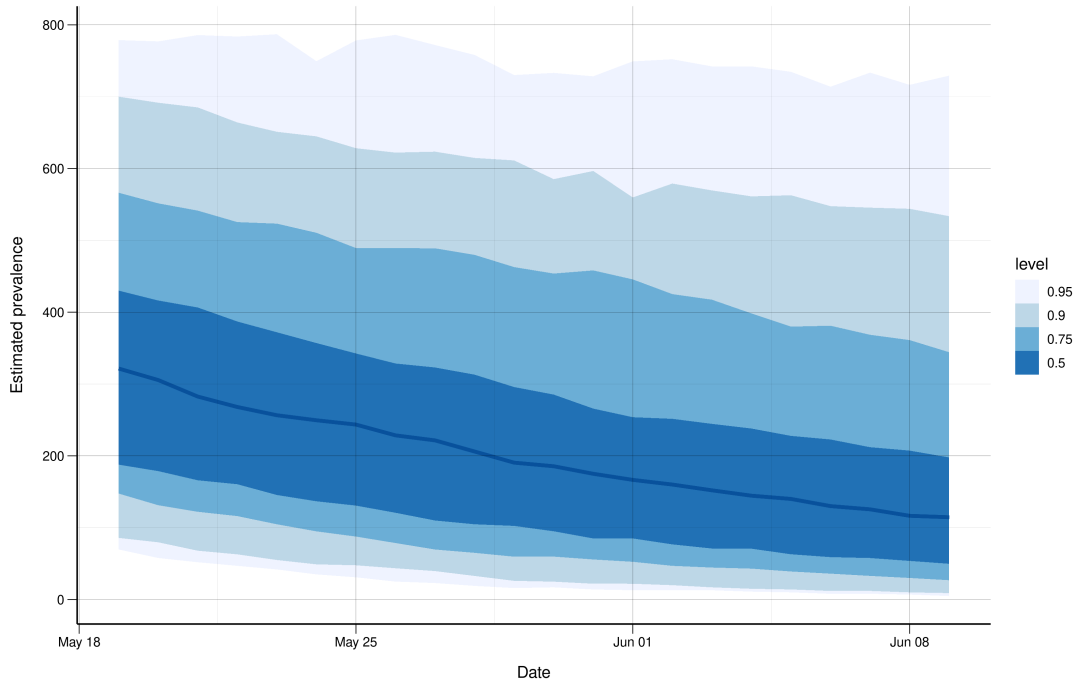
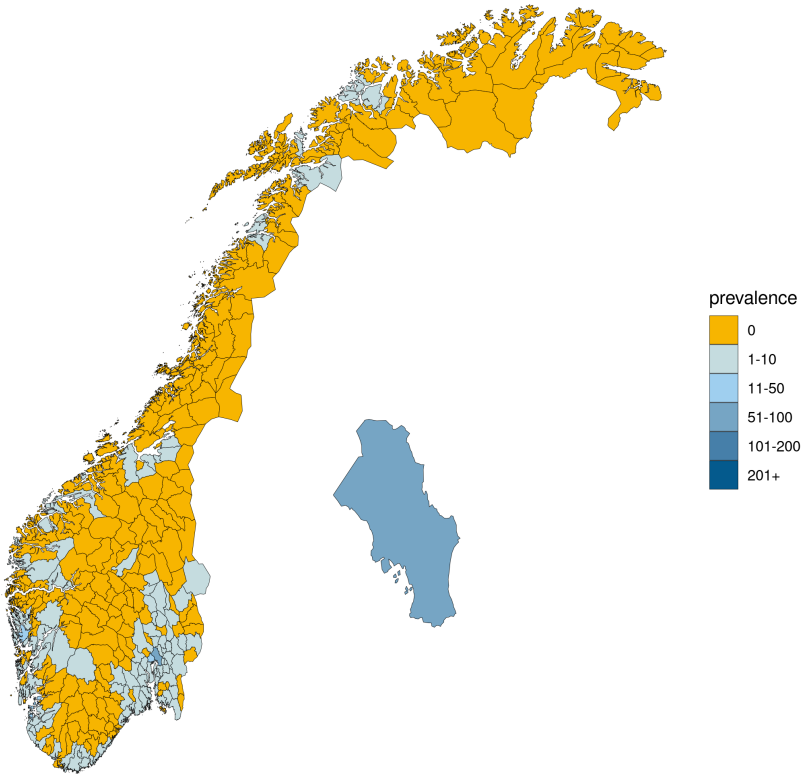


Table 6: Predicted prevalence. Number of infectious individuals (asymptomatic plus pre-symptomatic plus symptomatic) per day. Means and 95 perc. CI for three weeks prediction.

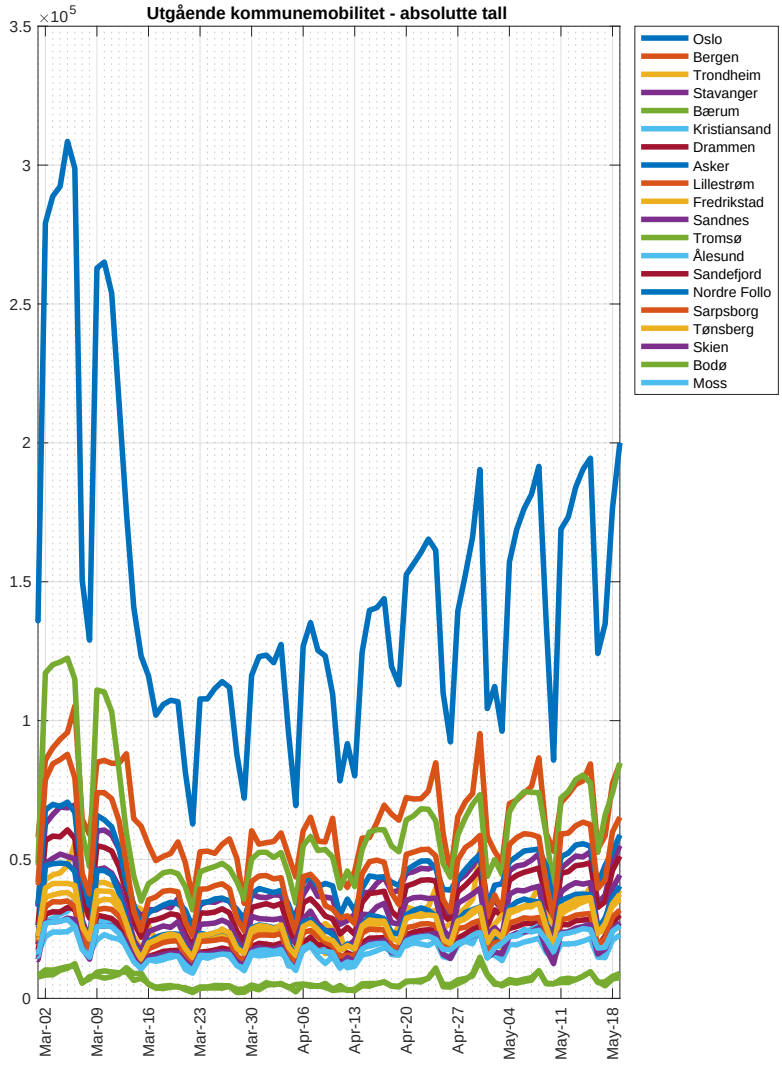
Region	Mean, 26 May	Mean, 02 June	Mean, 09 June	low CI, 09 June	high CI, 09 June
Norway	264	210	173	5	729
Agder	17	14	12	0	54
Innlandet	20	16	14	0	72
Møre og Romsdal	7	6	5	0	26
Nordland	6	5	4	0	18
Oslo	41	33	27	0	113
Rogaland	32	25	21	0	103
Troms og Finnmark	8	6	5	0	28
Trøndelag	13	11	9	0	47
Vestfold og Telemark	22	18	15	0	60
Vestland	30	25	20	0	84
Viken	73	57	47	1	200

Map of predicted prevalence. Number of infectious individuals (asymptomatic plus presymptomatic plus symptomatic) today in each municipality.



7 Mobility between municipalities

Number of trips out from each municipality during each day, based on Telenor mobility data. We have observed a large reduction in inter-municipality mobility in week 11 (around March 11), with a minimum reached on Tuesday 17 March. The reduction with respect to the weeks before (week 10, which we use as reference) is on average 50%. Thereafter, we observe a slight increasing trend: in Oslo, for example, out-mobility has increased of roughly 2% per day in the three weeks 12, 13 and 14. Weekends have a lower mobility, indicating that there is still commuting-to-job during weekdays. On Tuesday April 14th, after Easter, nationwide mobility was only reduced by 38% compared to week 10. On Monday April 20th, when kindergarten started to re-open, the nationwide reduction was only 23% compared to week 10. The nationwide mobility experienced a 27% reduction on Monday April 27 compared to week 10, which is the week where grades 1 to 4 in elementary school re-opened.

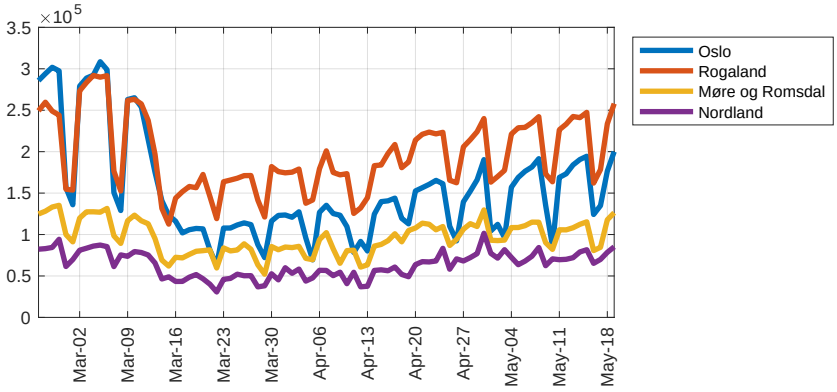


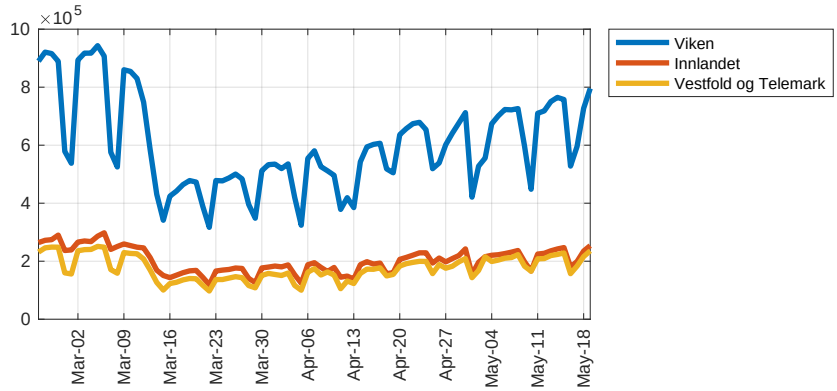
Percentage reduction in total mobility out from each municipality: Monday May 11th is compared to Monday March 2nd (last Monday before restrictions); Tuesday May 12th is compared to Tuesday March 3rd, etc. until Monday May 18th is compared to Monday March 2nd.

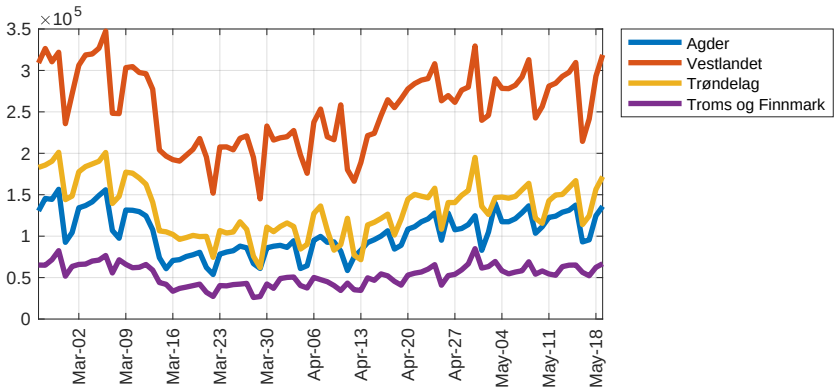
	Man_11	Tirs_12	Ons_13	Tors_14	Fre_15	Man_18	Tirs_19
Hele Norge	18,3%	19,5%	16,8%	17,3%	16,1%	14,5%	9,2%
Oslo	39,5%	40,0%	37,1%	38,2%	34,9%	36,8%	30,7%
Bergen	17,8%	18,6%	17,5%	18,2%	19,8%	9,7%	6,3%
Trondheim	29,4%	27,5%	26,4%	25,3%	28,0%	17,5%	12,1%
Stavanger	25,5%	25,8%	25,6%	25,7%	24,1%	21,8%	16,8%
Bærum	38,4%	38,0%	35,0%	34,3%	32,5%	36,9%	29,4%
Kristiansand	17,3%	18,0%	16,8%	18,8%	21,2%	13,3%	8,8%
Drammen	20,7%	21,9%	17,8%	20,7%	15,1%	18,8%	12,3%
Asker	24,7%	25,1%	20,1%	21,2%	18,2%	22,2%	15,7%
Lillestrøm	24,8%	29,6%	27,7%	27,8%	21,2%	23,9%	22,7%
Fredrikstad	12,6%	14,0%	11,1%	9,1%	1,4%	9,1%	3,9%
Sandnes	21,0%	20,0%	19,7%	19,5%	17,0%	18,3%	11,9%
Tromsø	31,9%	32,5%	33,3%	26,2%	24,2%	16,8%	11,9%
Ålesund	11,9%	18,1%	16,9%	14,3%	16,3%	5,9%	4,4%
Sandefjord	12,6%	14,9%	10,1%	13,8%	11,1%	10,1%	3,7%
Nordre Follo	26,2%	24,9%	23,1%	22,4%	18,5%	23,8%	16,5%
Sarpsborg	14,1%	17,4%	13,7%	13,7%	7,2%	11,3%	8,6%
Tønsberg	17,0%	17,4%	13,8%	13,0%	10,7%	14,2%	9,3%
Skien	13,2%	12,8%	8,7%	10,5%	6,8%	9,7%	0,7%
Bodø	32,8%	28,4%	37,0%	30,4%	17,2%	22,7%	11,8%
Moss	14,3%	14,6%	13,0%	11,6%	4,8%	10,3%	5,2%

Percentage reduction in total mobility out from each county: Monday May 11th is compared to Monday March 2nd (last Monday before restrictions); Tuesday May 12th is compared to Tuesday March 3, etc. until Monday May 18th is compared to Monday March 2nd.

	Man_11	Tirs_12	Ons_13	Tors_14	Fre_15	Man_18	Tirs_19
Oslo	39,5%	40,0%	37,1%	38,2%	34,9%	36,8%	30,7%
Rogaland	17,2%	17,7%	17,0%	16,8%	15,2%	14,5%	9,0%
Møre og Romsdal	11,8%	17,1%	15,1%	11,5%	12,3%	1,7%	0,9%
Nordland	14,1%	16,0%	16,3%	9,5%	4,4%	3,2%	-2,0%
Viken	20,5%	21,7%	18,2%	18,9%	16,5%	18,6%	13,3%
Innlandet	15,5%	15,8%	11,9%	15,4%	17,1%	11,6%	6,0%
Vestfold og Telemark	11,7%	12,8%	8,8%	11,1%	8,1%	8,5%	1,7%
Agder	8,6%	9,3%	8,9%	12,0%	11,8%	7,1%	0,6%
Vestlandet	8,2%	10,7%	8,5%	8,9%	10,9%	4,3%	0,0%
Trøndelag	19,7%	18,6%	19,7%	16,7%	16,9%	11,9%	6,6%
Troms og Finnmark	17,4%	20,3%	9,6%	8,6%	15,0%	5,3%	-0,7%

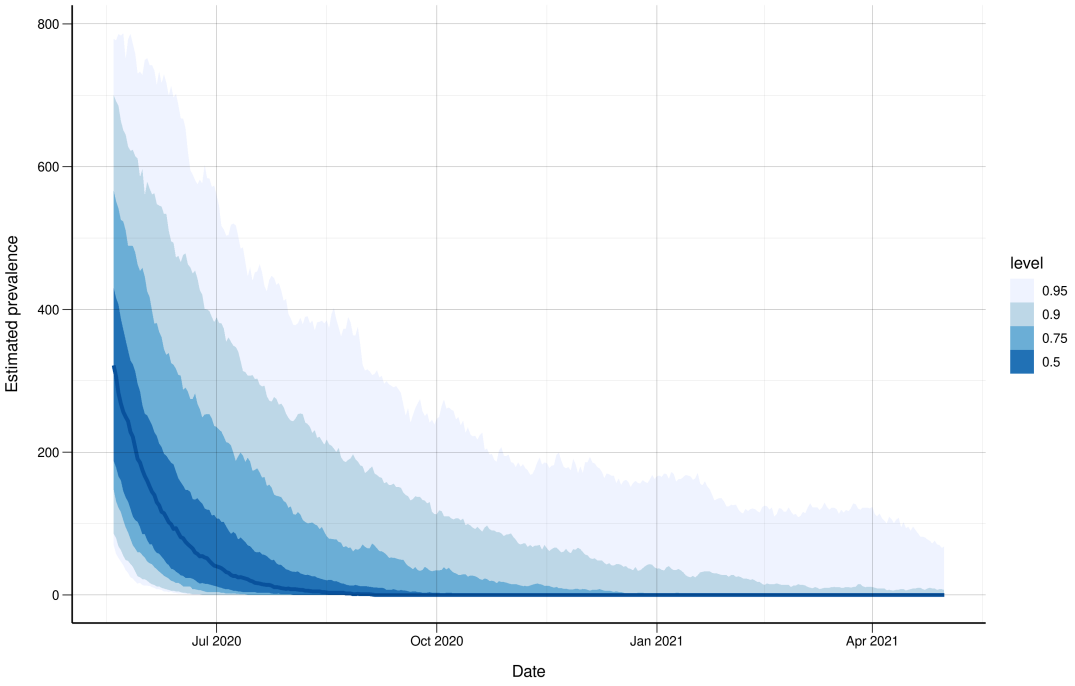

×10^5
3.5
3
2.5
2
1.5
1
0.5
0
Mar-02
Mar-09
Mar-16
Mar-23
Mar-30
Apr-06
Apr-13
Apr-20
Apr-27
May-04
May-11
May-18
Oslo
Rogaland
Møre og Romsdal
Nordland

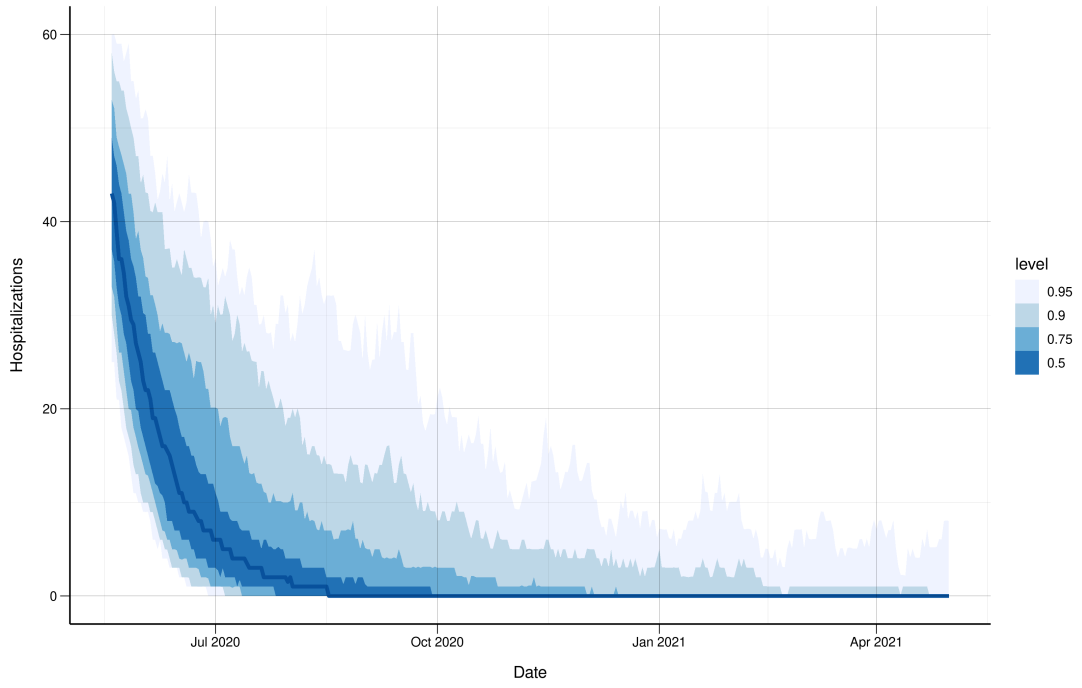

×10^5
10
8
6
4
2
0
Mar-02
Mar-09
Mar-16
Mar-23
Mar-30
Apr-06
Apr-13
Apr-20
Apr-27
May-04
May-11
May-18
Viken
Innlandet
Vestfold og Telemark

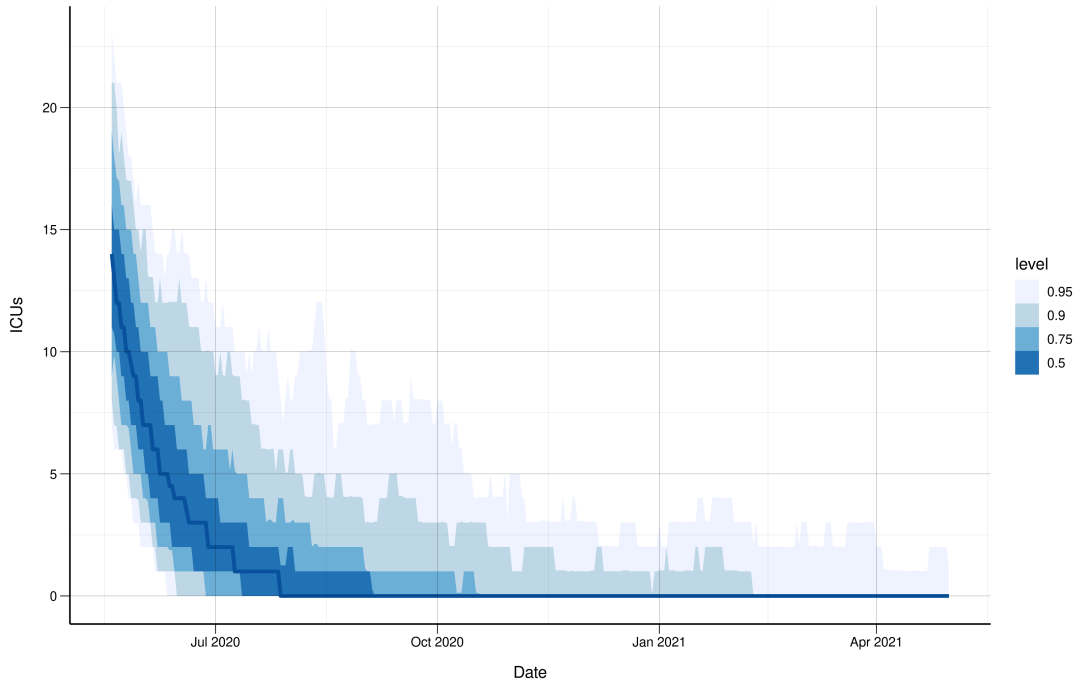

×10^5
3.5
3
2.5
2
1.5
1
0.5
0
Mar-02
Mar-09
Mar-16
Mar-23
Mar-30
Apr-06
Apr-13
Apr-20
Apr-27
May-04
May-11
May-18
Agder
Vestlandet
Trøndelag
Troms og Finnmark

8 Long-term prediction results

Predicted daily number of COVID-19 patients in hospital and receiving ventilator treatment in Norway until the end April, 2021, in addition to prevalence. The figures are made using 1000 candidate models, where the reproductive numbers are varying according to their estimated uncertainty.
The confidence intervals reflected on the plots are two tailed around the median, and therefore the upper 95 % level shows the 97.5 % boundary.



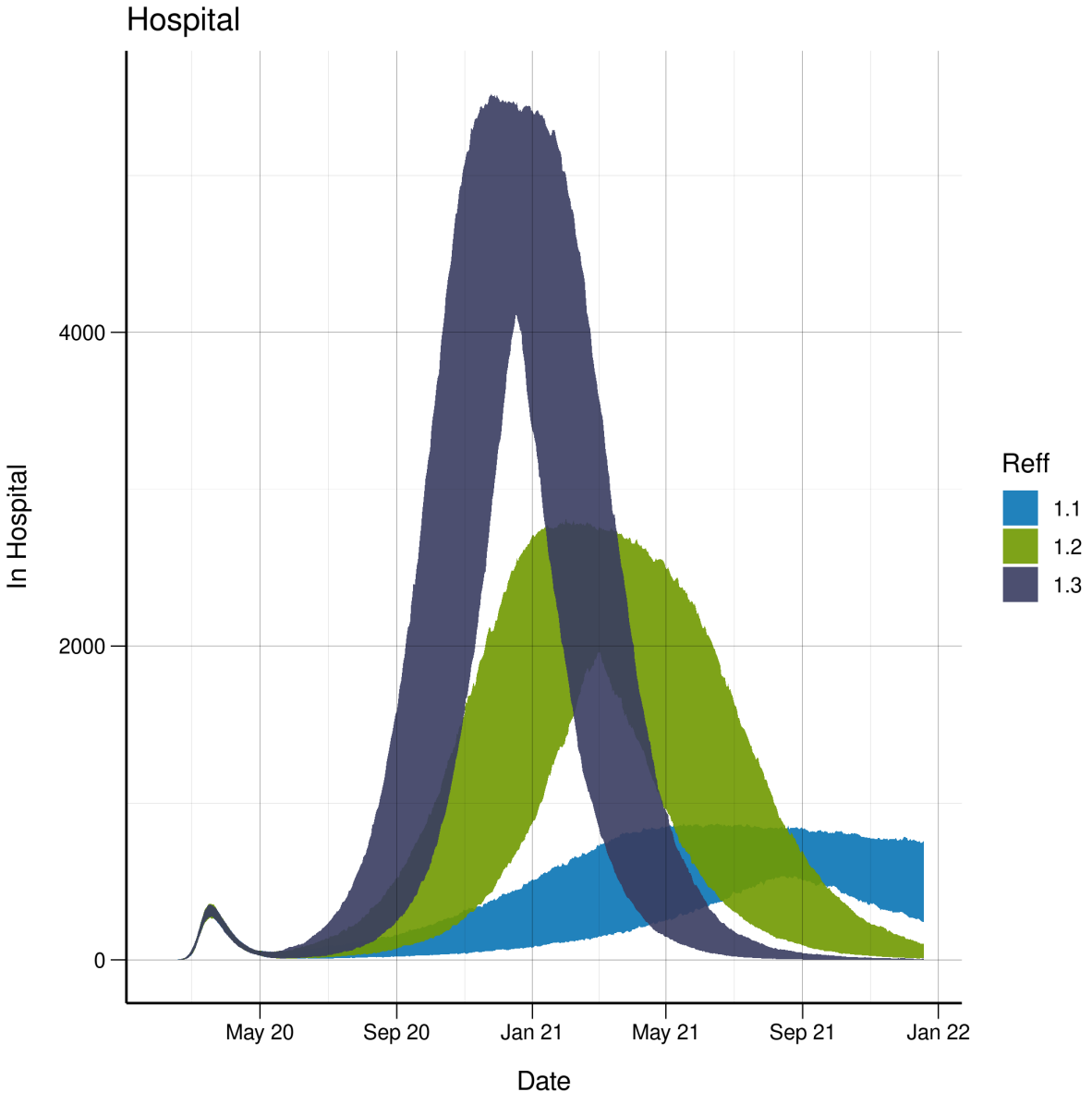


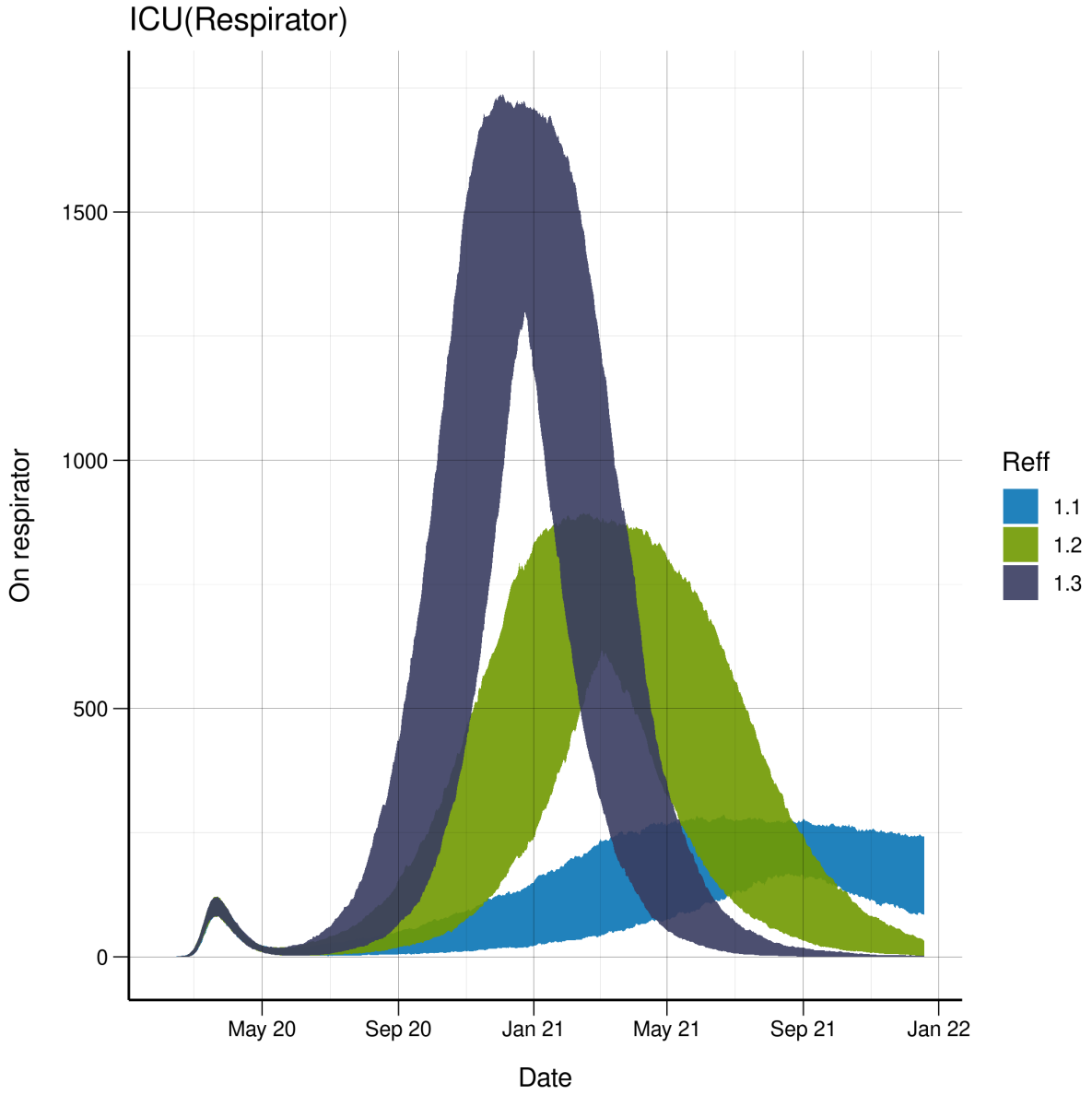


None of the simulations exceeded the surge capacity need of **1000 ICU** beds. The probability of a surge capacity need above **500 ICU** beds is **0.5 %** .

9 Long-term scenario results

Here we show how the epidemic will develop, from May 18th, under three assumed scenarios. We assume that until May 17th we follow our estimated reproductions numbers, but from May 18th we fix a new effective reproductive number. We show three cases, with this effective reproduction number equal to $1.1, 1.2$ or 1.3. We show the daily number of covid-19 patients in hospital (including with ventilator treatment) and the daily number of patients with ventilator treatment. In the table below we also show the number of totally infected individuals under these three scenarios. We indicate the number of patients estimated to need hospitalisation and ventilator treatment in total and at peak time. We show 95% confidence intervals. The reproduction number determines the prevalence and incidence at the peak, while the number in ICU and in hospital is in addition strongly dependent on probability of being hospitalised and the probability of needed ventilator treatment.





	Reff=1.1	**Reff=1.2**	**Reff=1.3**
Total infected	907.000(804.000 - 951.000)	1.670.000(1.650.000 - 1.680.000)	2.270.000(2.260.000 - 2.280.000)
Total Hospital	36.200(32.000 - 37.800)	65.400(64.600 - 66.200)	88.500(87.900 - 89.200)
Total on respirator	5.480(4.870 - 5.780)	9.900(9.680 - 10.100)	13.400(13.200 - 13.600)
Ward[1]	584(506 - 643)	1.890(1.730 - 2.000)	3.740(3.480 - 3.910)
Hospital[2]	836(736 - 926)	2.730(2.500 - 2.880)	5.380(5.020 - 5.620)
Respirator at Peak	274(239 - 312)	863(794 - 925)	1.690(1.570 - 1.780)

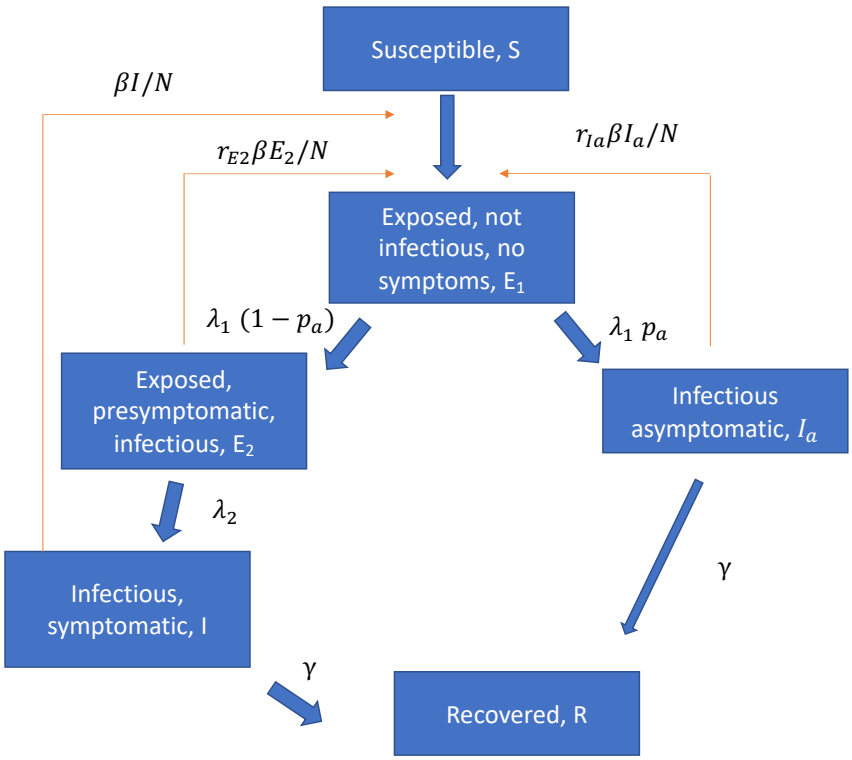
[1]In hospital not on respirator
[2]Includes both patients receiving respiratory treatment and patients who do not.

Model

We use a metapopulation model to simulate the spread of COVID-19 in Norway in space and time. The model consists of three layers: the population structure in each municipality, information about how people move between different municipalities, and local transmission within each municipality. In this way, the model can simulate the spread of COVID-19 within each municipality, and how the virus is transported around in Norway.

Transmission model

We use an SEIR (Susceptible-Exposed-Infected-Recovered) model without age structure to simulate the local transmission within each area. Mixing between individuals is assumed random. Demographic changes due to births, immigration, emigration and deaths are not considered. The model distinguishes between asymptomatic and symptomatic infection, and we consider presymptomatic infectiousness among those who develop symptomatic infection. In total, the model consists of 6 disease states: Susceptibles (S), Exposed, infected, but not infectious (E), Presymptomatic infected (E2), Symptomatic infected (I), Asymptomatic infected (Ia), and Recovered, either immune or dead (R). A schematic overview of the model is shown below:



Movements between municipalities:

We use 6-hourly mobility matrices from Telenor to capture the movements between municipalities. The matrices are scaled according to the overall Telenor market share in Norway, estimated at 48%. Since week 8, we use the actual daily mobility matrices to simulate the past. In this way, alterations in the mobility pattern will be incorporated in our model predictions. To predict future movements, we use the latest weekday measured by Telenor. We follow closely the development in the mobility matrices, and weekend patterns will be introduced if needed.

Healthcare utilization

Based on the estimated daily incidence data from the model and the population age structure in each municipality, we calculated the hospitalization using a weighted average. The hospitalization is assumed delayed relative to symptom onset. We calculate the number of patients admitted to ventilator treatment from the patients in hospital using age adjusted probabilities and an assumed delay.

Seeding

At the start of each simulation, we locate 5.367.580 people in the municipalities of Norway according to data from SSB per January 1. 2020. All confirmed Norwegian imported cases with information about residence municipality and test dates are used to seed the model, until 18th March. For each case, we add an additional random number of infectious individuals, in the same area and on the same day, to account for asymptomatic imported cases who were not tested or others missed. This is called amplification factor.

Reproduction number and calibration

We assume a first reproduction number R_0 until March 14, a second reproduction number R_1 until April 19 and a third reproduction number R_2 thereafter. This last reproduction number is used in the future. The change points follow the change of restrictions introduced. We estimate the reproduction numbers so that the predicted number of hospitalized individuals is closest to the true number of hospitalized individuals, from March 10 until today. We use a method called sequential ABC which tests thousands of combinations of R_0, R_1, R_2 and the amplification factor, to determine the 200 ones that lead to the best fits of hospitalisations. The algorithm is described in Engebretsen et al. (2020) https://www.medrxiv.org/content/10.1101/2020.03.11.20033555v1.

Update notes: what is new in this report.

Here we list aspects of the model or of the input parameters which have changed compared to previous reports, and we explain the reason for these changes. Some changes will have big effects on some of our estimates.

– 14 April: **Hospitalisation risk:** Our model requires the specification of the proportion of symptomatic and asymptomatic patients requiring hospitalisation. Previously we used estimates from Verity et al. (2020) based on Chinese data, adapted to the Norwegian demography, and to the reduced mobility of elderly patients living in elderly homes. We summarised this proportion to be 5.6%. Under these assumptions, our model estimates a cumulative number of infected individuals of ca. 14.000. As we have had ca 135 confirmed deaths in Norway, this corresponds to an Infection Fatality Ratio (IFT) of roughly 1%. However, international studies indicate that the IFT should be around 0.3% (https://www.cebm.net/covid-19/global-covid-19-case-fatality-rates/). We therefore calibrate our model to this IFT (in addition to calibrate the model to the hospitalisation data), by adjusting the hospitalisation risk in our model, reducing it by a third, to 1.85%. The effect of this change is visible on the estimated cumulative number of infected individuals, which is now approximately 45.000. A further effect of this change is that the reproductive numbers are different, with R_0 larger and R_{eff} smaller than before, when we had a higher hospitalisation risk.

– 14 April: **Change point for the reproductive number:** On March 12, a number of contact restrictions were implemented. During that week 11, mobility was reduced significantly, and appears to stabilize on Monday March 16th. Between the 11th and 16th of March we expect a reduction of the reproduction rate. We model this change as a sudden jump from a first reproduction rate R_0 to a second and lower reproduction rate R_{eff}, through a change in the model parameter β. We have chosen Monday March 15 as the changepoint for the reproductive number because it gives the best fit to the hospitalisation data. If we move the changepoint to March 14, or assume a

continuous linear reduction during week 11, the fit deteriorates. We also notice that the best changepoint depends on the assumed time between symptoms appearance and hospitalisation, which is assumed to have mean 8 days in this report. The optimal changepoint also depends on the assumed hospitalisation risk.

– 20 April: **Change in parameter estimation method:** We use sequential ABC instead of iterative parameter calibration. Estimation of the reproduction numbers and of the amplification factor in the seeding of the epidemic at the start is done using Approximate Bayesian Computation (ABC), as described in Engebretsen et al. (2020)[3]. Sequential ABC avoids to calibrate R_0 first on part of the data and then, given the best values of such R_0, to find the best fitting R_{eff}, which might not lead to optimal estimation and is based on more ad-hoc choices. We also do not weigh the last part of the data more than the rest. Sequential ABC takes more time to run: therefore the daily report might use only the hospitalisation until yesterday.

– 3 May: **New reproduction number active from 20 April:** We introduce a new changepoint in the reproduction number, so that R_1 is active until 19 April and R_2 from 20 April. This is the day the kindergarten reopened. On April 27 also part of primary school reopened, and we will see if a further change point will be useful to fit the data best.

– 15 May: **New parameters related to hospitalisation risk:** Our model requires the specification of the proportion of symptomatic and asymptomatic patients requiring hospitalisation. Previously we used estimates from Verity et al. (2020) based on Chinese data, adapted to the Norwegian demography and to the reduced mobility of elderly patients living in elderly homes, and calibrated to obtain a Infection Fatality Ratio (IFT) of roughly 0.3%. We adjust again the hospitalisation risk in our model based on Salje et al Science 13 May 2020[4], again adapted to Norwegian demography and to the reduced mobility of elderly in elderly homes. The effect of this change is visible on the estimated cumulative number of infected individuals, which is now approximately 35.000. The infection fatality rate in this study is 0.7%

– 15 May: **Change of the data we use, from occupied beds to new admissions to hospital:** We use the daily number of lab-confirmed COVID-19 patients admitted to hospitals in Norway to estimate the reproduction numbers and the amplification factor. Before we were using the daily number of beds occupied by lab-confirmed COVID-19 cases. We have moved from hospital prevalence to hospital incidence. The prevalence is influenced by the length of stay in hospital for the patients, while incidence is not. In this sense the incidence data should carry a clearer signal of the infection strengths in the country. However, both data capture this signal with a delay, which we estimate to have an expectation of 14 days. The incidence data are less smooth in time (more irregular) and are more difficult to fit well, as can be seen in Figure 1. The estimated hospital prevalence (Figure 2) is fitted in a satisfying way. The incidence data are available at hospital level.

– 15 May: **New parameter value related to periods of stay in hospital:** Our model requires the specification of several lengths of stay in hospital: time spent in hospital for patients not requiring ventilator treatment; time spent with ventilator treatment; etc. We also need the time between onset of symptoms and hospitalisation. See the graph at the end of this report for a full specification. We have now estimated the distributions of all these lengths, and of the probability of requiring ventilator treatment if hospitalised, from data covering almost all patients hospitalised in Norway so far. Previously, we used parameters published in Fraser et al. which were not based on the Norwegian epidemic. A note which documents the way we estimate the new parameters is in preparation. We will regularly re-estimate these parameters on the basis of additional new hospitalised patients.

– 20 May: **New estimated period in ward after ICU stay :** We have estimated that patients stay on average 7.7 days in a non-ICU ward in hospital, after being off from ventilator treatment.

[3] https://www.medrxiv.org/content/10.1101/2020.03.11.20033555v1
[4] https://science.sciencemag.org/content/early/2020/05/12/science.abc3517.abstract

Parameters used today

The figure below indicates which assumptions we make in our model, related to hospitalisation. We obtained estimates from Norwegian data, namely NPR data linked with MSIS data. These estimates will be regularly updated, on the basis of new data.

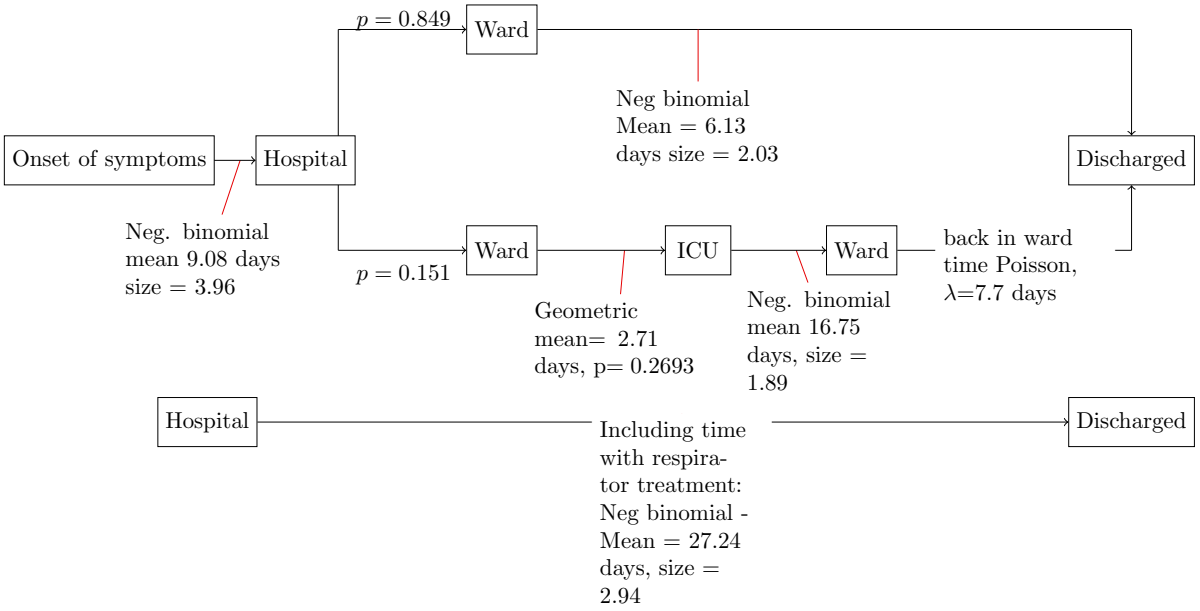


Figure 1: Hospital assumptions and parameters

Table 7: Assumptions I

Assumptions	Mean	Distribution	Reference
Seeding			
Scaling factor on imported cases	Min. 1.08 1st Qu. 1.72 Median 2.03 Mean 2.02 3rd Qu. 2.28 Max. 3.30	random	Calibrated to hospitalizations
Telenor coverage	48%		https://ekomstatistikken.nkom.no/
Model parameters			
Exposed period ($1/\lambda_1$)	3 days	Exponential	Fraser et al. Not published
Pre-symptomatic period ($1/\lambda_2$)	2 days	Exponential	Fraser et al. Not published
Symptomatic infectious period ($1/\gamma$)	5 days	Exponential	Fraser et al. Not published
Asymptomatic, infectious period ($1/\gamma$)	5 days	Exponential	Fraser et al. Not published
Infectiousness asympt. (r_{I_a})	0.1	Fixed	Fraser et al. Not published
Infectiousness presymp (r_{E_2})	1.25	Fixed	Fraser et al. Not published
Prob. asymptomatic infection (p_a)	0.4		Fraser et al. Not published
R_0, until March 14	Min. 2.38 1st Qu. 2.90 Median 3.05 Mean 3.06 3rd Qu. 3.26 Max. 3.80	random	Calibrated to hospitalizations
R_1, from 15 March until 19 April	Min. 0.43 1st Qu. 0.52 Median 0.55 Mean 0.55 3rd Qu. 0.57 Max. 0.64	random	Calibrated to hospitalizations
R_2, from 20 April until today	Min. 0.22 1st Qu. 0.52 Median 0.64 Mean 0.64 3rd Qu. 0.74 Max. 1.15	random	Calibrated to hospitalizations

Table 8: Assumptions II

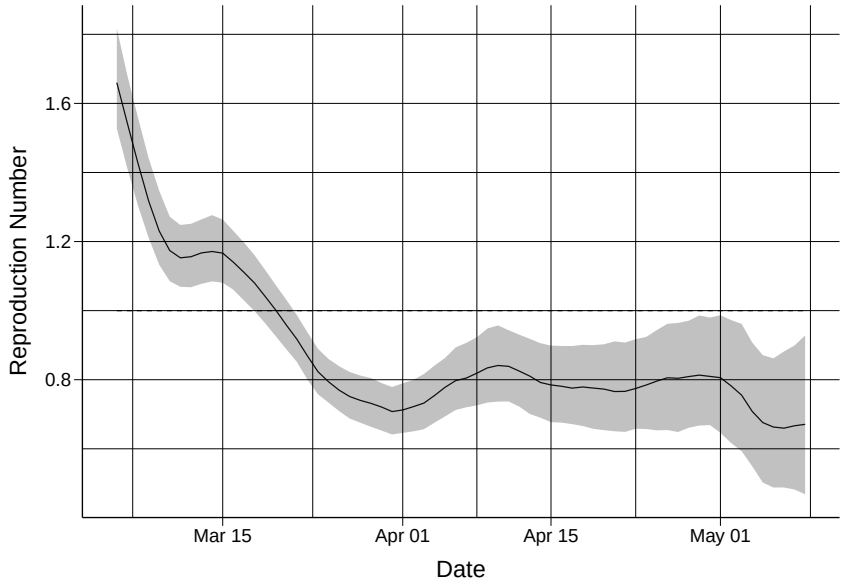
Assumptions	Mean	Distribution	Reference
Healthcare			
Time sympt. onset to hospitalisation	9 days	Neg. binomial	
Fraction asymptomatic infections	40%	Fixed	Mizumoto et al 2020 20% for the old population, Diamond Princess
% symptomatic and asymptomatic infections requiring hospitalization: 0-9 years 10 - 19 years 20 - 29 years 30 - 39 years 40 - 49 years 50 - 59 years 60 - 69 years 70 - 79 years 80+ years	 0.02% 0.02% 0.06% 0.13% 0.17% 3.5% 7.1% 11.3% 27%	Fixed	Saljie et al 2020 corrected for: % of elderly living in of elderly living in Norway (last two age groups).
% hospitalized patients requiring ICU Feb - March April May -	 20% 10% 15.1 %	Fixed	Estimated from "Beredskapsregistret BeredtC19"
Overall hospitalization risk	3.9%	Fixed	Saljie et al 2020 (adapted to Norwegian population)
Mobile phone mobility			
Until May 19	Measured Telenor mobility		
Data used in the predictions	May 19	Fixed	Corrected to preserve population

Supplementary analysis: Instantaneous reproduction number based on lab-confirmed cases

To complement the results of the metapopulation model, we present estimates of the temporal evolution of the reproduction number in Norway based on an analysis of lab-confirmed cases. The primary purpose of this analysis is to provide a more comprehensive perspective on the epidemic situation, taking into account several data sources.
The hospitalization data are a less biased estimator of the number of infections compared to case data because the testing criteria in Norway has changed. For this reason, the present results should be interpreted with caution. During the early part of the period, testing of individuals was mainly based on travel history to areas with an ongoing outbreak. Since the middle of March, testing is recommended for people with an acute respiratory infection. From early May the testing criteria have been expanded to include less severe symptoms. The analysis of laboratory-confirmed cases does not take into account the effect of imported cases during the early outbreak in Norway; the early results are less reliable than later results when the impact of importations is negligible. Overall, the reproduction numbers estimated by this method gives a similar conclusion to the analysis based on the metapopulation model from the middle of March onwards.

EpiEstim method and assumptions

We estimate the instantaneous reproduction number using the procedure outlined in Thompson et al. (2019). This method, implemented in the EpiEstim R-package uses a Bayesian approach to estimate the instantaneous reproduction number smoothed over a sliding window of 5 days. For the results to be comparable to those of the metapopulation model, we use the same natural history parameters. We estimate the date of infection for each confirmed case by first estimating the date of symptom onset and then subtracting 5 days for the incubation period. We estimate the date of symptom onset from the empirical delay between onset and testing in the first reported cases. For each case, we draw 100 possible onset dates from the delay distribution; this gives us 100 epi-curves that we use to estimate the reproduction number. The displayed results are the combined results from all these 100 simulated epi-curves. The serial interval was assumed at 5 days with uncertainty; the serial interval refers to the time between symptom onset between successive cases in a chain of transmission (see https://www.medrxiv.org/content/10.1101/2020.02.03.20019497v2). To account for censoring of observations with onset dates in the last few days we correct the observed data by the mean of a negative binomial distribution with observation probability given by the empirical cumulative distribution of the onset to reporting date distributions. Due to this correction, the results from the last few days are uncertain, as indicated by increasing credible intervals.


Reproduction Number
1.6
1.2
0.8
Mar 15
Apr 01
Apr 15
May 01
Date

FHI COVID-19 modelling team:

- **Birgitte Freiesleben de Blasio** - Department of Method Development and Analytics. Norwegian Institute of Public Health.
- **Francesco Di Ruscio** - Department of Method Development and Analytics. Norwegian Institute of Public Health.
- **Gunnar Øyvind Isaksson Rø** - Department of Method Development and Analytics. Norwegian Institute of Public Health.
- **Solveig Engebretsen** - Norsk Regnesentral.
- **Arnoldo Frigessi** - Oslo Centre for Biostatistics and Epidemiology, University of Oslo and Oslo University Hospital.
- **Alfonso Diz-Lois Palomares** - Department of Method Development and Analytics. Norwegian Institute of Public Health.
- **David Swanson** - Oslo Centre for Biostatistics and Epidemiology, University of Oslo and Oslo University Hospital.
- **Magnus Nygård Osnes** - Department of Method Development and Analytics. Norwegian Institute of Public Health.
- **Anja Bråthen Kristoffersen** - Department of Method Development and Analytics. Norwegian Institute of Public Health.
- **Kenth Engø-Monsen** - Telenor Research.
- **Richard White** - Department of Method Development and Analytics. Norwegian Institute of Public Health.
- **Gry Marysol Grøneng** - Department of Method Development and Analytics. Norwegian Institute of Public Health.