

# Situational awareness and forecasting

FHI COVID-19 modelling team

8 May 2020

## Highlights today:

- We have introduced a new reproduction number  $R_2$  acting from 20 April, when restrictions started to be lifted. We estimate  $R_2$  to have a mean equal to 0.49 with an interquartile range of (0.33-0.63) and a large 95% confidence interval (0.09-0.95).
- The estimate of  $R_2$  is still uncertain, because there is only little information in the hospitalisation data about infections contracted on 20 April and the days thereafter. Individuals who got infected on 20 April and need hospitalisation, will be admitted to hospital around 2 May. This week 19 of data informs us on infectious contracted in week 17 and not beyond. The large confidence interval for  $R_2$  means that there is still insufficient data about  $R_2$ . The probability that  $R_2$  is larger than 1 is however very small, because hospitalisations dropped during week 19.
- Assuming that reproduction numbers and mobility remain like now, in the next three weeks we predict that the mean hospitalisation and the mean number of patients needing ventilator treatment will decrease. Still, due to the uncertainty, we forecast with small probability that a slight increase could still happen.
- We present long term predictions (prevalence, hospitalisation, ventilator treatment) for the next twelve months, under the assumptions that  $R_2$  in the future follows the estimated distribution we have obtained today and mobility remains as now. In this case, we likely have already seen the peak of the number of patients in ventilator treatment. We estimate to only 0.5% the probability that more than 500 ventilator treatments will be needed simultaneously at peak time.
- We contrast this current estimate of the situation with three scenarios, assuming an increase of  $R_2$  to 1.1, 1.2 or 1.3 from today. In these cases, a second peak is expected later. If  $R_2$  would be 1.1, the peak would be in early 2021, with a predicted mean number of patients in ventilator treatment at peak equal to ca. 200. If  $R_2$  would be 1.2, the peak would be in late 2020, with a predicted mean number of patients in ventilator treatment at peak equal to ca. 650. If  $R_2$  would be 1.3, the peak would be already in autumn 2020, with a predicted mean number of patients in ventilator treatment at peak equal to ca. 1300.
- Because in this report we calibrate our model using national hospitalisation data, the predictions at county level can only be taken as an indication. See our regional report, where we use county-wise hospitalisation data, for more reliable regional predictions.

## 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 hospitalization prevalence data since March 10 until today. We seed new infections into the model using imported COVID-19 cases in Norway 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, median, 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: First, there are uncertainties related to the natural history of SARS-CoV-2, including the importance of asymptomatic and presymptomatic infection. Second, there are uncertainties related to the timing of hospitalization relative to symptom onset, the severity of the COVID-19 infections by age, and the duration of hospitalization 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 7. They account for the changes in the movement patterns between municipalities that have occurred since start of the epidemic.

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 hospitalization data until today. Estimates of  $R_0$ ,  $R_1$  and  $R_2$  are uncertain, and we use their distribution to guarantee 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 in the estimation of reproductive numbers. We will update the parameters related to permanence in hospital and ICU as soon as NPR data will be linked with MSIS and checked.

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

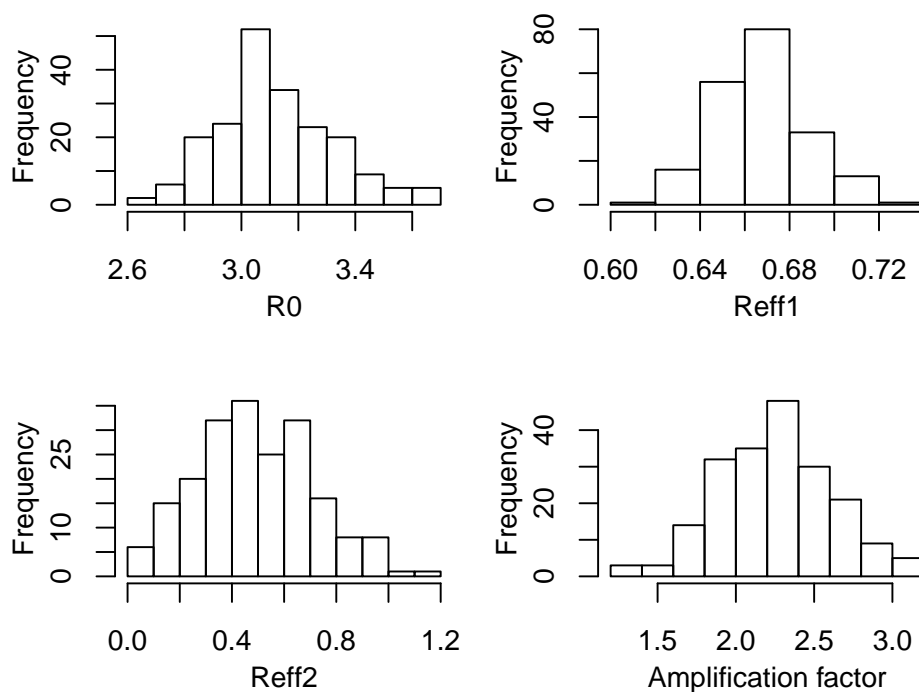
# 1 Estimated Reproductive Numbers

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

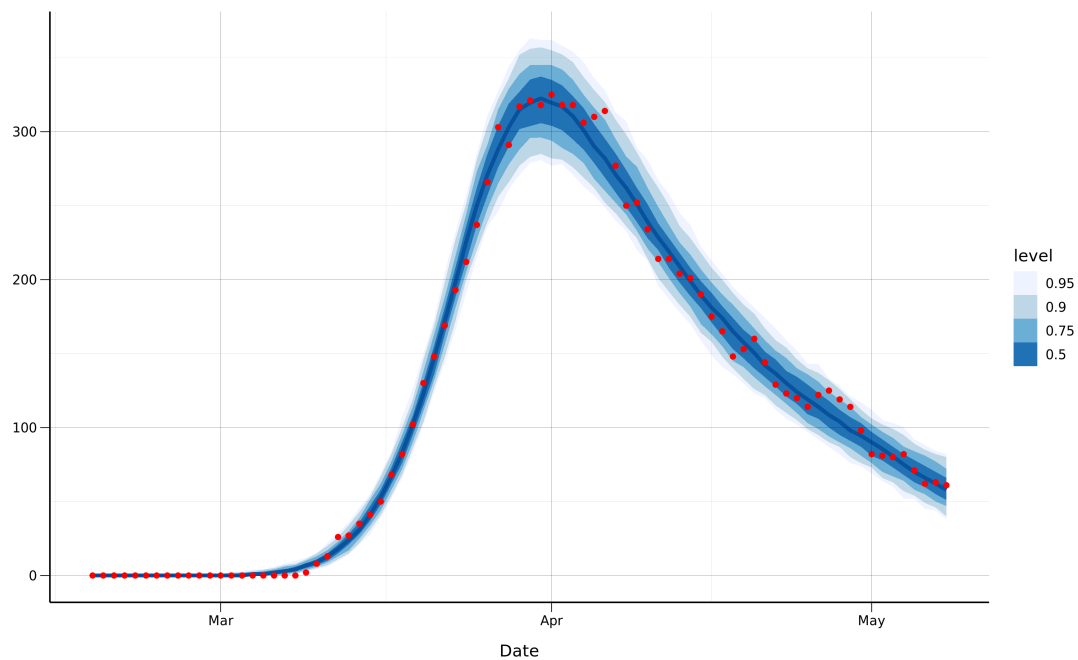
Table 1: Calibration results

Parameter	Mean	Median	Confidence interval (95 %)
Amplification factor	2.26	2.25	(1.53-2.99)
$R_0$	3.13	3.09	(2.74-3.58)
$R_1$	0.67	0.67	(0.63-0.71)
$R_2$	0.49	0.47	(0.09-0.95)

Estimated densities of these four parameters are plotted below:



Our model estimates the number of hospitalised Covid-19 patients, plotted below with blue median and interquartile bands, which are compared with the actual hospitalisation data, in red. The uncertainty captures the uncertainty in the calibrated parameters in addition to the stochastic elements of our model.



True total number of hospitalisations (red) and predicted values (blue)

## 2 Estimated cumulative number of infected individuals

Table 2: Estimated cumulative number of infections, 2020-05-08

Region	Total	Symptomatic	No. confirmed	Fraction reported	Min. fraction
Norway	50845 (46792; 54856)	31220 (28747; 33663)	8034	16%	15%
Agder	3166 (2405; 4071)	1943 (1470; 2466)	334	11%	8%
Innlandet	2678 (2040; 3462)	1634 (1256; 2094)	457	17%	13%
Møre og Romsdal	999 (707; 1383)	619 (419; 866)	127	13%	9%
Nordland	842 (472; 1314)	518 (295; 806)	116	14%	9%
Oslo	11740 (10398; 13205)	7161 (6306; 8047)	2499	21%	19%
Rogaland	6770 (5492; 8356)	4155 (3351; 5120)	436	6%	5%
Troms og Finnmark	1521 (761; 2479)	929 (466; 1521)	250	16%	10%
Trøndelag	2293 (1621; 3017)	1409 (1004; 1845)	513	22%	17%
Vestfold og Telemark	4020 (3084; 5227)	2459 (1883; 3191)	279	7%	5%
Vestland	5437 (4099; 6973)	3328 (2514; 4249)	872	16%	13%
Viken	11380 (10006; 12841)	7065 (6220; 7951)	2150	19%	17%

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.

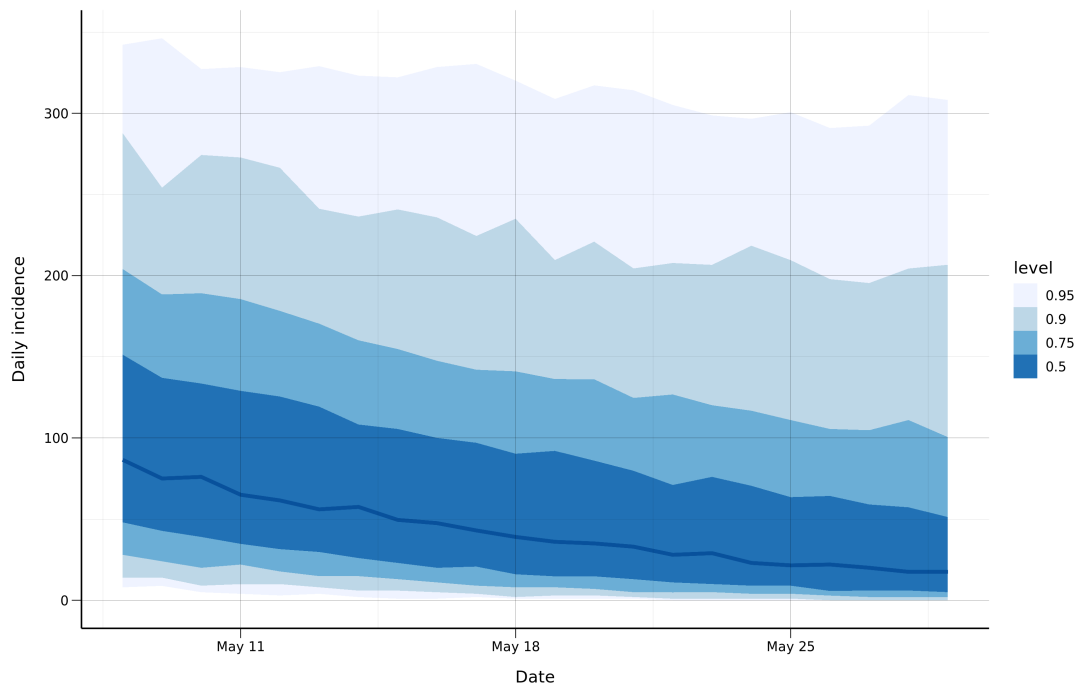


Table 3: Predicted incidence per day.

Region	1 week prediction (15 May)	2 weeks prediction (22 May)	3 weeks prediction (29 May)
Norway	80 (1-322)	60 (0-305)	49 (0-308)
Agder	5 (0-20)	4 (0-22)	3 (0-21)
Innlandet	6 (0-25)	5 (0-22)	4 (0-23)
Møre og Romsdal	2 (0-8)	2 (0-8)	2 (0-8)
Nordland	2 (0-8)	1 (0-6)	2 (0-6)
Oslo	13 (0-54)	10 (0-47)	8 (0-52)
Rogaland	10 (0-38)	8 (0-40)	6 (0-39)
Troms og Finnmark	3 (0-9)	2 (0-12)	2 (0-9)
Trøndelag	4 (0-21)	4 (0-17)	3 (0-19)
Vestfold og Telemark	7 (0-29)	5 (0-28)	5 (0-27)
Vestland	10 (0-39)	7 (0-40)	6 (0-40)
Viken	22 (0-84)	17 (0-87)	13 (0-81)

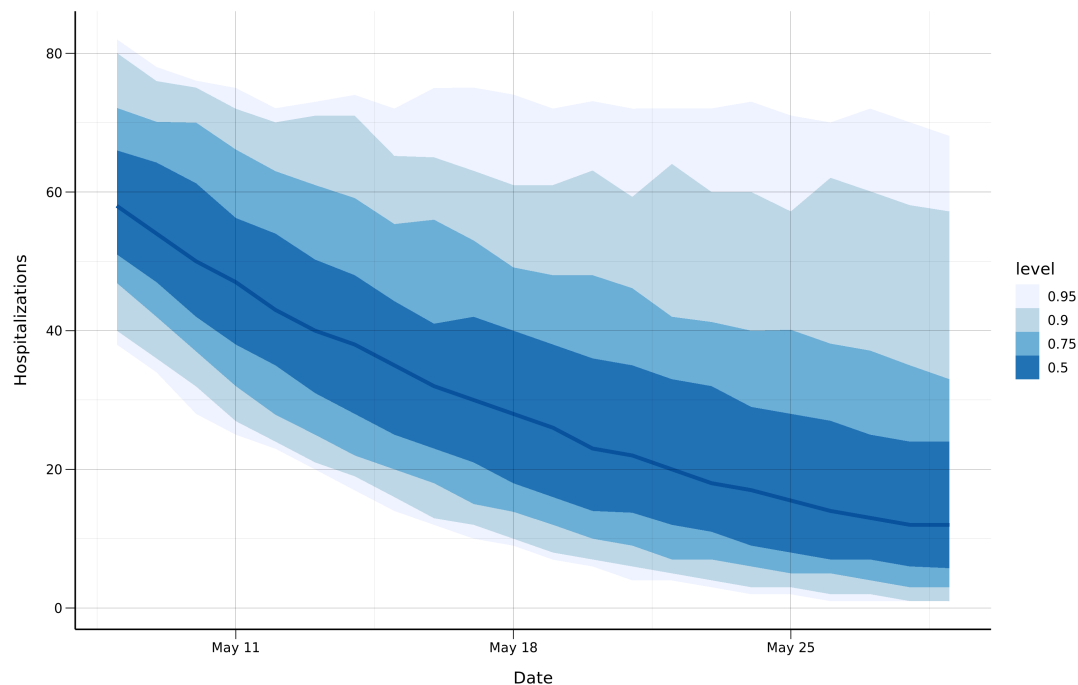
## 4 Predicted hospitalisation, next three weeks, including patients in ventilator treatment

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

Region	1 week prediction (15 May)	2 weeks prediction (22 May)	3 weeks prediction (29 May)
Norge	37 (11-74)	25 (3-77)	17 (0-69)
Agder	2 (0-8)	1 (0-6)	1 (0-6)
Innlandet	3 (0-9)	2 (0-8)	1 (0-8)
Møre og Romsdal	1 (0-5)	1 (0-4)	0 (0-3)
Nordland	1 (0-4)	1 (0-3)	0 (0-3)
Oslo	7 (0-18)	4 (0-13)	2 (0-10)
Rogaland	4 (0-12)	3 (0-10)	2 (0-8)
Troms og Finnmark	1 (0-5)	1 (0-4)	1 (0-3)
Trøndelag	2 (0-5)	1 (0-6)	1 (0-5)
Vestfold og Telemark	4 (0-11)	2 (0-9)	2 (0-6)
Vestland	4 (0-12)	3 (0-12)	2 (0-11)
Viken	9 (0-22)	6 (0-21)	5 (0-19)

Yesterday's real value for Norway: 61

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



Similar table and figure for each county (fylke) available on request.

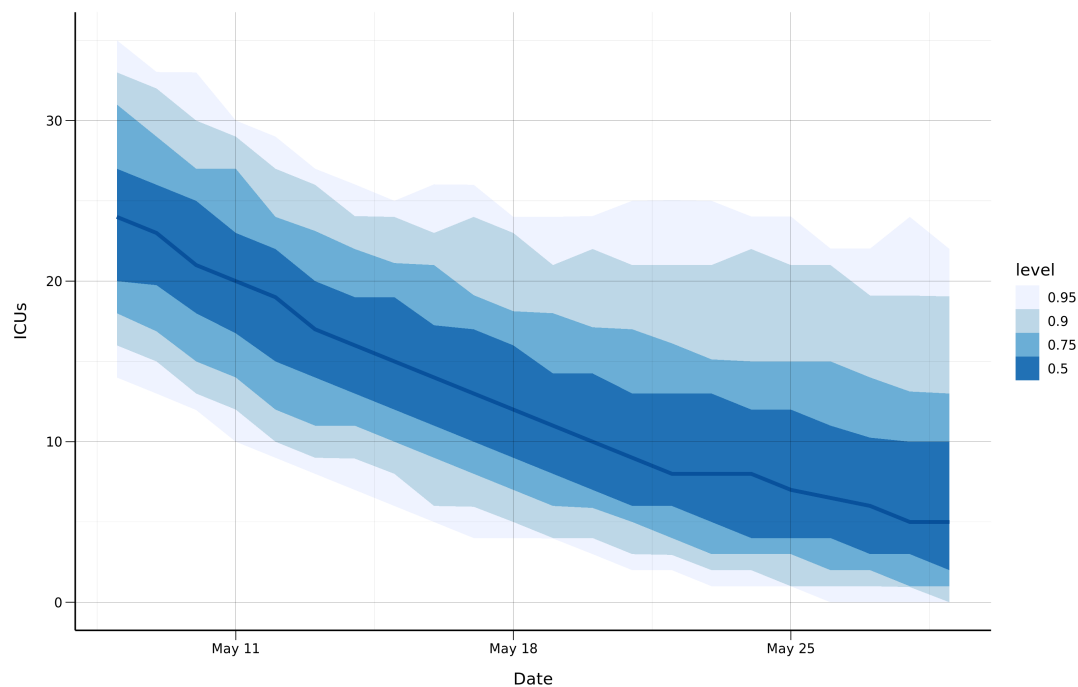
## 5 Predicted number of patients in ventilator treatment: next three weeks

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

Region	1 week prediction (15 May)	2 weeks prediction (22 May)	3 weeks prediction (29 May)
Norge	15 (6-25)	10 (2-25)	7 (0-22)
Agder	1 (0-3)	1 (0-2)	0 (0-2)
Innlandet	1 (0-4)	1 (0-3)	1 (0-3)
Møre og Romsdal	0 (0-2)	0 (0-2)	0 (0-2)
Nordland	0 (0-2)	0 (0-1)	0 (0-1)
Oslo	3 (0-6)	2 (0-5)	1 (0-3)
Rogaland	2 (0-5)	1 (0-4)	1 (0-3)
Troms og Finnmark	0 (0-2)	0 (0-2)	0 (0-1)
Trøndelag	1 (0-2)	0 (0-2)	0 (0-2)
Vestfold og Telemark	2 (0-4)	1 (0-4)	1 (0-3)
Vestland	2 (0-5)	1 (0-4)	1 (0-4)
Viken	4 (0-9)	3 (0-8)	2 (0-6)

Yesterday's real value for Norway: 16

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



Similar table and figure for each county (fylke) available on request.



## 6 Predicted prevalence of infectious individuals, next three weeks:

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

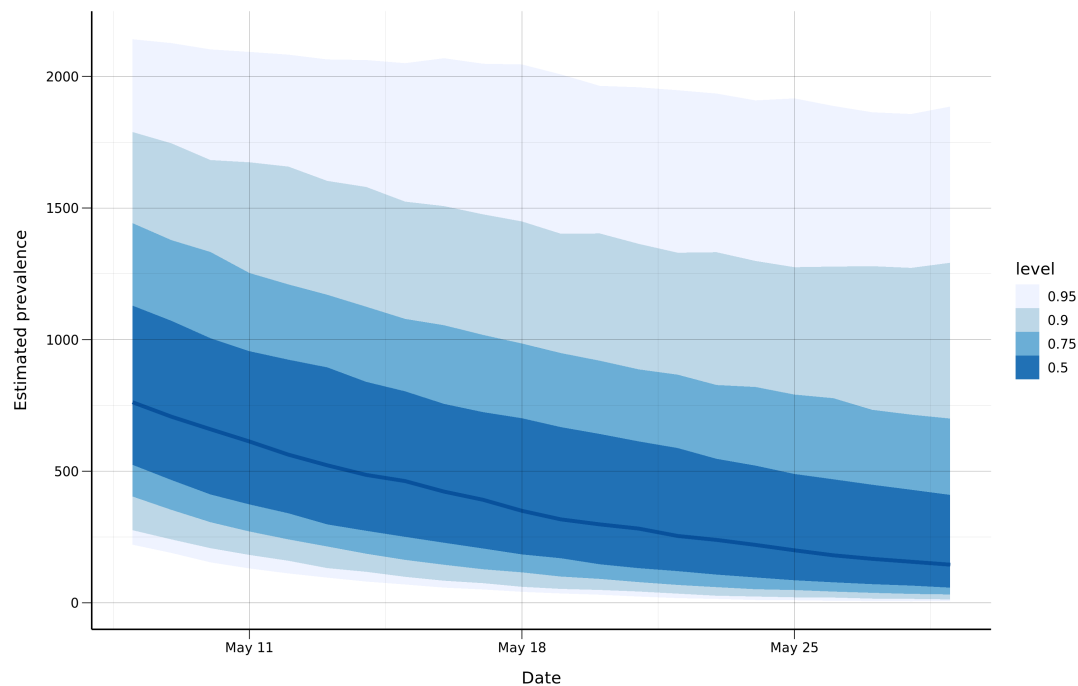
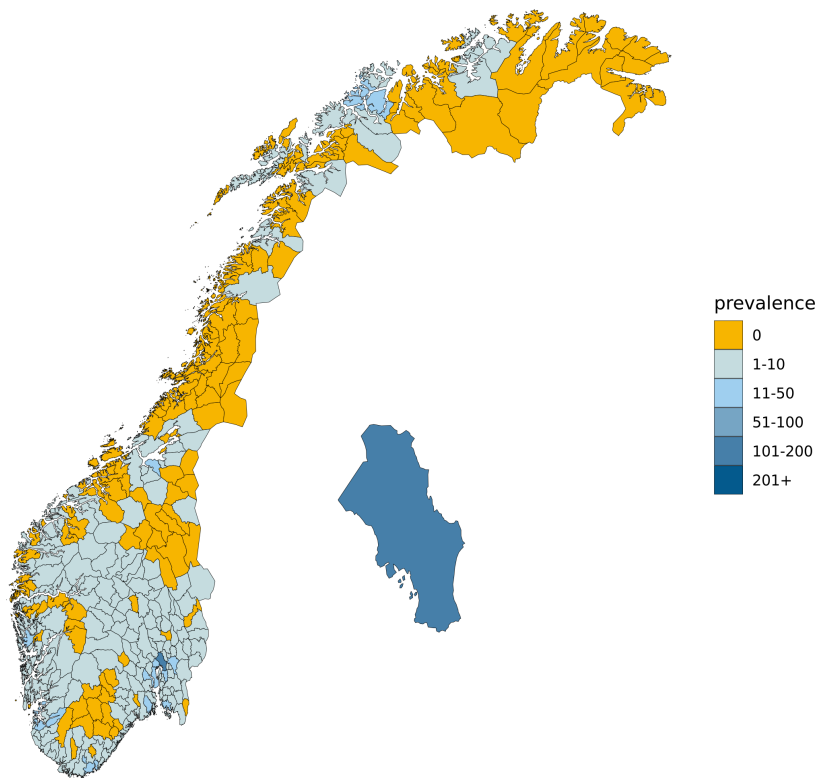


Table 6: Predicted prevalence. Number of infectious individuals (asymptomatic plus pre-symptomatic plus symptomatic) per day. Means and 95 perc. CI for three weeks prediction.

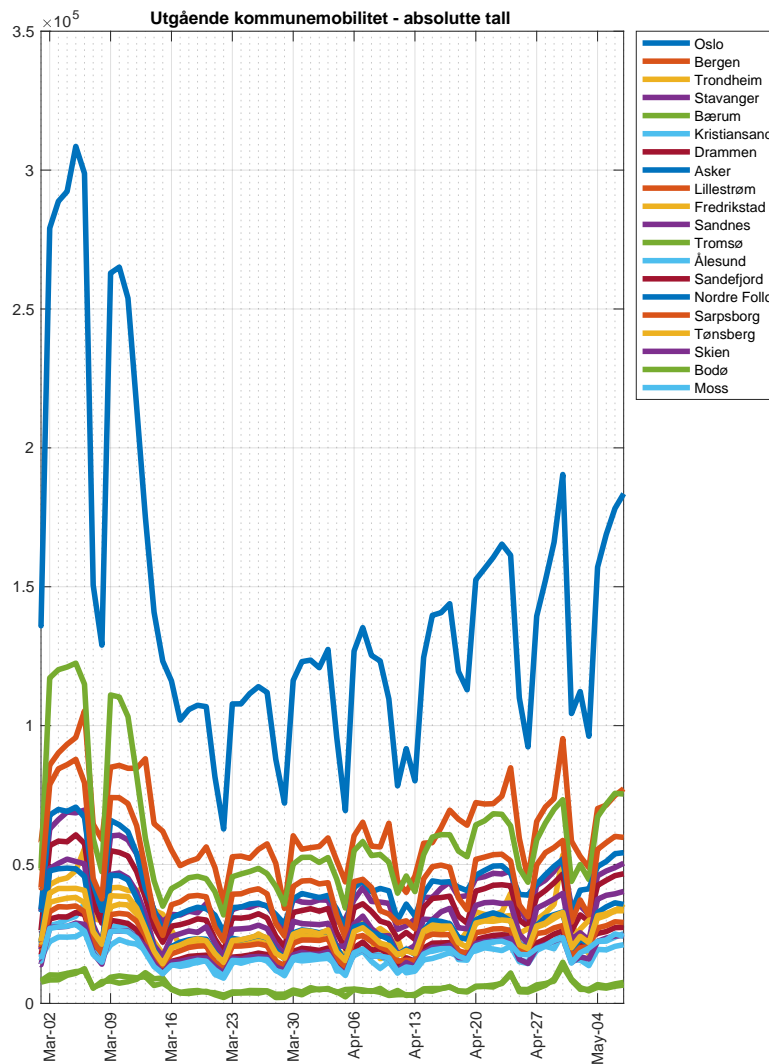
Region	Mean, 15 May	Mean, 22 May	Mean, 29 May	low CI, 29 May	high CI, 29 May
Norway	606	445	344	7	1885
Agder	39	28	21	0	104
Innlandet	45	33	26	0	135
Møre og Romsdal	14	10	9	0	50
Nordland	12	8	7	0	37
Oslo	94	69	54	1	302
Rogaland	74	54	41	1	223
Troms og Finnmark	17	13	9	0	51
Trøndelag	31	22	18	0	102
Vestfold og Telemark	51	37	29	0	153
Vestland	69	52	41	0	218
Viken	166	122	93	0	532

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.

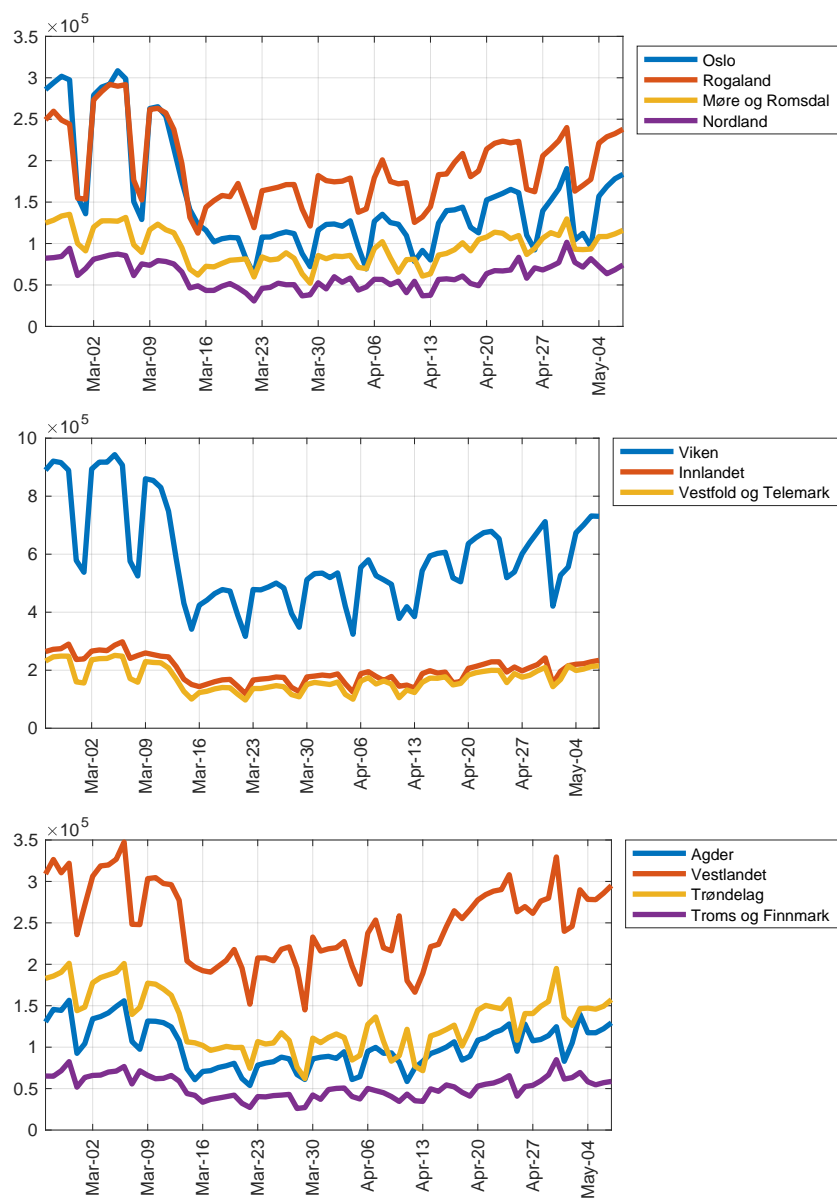


Percentage reduction in total mobility out from each municipality: Monday April 27th is compared to Monday March 2nd (last Monday before restrictions); Tuesday April 28st is compared to Tuesday March 3rd, etc. until Monday May 4th is compared to Monday March 2nd.

	Man_27	Tirs_28	Ons_29	Tors_30	Fre_01	Man_04	Tirs_05	Ons_06	Tors_07
Hele Norge	27,3%	25,3%	22,3%	15,5%	44,9%	20,4%	21,4%	19,1%	19,8%
Oslo	50,0%	47,3%	43,2%	38,3%	65,1%	43,7%	41,5%	39,0%	40,5%
Bergen	23,6%	21,6%	21,0%	0,4%	44,5%	18,2%	20,9%	19,7%	19,3%
Trondheim	29,5%	26,8%	21,0%	-11,8%	47,9%	26,4%	27,4%	26,4%	25,0%
Stavanger	32,5%	32,9%	31,0%	24,0%	50,1%	26,9%	27,9%	29,0%	26,4%
Bærum	49,8%	46,0%	42,3%	40,1%	61,8%	42,7%	40,3%	37,6%	38,5%
Kristiansand	27,8%	27,8%	26,3%	17,2%	55,5%	20,3%	22,2%	21,1%	19,9%
Drammen	32,5%	30,4%	25,4%	23,2%	54,7%	25,2%	24,2%	21,0%	23,1%
Asker	36,6%	33,7%	28,6%	26,7%	51,0%	27,3%	26,8%	22,1%	23,2%
Lillestrøm	36,7%	35,7%	34,7%	33,2%	63,2%	29,6%	31,5%	30,0%	32,0%
Fredrikstad	24,5%	23,2%	19,4%	15,1%	39,3%	15,9%	15,0%	12,0%	12,6%
Sandnes	29,4%	28,9%	27,6%	22,4%	54,2%	22,8%	22,8%	24,1%	21,1%
Tromsø	36,8%	23,3%	12,7%	-36,7%	30,1%	31,1%	35,1%	39,0%	39,0%
Ålesund	14,4%	13,9%	17,6%	-4,4%	40,2%	12,7%	19,3%	13,9%	12,1%
Sandefjord	28,5%	25,8%	19,7%	20,1%	43,6%	17,1%	17,0%	12,3%	16,4%
Nordre Follo	41,2%	36,2%	34,4%	32,1%	60,4%	31,5%	28,3%	25,6%	26,5%
Sarpsborg	23,8%	26,5%	21,7%	20,1%	49,0%	17,6%	19,7%	15,3%	17,0%
Tjønsberg	29,8%	30,1%	23,7%	20,9%	50,8%	20,4%	22,1%	18,6%	18,2%
Skien	26,6%	22,8%	19,0%	18,3%	48,1%	18,3%	14,4%	12,5%	15,4%
Bodø	35,1%	29,6%	25,5%	-16,8%	28,6%	33,9%	38,5%	34,9%	34,1%
Moss	26,6%	24,2%	18,6%	16,8%	44,2%	17,3%	17,1%	10,1%	15,0%

Percentage reduction in total mobility out from each county: Monday April 27th is compared to Monday March 2nd (last Monday before restrictions); Tuesday April 28st is compared to Tuesday March 3, etc. until Monday May 4th is compared to Monday March 2nd.

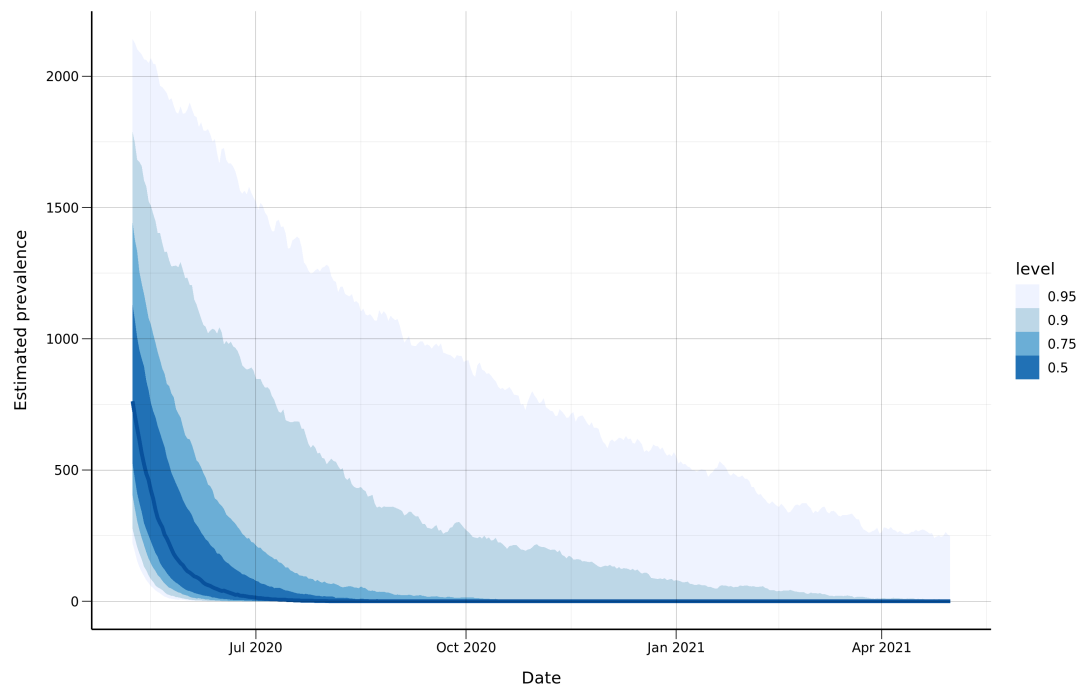
	Man_27	Tirs_28	Ons_29	Tors_30	Fre_01	Man_04	Tirs_05	Ons_06	Tors_07
Oslo	50,0%	47,3%	43,2%	38,3%	65,1%	43,7%	41,5%	39,0%	40,5%
Rogaland	24,7%	24,4%	23,3%	17,2%	44,1%	19,1%	19,3%	20,4%	17,9%
Møre og Romsdal	11,2%	11,2%	13,9%	-2,2%	29,2%	9,6%	14,8%	12,4%	8,6%
Nordland	16,0%	13,6%	10,6%	-16,3%	9,5%	10,7%	23,8%	20,6%	15,0%
Viken	32,7%	30,1%	26,3%	24,5%	53,6%	24,6%	23,6%	20,2%	22,5%
Innlandet	25,7%	22,5%	18,0%	15,3%	48,0%	17,1%	17,6%	14,4%	18,3%
Vestfold og Telemark	25,5%	23,9%	17,8%	16,7%	42,3%	15,6%	15,0%	11,6%	14,4%
Agder	19,7%	20,2%	19,4%	16,4%	46,8%	12,5%	14,3%	13,5%	13,2%
Vestlandet	14,6%	13,3%	12,5%	-0,8%	31,0%	9,1%	12,8%	10,6%	9,7%
Trøndelag	20,9%	18,9%	17,1%	-2,4%	32,4%	17,2%	20,7%	20,2%	17,3%
Troms og Finnmark	18,1%	10,5%	4,8%	-19,4%	19,8%	11,6%	17,7%	18,3%	17,5%

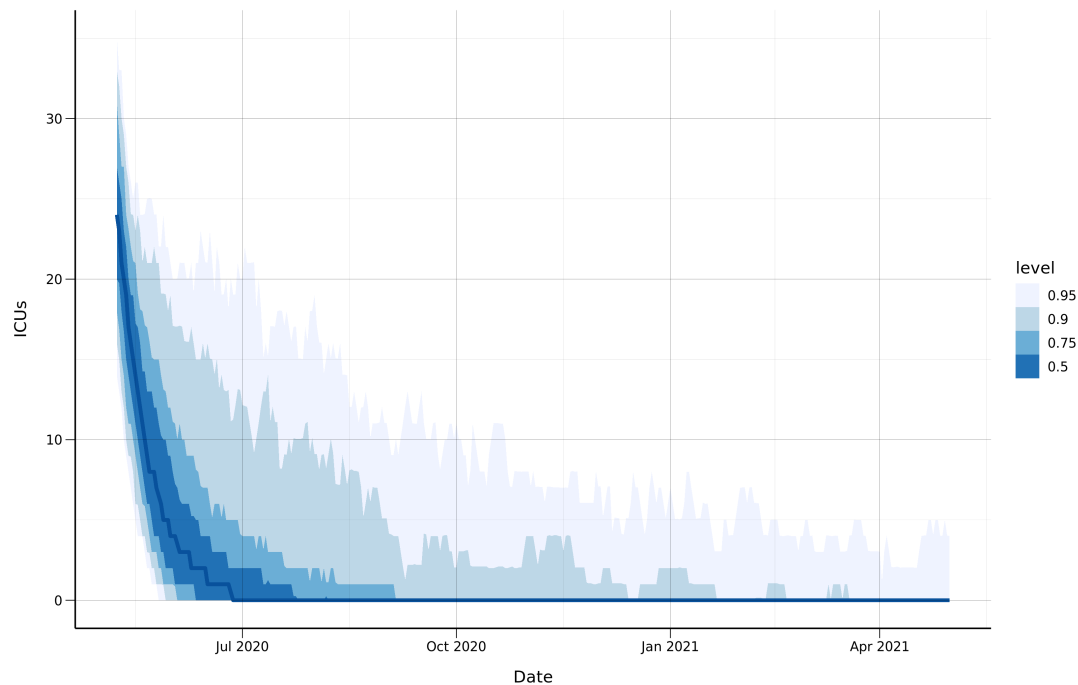
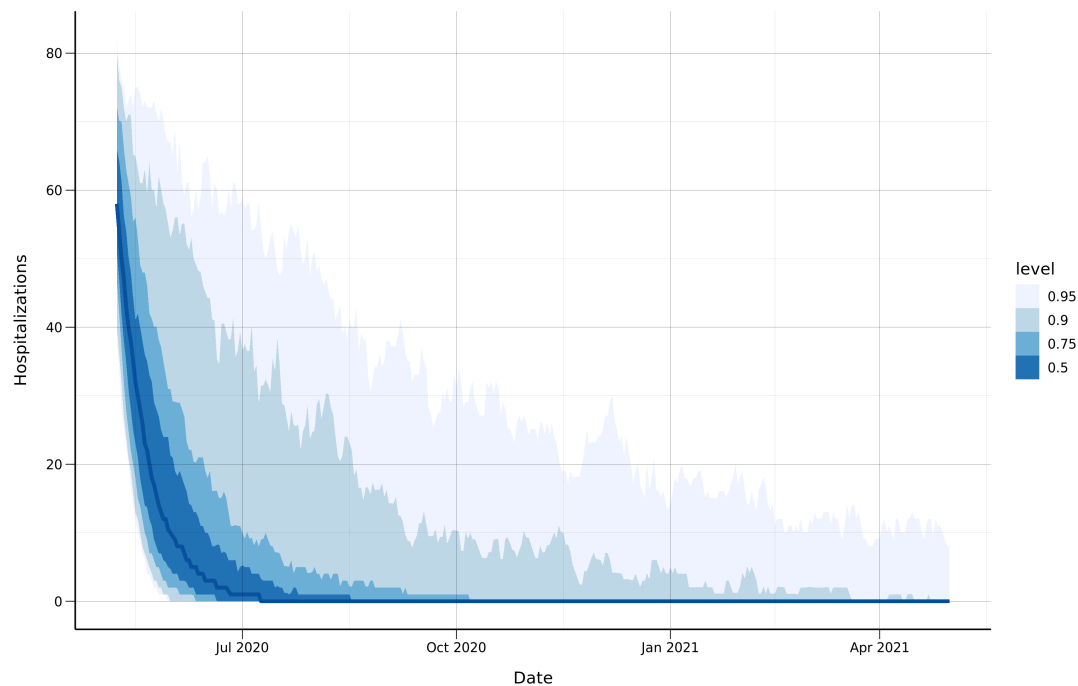


## 8 Long-term prediction results

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.

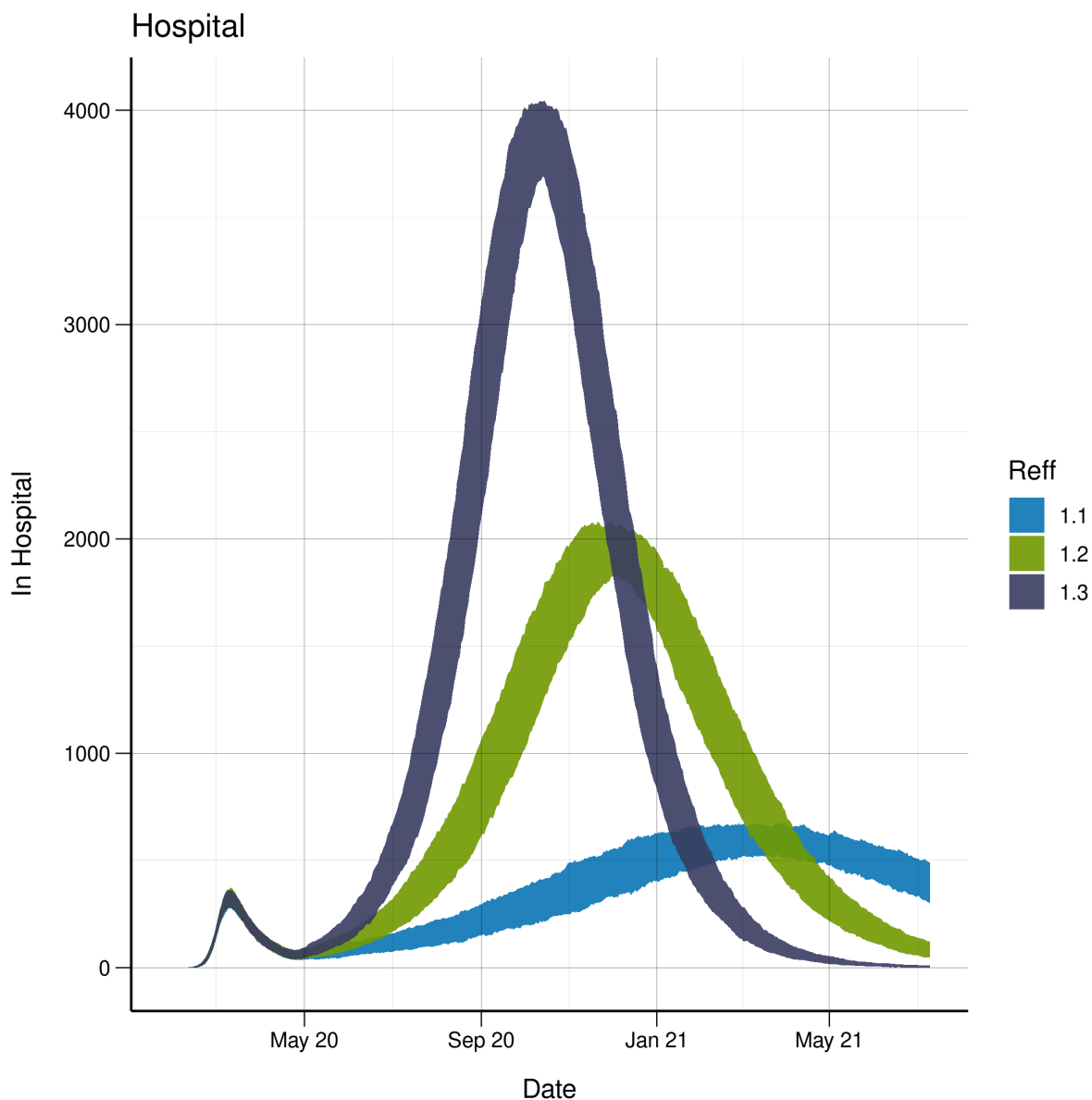




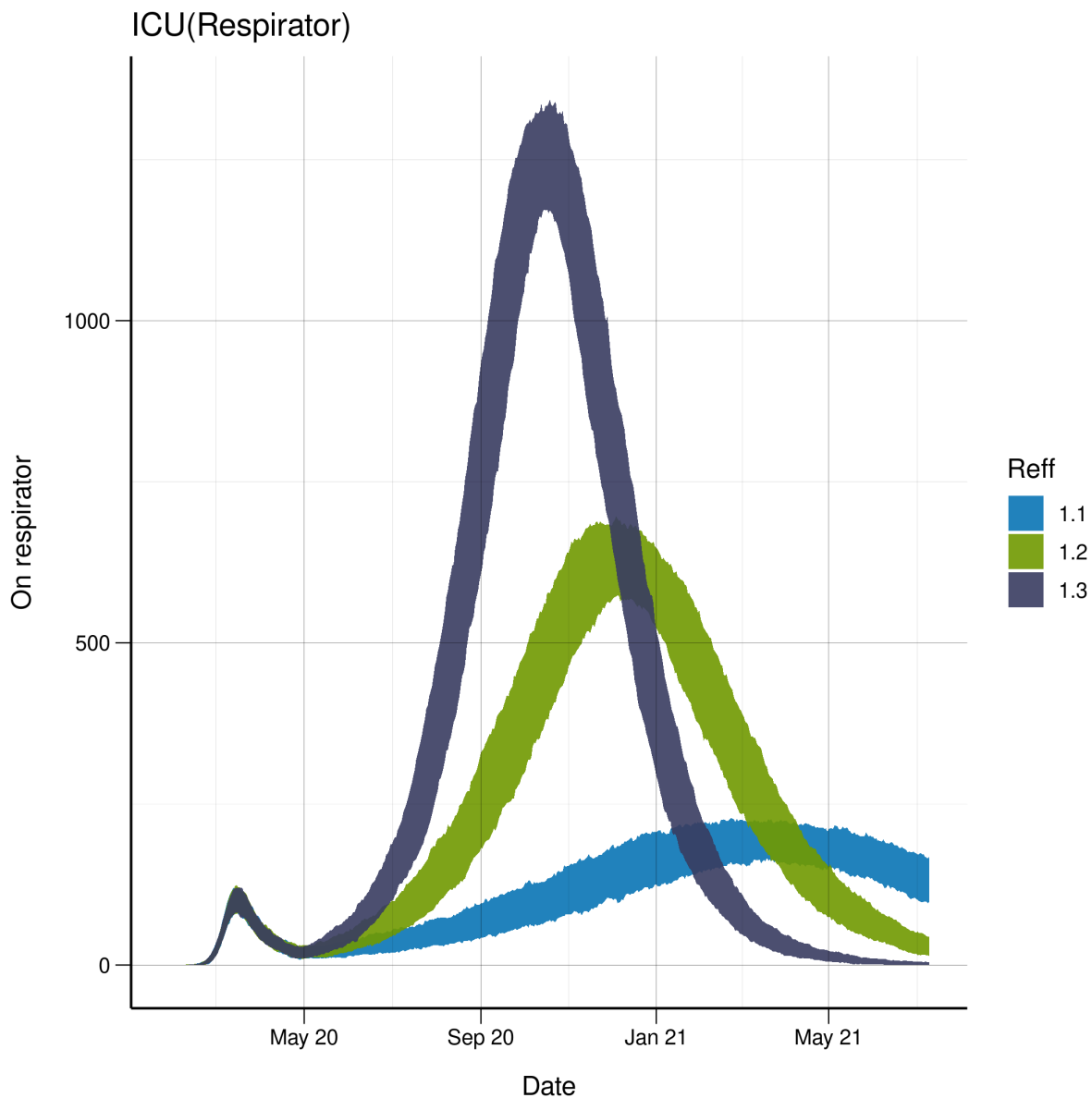
None of the simulations exceeded the surge capacity need of **1000 ICU** beds. The probability of a surge capacity need above **500 ICU** beds is **0.5 %** .

## 9 Long-term scenario results

Here we show how the epidemic will develop, from 4. May, under three assumed scenarios. We assume that until 3. May we follow our estimated reproductions numbers, but from 4. May 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	917.000(882.000 - 948.000)	1.680.000(1.660.000 - 1.700.000)	2.270.000(2.260.000 - 2.290.000)
Total Hospital	17.900(17.200 - 18.500)	32.000(31.600 - 32.400)	43.000(42.600 - 43.400)
Total on respirator	5.150(4.930 - 5.370)	9.260(9.090 - 9.450)	12.400(12.300 - 12.600)
Ward <sup>1</sup> at Peak	444(410 - 477)	1.380(1.310 - 1.440)	2.690(2.600 - 2.780)
Hospital <sup>2</sup> at Peak	642(598 - 696)	2.010(1.900 - 2.110)	3.940(3.810 - 4.070)
Respirator at Peak	218(200 - 237)	664(630 - 703)	1.290(1.230 - 1.350)

<sup>1</sup>In hospital not on respirator

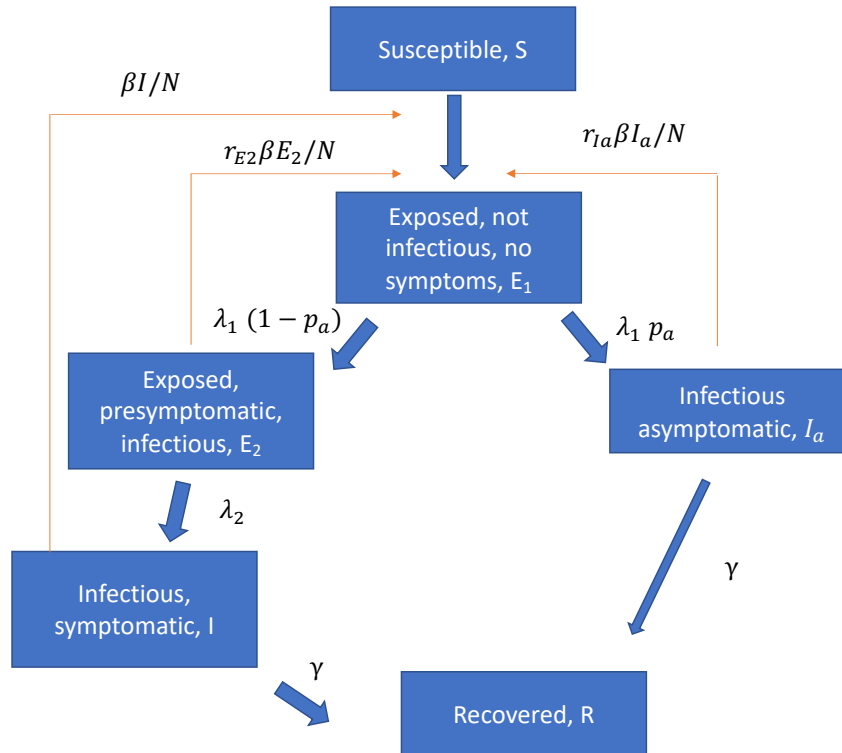
<sup>2</sup>Includes both patients receiving respiratory treatment and patients who do not.

## 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 (E<sub>2</sub>), Symptomatic infected (I), Asymptomatic infected (I<sub>a</sub>), 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  $\beta$ . 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)<sup>3</sup>. 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 change point in the reproduction numbers, so that  $R_1$  is active until 19 April and  $R_2$  from 20 April. This is the day the kindergarten reopened. On 27 April also part of primary school reopened, and we will see if a further change point will be useful to fit the data best.

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<sup>3</sup><https://www.medrxiv.org/content/10.1101/2020.03.11.20033555v1>

## Parameters used today

Table 7: Assumptions I

Assumptions	Mean	Distribution	Reference
<b>Seeding</b>			
Scaling factor on imported cases	Min. 1.32 1st Qu. 1.99 Median 2.25 Mean 2.26 3rd Qu. 2.51 Max. 3.19	random	Calibrated to hospitalizations
Telenor coverage	48%		<a href="https://ekomstatistikken.nkom.no/">https://ekomstatistikken.nkom.no/</a>
<b>Model parameters</b>			
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. 2.68 1st Qu. 2.99 Median 3.09 Mean 3.13 3rd Qu. 3.26 Max. 3.68	random	Calibrated to hospitalizations
$R_1$ , from 15 March until 19 April	Min. 0.61 1st Qu. 0.65 Median 0.67 Mean 0.67 3rd Qu. 0.68 Max. 0.74	random	Calibrated to hospitalizations
$R_2$ , from 20 April until today	Min. 0.0028 1st Qu. 0.33 Median 0.47 Mean 0.49 3rd Qu. 0.63 Max. 1.17	random	Calibrated to hospitalizations

Table 8: Assumptions II

Assumptions	Mean	Distribution	Reference
<b>Healthcare</b>			
Time sympt. onset to hospitalisation	8 days	Poisson	
Fraction asymptomatic infections	40%	Fixed	<a href="#">Mizumoto et al 2020</a> 20% for the old population, Diamond Princess
% symptomatic and asymptomatic infections requiring hospitalization:			<a href="#">Verity et al 2020</a> corrected for: % of elderly living in of elderly living in Norway (last two age groups). Also corrected by 1/3 to account for severity in comparison with the expected fatality rate.
0-9 years	0.00%	Fixed	
10 - 19 years	0.013%		
20 - 29 years	0.37%		
30 - 39 years	1.13%		
40 - 49 years	1.43%		
50 - 59 years	2.73%		
60 - 69 years	3.93%		
70 - 79 years	5.53%		
80+ years	5.33%		
% hospitalized patients requiring ICU			
0-9 years	5%	Fixed	<a href="#">Verity et al 2020</a>
10 - 19 years	5%		
20 - 29 years	5%		
30 - 39 years	5%		
40 - 49 years	6.3%		
50 - 59 years	12.2%		
60 - 69 years	27.4%		
70 - 79 years	43.2%		
80+ years	70.9%		
Overall hospitalization risk	1.9%	Fixed	<a href="#">Verity et al 2020</a> (adapted to Norwegian population)
Normal hospitalization length	8 days	Poisson	<a href="#">Ferguson et al 2020</a>
Time in hospital before ICU	4 days	Poisson	<a href="#">Ferguson et al 2020</a> , Expert opinion
Time in ICU	12 days	Poisson	<a href="#">Ferguson et al 2020</a> , Expert opinion
<b>Mobile phone mobility</b>			
Until May 7	Measured Telenor mobility		
Data used in the predictions	May 7	Fixed	Corrected to preserve population

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## Supplementary analysis:

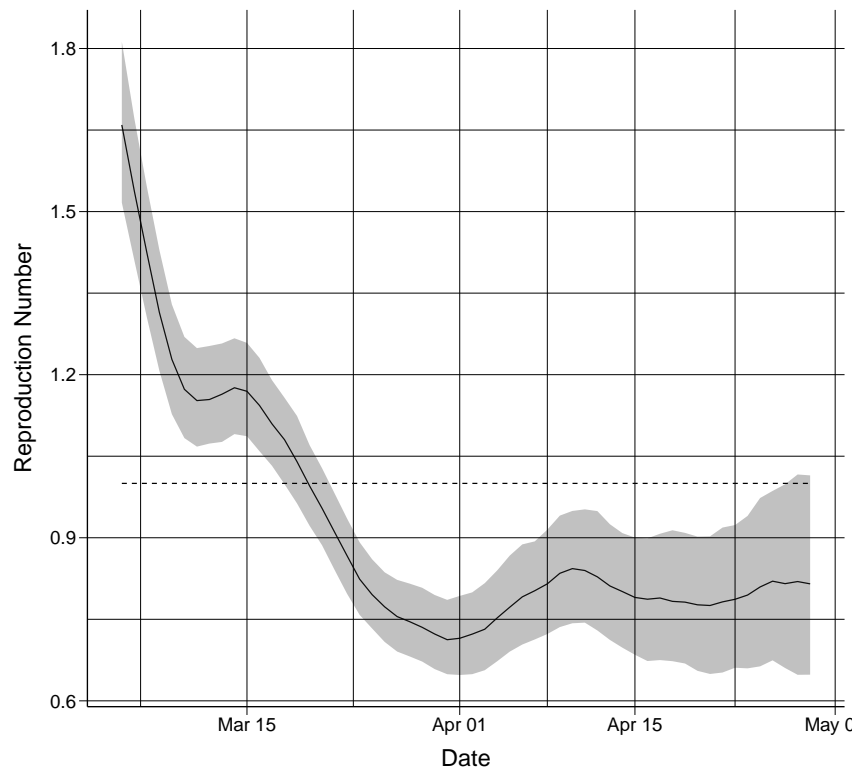
### Instantaneous reproduction number based on lab-confirmed cases

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.





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