NIPH
Norwegian Institute of Public Health

Situational awareness and forecasting

FHI COVID-19 modelling team

12 October 2020

Highlights from this report:

- Our models evaluate the present situation as relatively stable. The reproduction number acting from September 1 is estimated to be 1.08 (median), with a 95% confidence interval (0.66 - 1.51). Compared to a week ago, the estimated reproduction number is similar, with less uncertainty. The estimated probability that the reproduction number R_6 is larger than 1 is 60 %.
- The hospitalisation incidence is subject to a reporting delay, meaning that in the data we have today, the incidence for the last couple of days is under-reported and updated only a few days later. The delay in reporting is likely stronger during the weekends. We therefore correct for the reporting delay in our simulations, by imputing the number of missing hospitalisations. This is done by using the information about the delay from the past data. In this way, we avoid that our estimates are biased downwards because of this reporting delay. Details are provided at the end of the report.
- The model estimates the total number of infected individuals to be between 80.000 and 110.000, with a mean of ca. 94.000. In one week, the number of new cases per day is ca 400 (median) and will remain at that level in three weeks. The uncertainty is, however, increasing. The predicted number of infected individuals in a week is about 2 500 (median) with substantial uncertainty.
- The SMC model estimates the 7-days averaged reproduction number two weeks ago to be 1.24 (0.59-2.03); the estimated probability that the daily reproduction number two weeks ago was larger than 1 is 69%. This is in good correspondence with the change point model.
- The probability that the total number of new infections exceeds 20 per 100.000 is increasing, and is above 90% in all counties except Troms og Finnnmark.
- Hospitalisation is expected to increase slightlyand we expect 56 (median) covid19 patients to be in hospital in a week. Our model currently overestimates the number of COVID-19 patients in hospital and the number of these requiring ventilation treatment. We are working on this aspect.
- Long term predictions for the next 12 months, assuming that the reproduction number R_6 remains as now, show a likely hospitalisation peak in the spring next year. The probability that more than 500 patients need ventilator treatment at the peak is estimated to be 18% (and 5% for more than 1000).
- Inter-municipality mobility, measured as mobility of Telenor mobile phones out from each municipality is increasing compared to the last week, in most counties.
- Caveat on results per county in this report: as usual, this national report uses aggregated hospitalisation data to estimate common reproduction numbers for the whole of Norway. The total number of infected individuals, hospitalised individuals and individuals requiring ventilator treatment are then distributed to the various counties in the model simulations through use of the Telenor mobility data and age-structured demography of every municipality. The results on county level are

therefore different from the ones in our regional report, where we assume that reproduction numbers can vary between counties, and where we estimate them using county-specific hospitalisation incidence data. We will therefore soon merge the two reports, to avoid confusion.

- Since the last report we have updated the hospitalisation parameters (time to hospitalisation, length of stay, etc.) based on more recent data. In particular, we introduced a changepoint in the hospitalisation parameters on 1 April, where the data before and after 1 April are used to estimate the different parameters. The new parameters are provided at the end of the report, Figure 21 and 22.

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 yesterday. We seed the model with infections imported to Norway from February 26 until yesterday.

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 the 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 October 3^{rd}. 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 six 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 May 10.
- R_3 active from May 11 until June 30.
- R_4 active from July 1 until July 31.
- R_5 active in August.

- R_6 active from September 1

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

The basic reproductive numbers are calibrated to hospital incidence data until yesterday. Estimates of all reproduction numbers 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 weeks 11 and 17, imply that the 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 to hospitalisation data leads to the following estimates (figure 1 and table 1):

Table 1: Calibration results

Parameter	Mean	Median	Confidence interval (95 %)
Amplification factor	4.60	4.55	(2.72-6.91)
R0	3.48	3.47	(2.62-4.36)
R1	0.55	0.54	(0.47-0.64)
R2	0.52	0.53	(0.19-0.91)
R3	0.85	0.87	(0.47-1.2)
R4	0.71	0.68	(0.05-1.43)
R5	0.78	0.78	(0.3-1.28)
R6	1.08	1.08	(0.66-1.51)

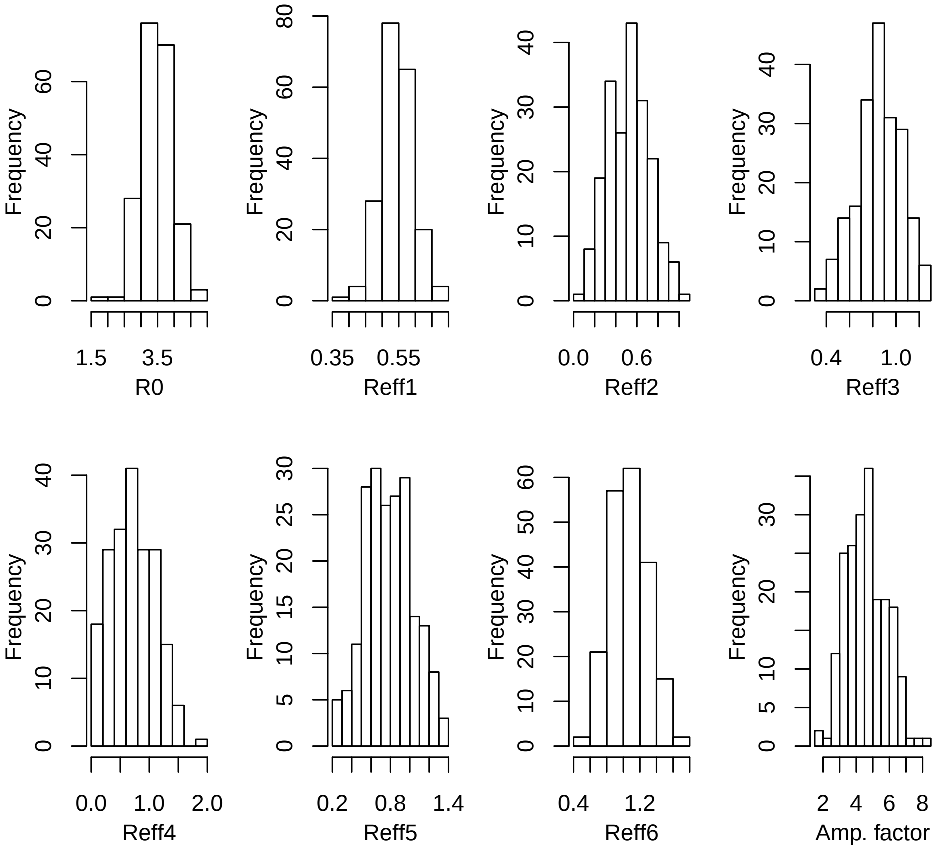


Figure 1: Estimated densities of the eight parameters.

Our changepoint model estimates the number of COVID-19 patients admitted daily to hospitals, plotted in figure 2 with blue median and interquartile bands, which are compared to the actual true data, provided 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.

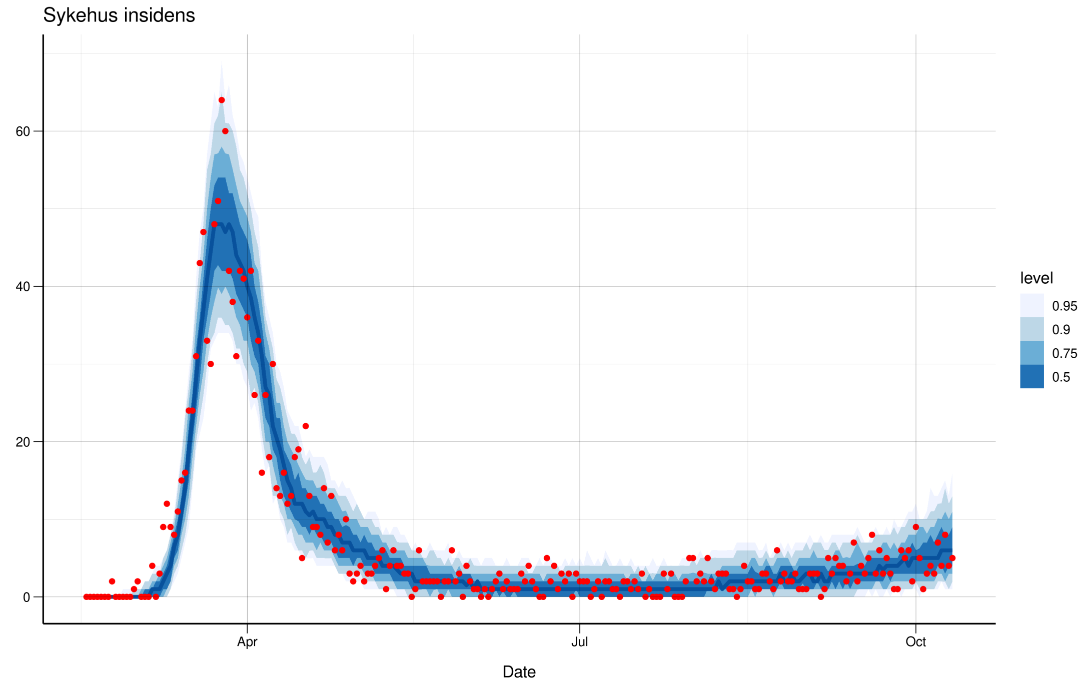


Figure 2: True total number of hospital admissions (red) and predicted values (blue)

In figure 3, we show how our model fits the hospital prevalence data, which are not used to estimate the parameters, and can therefore be seen as a validation of the model assumptions.

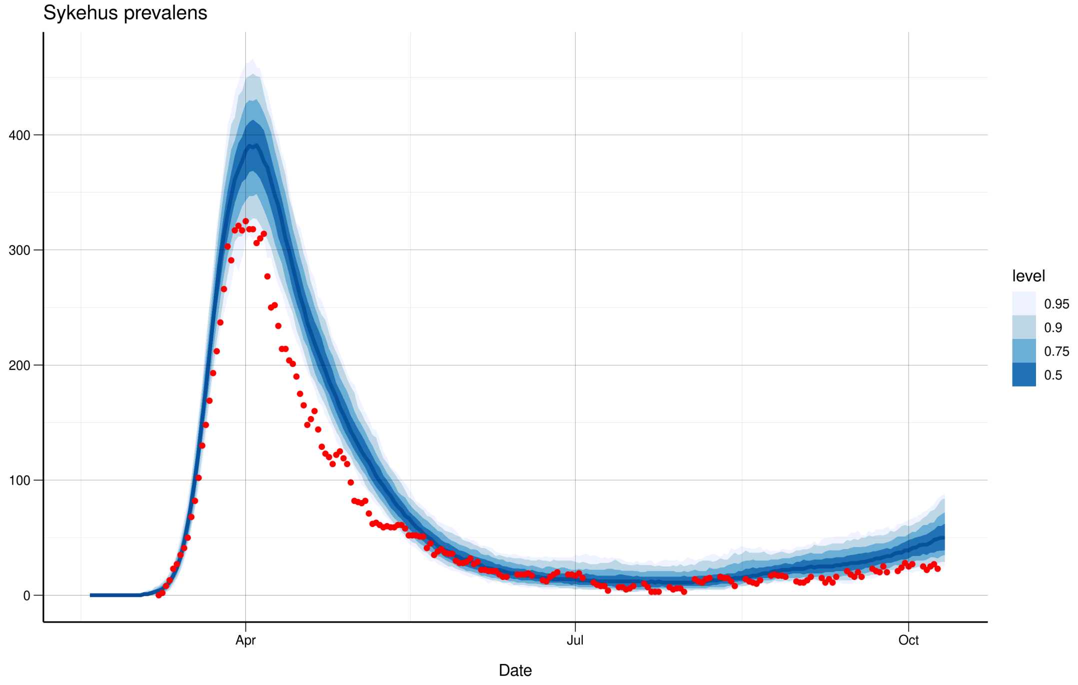


Figure 3: True total number of hospitalisations (red) and predicted values (blue)

Finally, in figure 4 we compare the true daily number of patients receiving ventilator treatment (red) with the model estimates (blue).

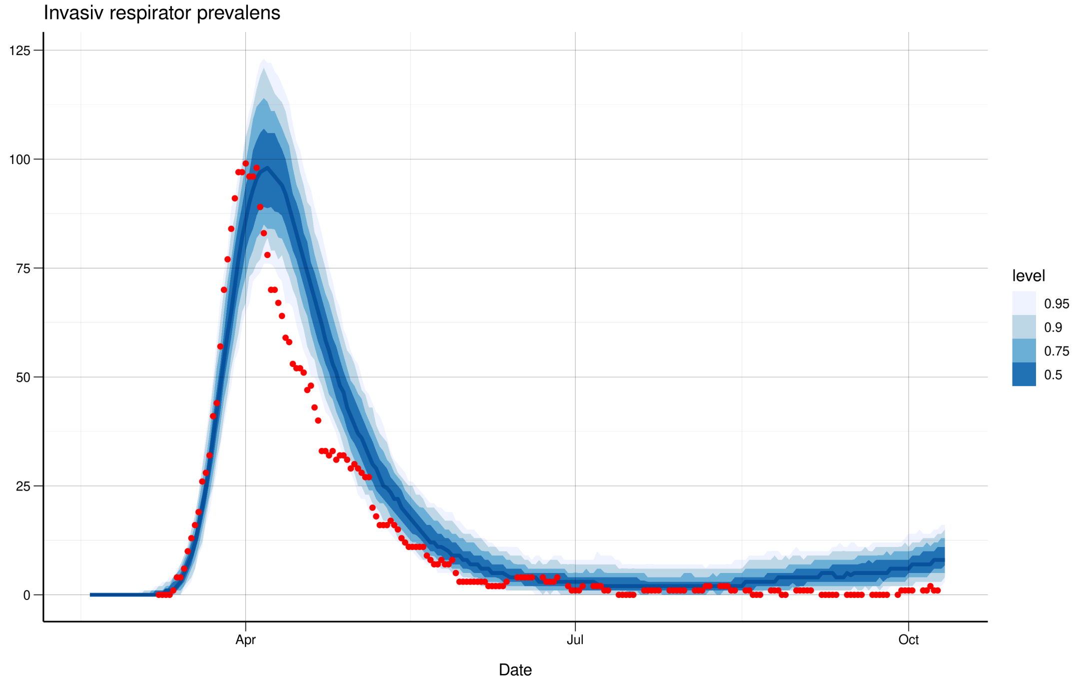


Figure 4: True total number on ventilator (red) and predicted values (blue)

1.1 Time varying reproduction number

We introduce a new model of the Norwegian COVID-19 pandemic, which is based on Sequential Monte Carlo, and is therefore called the SMC model. We allow for a daily varying reproduction number, so that we estimate a different reproduction number for each day t. In order to reduce spurious fluctuation, we report a 7-days moving average, so that $R(t)$ represents the average reproduction number for the whole week before day t. Until March 8 we keep the reproduction number constant. (The SEIR model remains unchanged, except for the daily reproduction number, which replaces the piece-wise constant reproduction number assumed before.) By assuming a time varying reproduction number $R(t)$, we can detect changes without having to introduce explicit changepoints, which means that we can easier detect unexpected changes. However, this model requires additional parameters to be estimated, one per day. Estimating all these parameters is a difficult task, which we solve by using a method called Sequential Monte Carlo, see the Methods section at the end for details.

As for the changepoint model, we use hospitalisation incidence data to estimate all parameters. A patient hospitalised today was infected on average two weeks ago. Hence, hospitalisation data of today carry mainly information about the transmissibility 14 days ago. The estimated reproduction number of 14 days ago is thus the last one which is based on sufficient data. The estimated reproduction numbers of the days thereafter are based on diminishing information, and in particular there are no data to inform the reproduction number of today. Therefore, the uncertainty of the estimates of the reproduction numbers for the last 14 days is very large. This is also true for the reported 7-day-average reproduction numbers R_t. In the changepoint model, we are keeping the reproduction number constant after the last change point. In this way, there are more hospitalisation data points to inform the estimate of R_6. For this reason, the confidence intervals were more narrow.

The figure below shows the SMC estimate of the 7-day-average daily reproduction number $R(t)$ until today. We observe that $R(t)$ dropped below 1 in the middle of March, corresponding to the lockdown. It remained stable around 0.5 until the end of April, when it increased to 1 in the beginning of May. It then kept oscillating below and above 1, in accordance with increases and decreases of the number of new hospitalisations. $R(t)$ is sensitive to these oscillations in the data. An increase in hospital admissions indicates a daily reproduction number (14 days before on average) above 1. A decrease in hospital admissions suggests that the reproduction number was below 1 (again 14 days prior). In the figure we plot the 95% confidence interval and several quantiles of the estimated posterior distribution of $R(t)$.

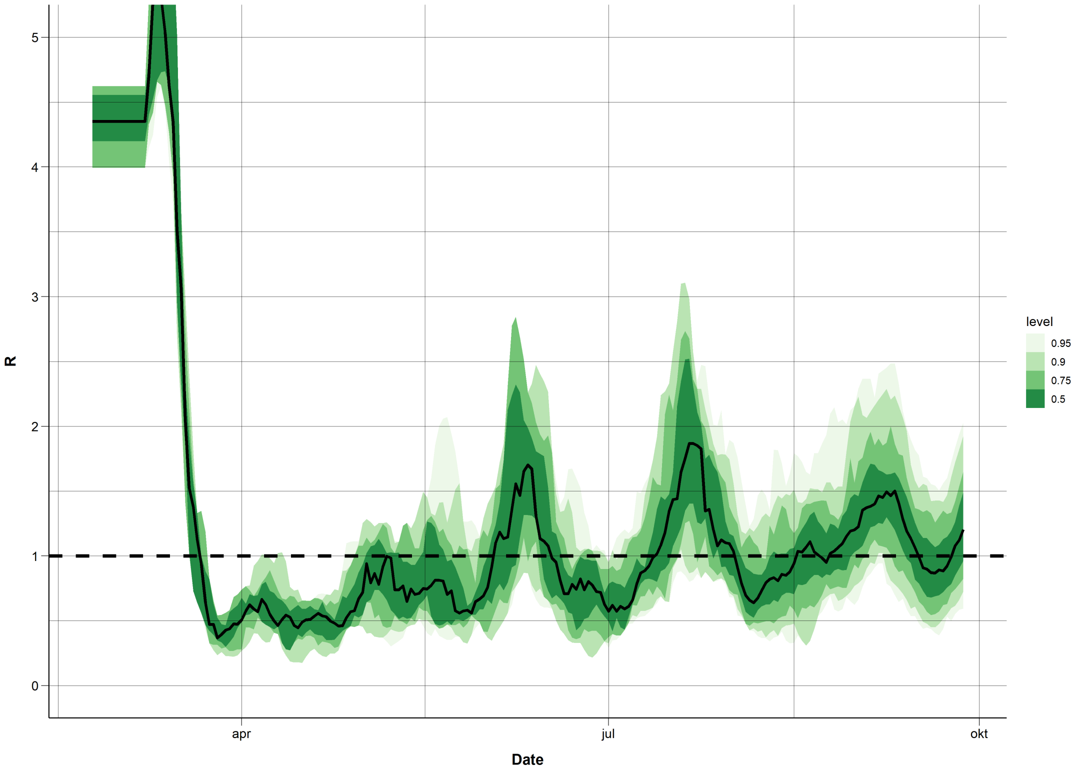


Figure 5: R(t) estimates until 14 days ago using a Sequential Monte Carlo (SMC) approach calibrated to incidence data. The large uncertainty during the last 14 days reflects the lack of available data due to the time period between infection, symptoms onset and hospitalisation. Therefore we omit the plot of the last 14 days. The green band shows the 95% posterior confidence interval.

2 Estimated cumulative number of infected individuals

The changepoint model estimates both the total number of infections and the symptomatic cases that have occurred both nationally and in each county. This result together with number of true confirmed cases can be found in table 2.

Table 2: Estimated cumulative number of infections, 2020-10-11

Region	Total	Symptomatic	No. confirmed	Fraction reported	Min. fraction
Norway	94081 (79241; 110421)	60815 (51584; 70523)	15524	17%	14%
Agder	6471 (5240; 8085)	4142 (3358; 5030)	551	9%	7%
Innlandet	8773 (7390; 10215)	5647 (4674; 6551)	732	8%	7%
Møre og Romsdal	4679 (3654; 5900)	3057 (2263; 3834)	301	6%	5%
Nordland	2701 (2079; 3745)	1767 (1337; 2412)	225	8%	6%
Oslo	13596 (11045; 16519)	8524 (6979; 10156)	5072	37%	31%
Rogaland	12296 (9798; 15038)	7845 (6333; 9374)	793	6%	5%
Troms og Finnmark	5380 (3170; 10414)	3462 (2138; 6392)	398	7%	4%
Trøndelag	6234 (4946; 7531)	4069 (3231; 4930)	734	12%	10%
Vestfold og Telemark	6974 (5662; 8379)	4529 (3623; 5454)	485	7%	6%
Vestland	8499 (6693; 10626)	5487 (4472; 6767)	2006	24%	19%
Viken	18479 (15163; 21966)	12285 (9908; 14434)	4226	23%	19%

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

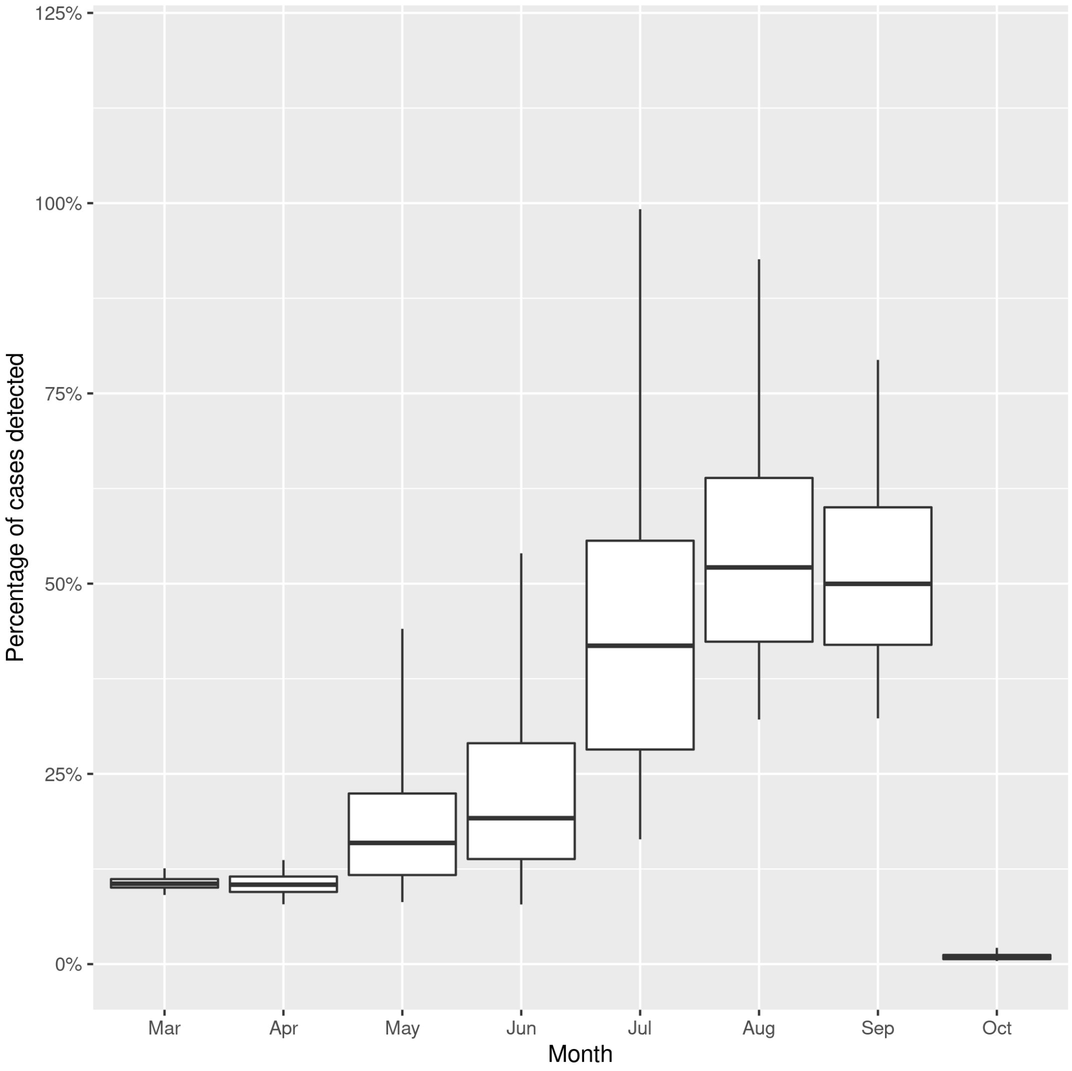


Figure 6: Percentage of cases detected through testing according to the model over time. The randomness shown in the 95% confidence intervals accounts only for the uncertainty in the parametrisation of the model. The confidence intervals do not account for the uncertainty about the infection rate. Test results are also prone to mistakes, which are not modelled here. The results should be interpreted with caution.

3 Predicted incidence of infected individuals, next three weeks

The changepoint model is used to predict the total number of infections (asymptomatic and symptomatic), see figure 7 and table 3.

Table 3: Predicted incidence per day: Median/Mean (CI)

Region	1 week prediction (18 Oct)	2 weeks prediction (25 Oct)	3 weeks prediction (01 Nov)
Norway	407/522 (66-1768)	425/625 (48-2585)	437/766 (34-3741)
Agder	27/33 (4-117)	26/39 (2-151)	25/47 (2-239)
Innlandet	26/35 (2-130)	29/43 (4-210)	29/54 (2-299)
Møre og Romsdal	16/21 (2-57)	17/25 (1-88)	17/31 (1-130)
Nordland	12/18 (1-56)	14/22 (0-91)	14/28 (0-139)
Oslo	54/71 (9-249)	53/85 (5-350)	58/105 (4-525)
Rogaland	44/59 (7-209)	45/69 (4-296)	46/84 (4-422)
Troms og Finnmark	10/16 (1-58)	12/20 (0-77)	12/23 (0-111)
Trøndelag	30/39 (4-131)	32/48 (3-191)	34/57 (2-258)
Vestfold og Telemark	32/42 (5-161)	35/50 (3-249)	38/63 (2-306)
Vestland	43/59 (5-197)	44/70 (4-306)	46/87 (3-428)
Viken	105/141 (16-493)	108/166 (10-714)	117/201 (10-971)

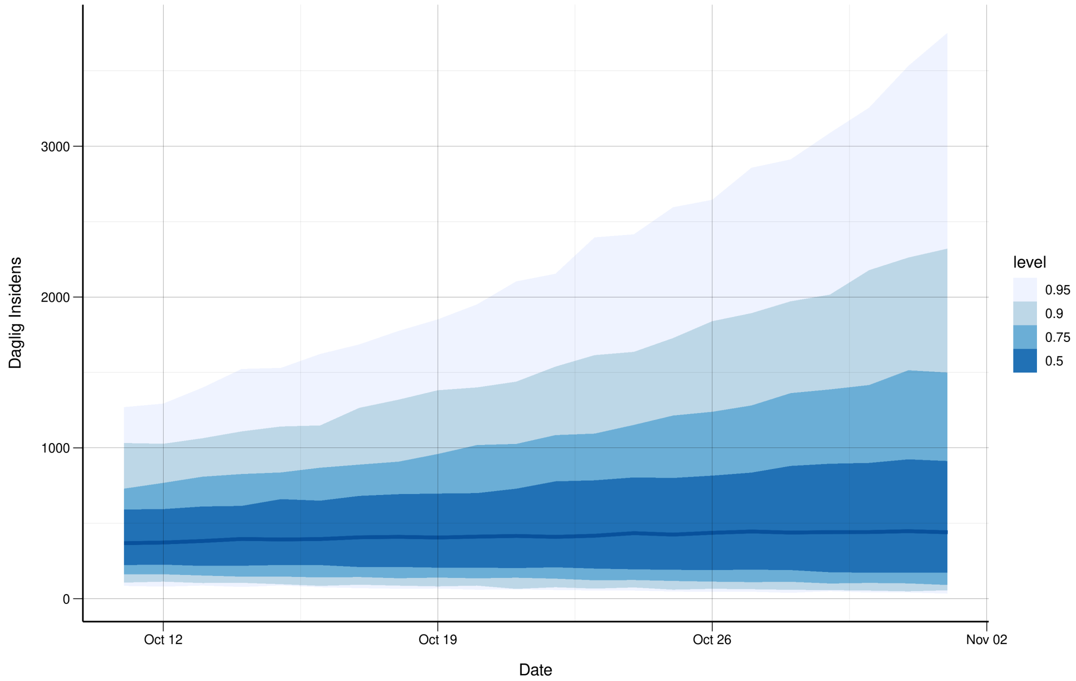


Figure 7: Predicted incidence (asymptomatic and symptomatic) for Norway per day, with confidence intervals.

The table 4 shows the probability that the bi-weekly cumulative incidence for each county exceeds 20 cases per 100.000 population.

Table 4: Probability of exceeding 20 cases per 100.000 population as cumulative incidence during the next two weeks according to our simulations.

County	Prob. exceeding 20 cases per 100.000 population
Agder	0.98
Innlandet	0.95
Møre og Romsdal	0.95
Nordland	0.90
Oslo	0.96
Rogaland	0.98
Troms og Finnmark	0.84
Trøndelag	0.94
Vestfold og Telemark	0.95
Vestland	0.95
Viken	0.97

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

The changepoint model is used to predict the daily number of COVID-19 patients in hospital in Norway (95% confidence intervals and interquartile range), next three weeks, including patient's ventilator treatment, see figure 8 and table 5.

Table 5: Number of hospitalisation beds occupied by Covid-19 patients: Median/Mean (CI)

Region	1 week prediction (18 Oct)	2 weeks prediction (25 Oct)	3 weeks prediction (01 Nov)
Norge	56/62 (19-134)	64/73 (16-208)	65/85 (16-282)
Agder	3/4 (0-13)	4/5 (0-13)	3/5 (0-18)
Innlandet	4/5 (0-14)	4/5 (0-17)	5/6 (0-21)
Møre og Romsdal	2/2 (0-8)	2/3 (0-12)	2/4 (0-13)
Nordland	1/2 (0-8)	2/3 (0-9)	2/3 (0-11)
Oslo	8/10 (2-24)	9/11 (1-29)	9/12 (1-39)
Rogaland	6/7 (1-19)	6/8 (0-25)	7/9 (0-36)
Troms og Finnmark	1/2 (0-7)	1/2 (0-9)	2/3 (0-11)
Trøndelag	3/4 (0-13)	5/5 (0-18)	5/6 (0-20)
Vestfold og Telemark	5/5 (0-15)	5/6 (0-19)	6/7 (0-29)
Vestland	5/6 (0-16)	6/8 (0-24)	7/9 (0-34)
Viken	13/14 (2-36)	14/18 (1-55)	16/21 (2-86)

Yesterday's real value for Norway: 23

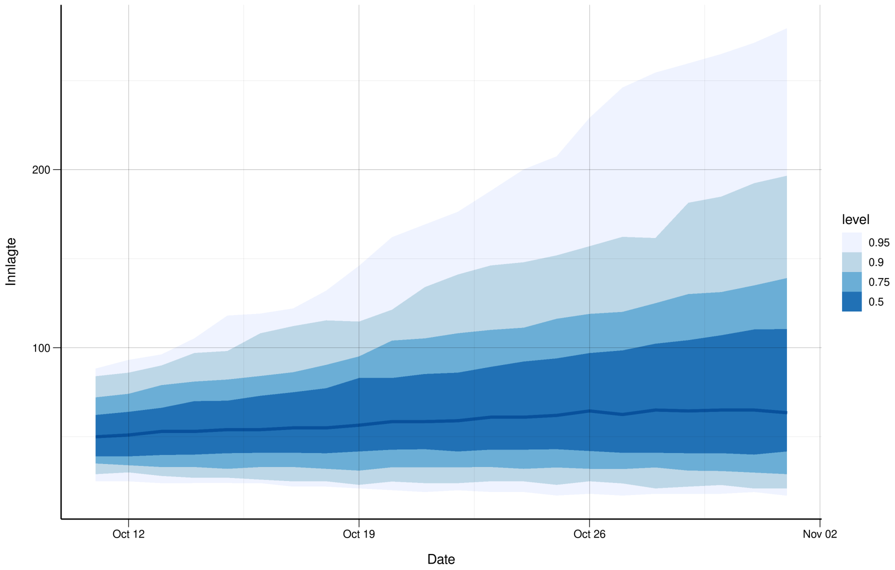


Figure 8: Predicted daily number of COVID-19 patients in hospital in Norway (95% confidence intervals and interquartile range), next three weeks, including patients ventilator treatment.

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

The changepoint model is used to predict the daily number of COVID-19 patients needing ventilator treatment in Norway (95% confidence intervals and interquartile range), the next three weeks, see figure 9 and table 6.

Table 6: Number of ICU beds occupied by Covid-19 patients: Median/Mean (CI)

Region	1 week prediction (18 Oct)	2 weeks prediction (25 Oct)	3 weeks prediction (01 Nov)
Norge	10/10 (3-22)	11/12 (3-28)	12/14 (2-38)
Agder	0/1 (0-3)	1/1 (0-3)	0/1 (0-3)
Innlandet	1/1 (0-3)	1/1 (0-4)	1/1 (0-4)
Møre og Romsdal	0/0 (0-2)	0/1 (0-3)	0/1 (0-3)
Nordland	0/0 (0-2)	0/0 (0-2)	0/0 (0-2)
Oslo	1/2 (0-4)	2/2 (0-5)	2/2 (0-6)
Rogaland	1/1 (0-4)	1/1 (0-5)	1/2 (0-5)
Troms og Finnmark	0/0 (0-2)	0/0 (0-2)	0/0 (0-2)
Trøndelag	0/1 (0-3)	1/1 (0-3)	1/1 (0-4)
Vestfold og Telemark	1/1 (0-3)	1/1 (0-4)	1/1 (0-4)
Vestland	1/1 (0-3)	1/1 (0-5)	1/2 (0-5)
Viken	2/2 (0-6)	2/3 (0-7)	3/3 (0-12)

Yesterday's real value for Norway: 1

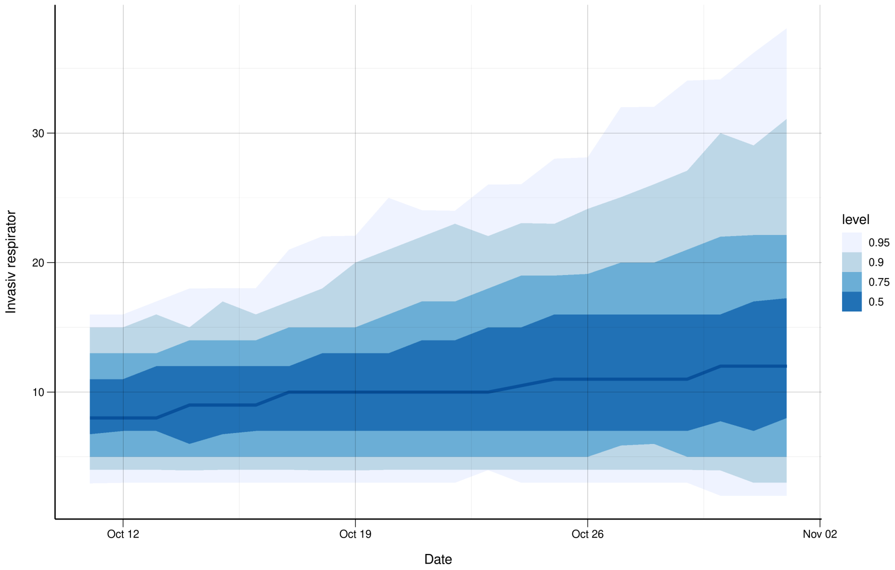


Figure 9: Predicted daily number of COVID-19 patients in ventilator treatment in Norway (95% confidence intervals and interquartile range), next three weeks.

6 Predicted prevalence of infectious individuals, next three weeks:

The changepoint model is used to predict the daily prevalence of asymptomatic, presymptomatic and symptomatic individuals the next three weeks, aggregated to the whole of Norway, see figure 10 and table 7.

Table 7: Predicted prevalence. Number of infectious individuals (asymptomatic plus pre-symptomatic plus symptomatic) per day. Median/Mean and 95 perc. CI for three weeks prediction.

Region	18 Oct	25 Oct	01 Nov	low CI, 01 Nov	high CI, 01 Nov
Norway	2418/2995	2593/3547	2720/4306	288	19283
Agder	147/184	154/216	166/260	20	1130
Innlandet	160/200	175/236	182/290	21	1382
Møre og Romsdal	95/116	101/139	112/171	13	714
Nordland	77/101	88/122	93/150	8	650
Oslo	316/399	338/479	364/585	35	2659
Rogaland	254/337	264/390	274/464	28	2169
Troms og Finnmark	62/83	65/100	74/125	4	564
Trøndelag	176/219	186/261	205/317	18	1294
Vestfold og Telemark	182/232	195/279	221/349	19	1578
Vestland	256/327	268/398	292/490	29	2325
Viken	635/808	660/939	695/1119	75	4955

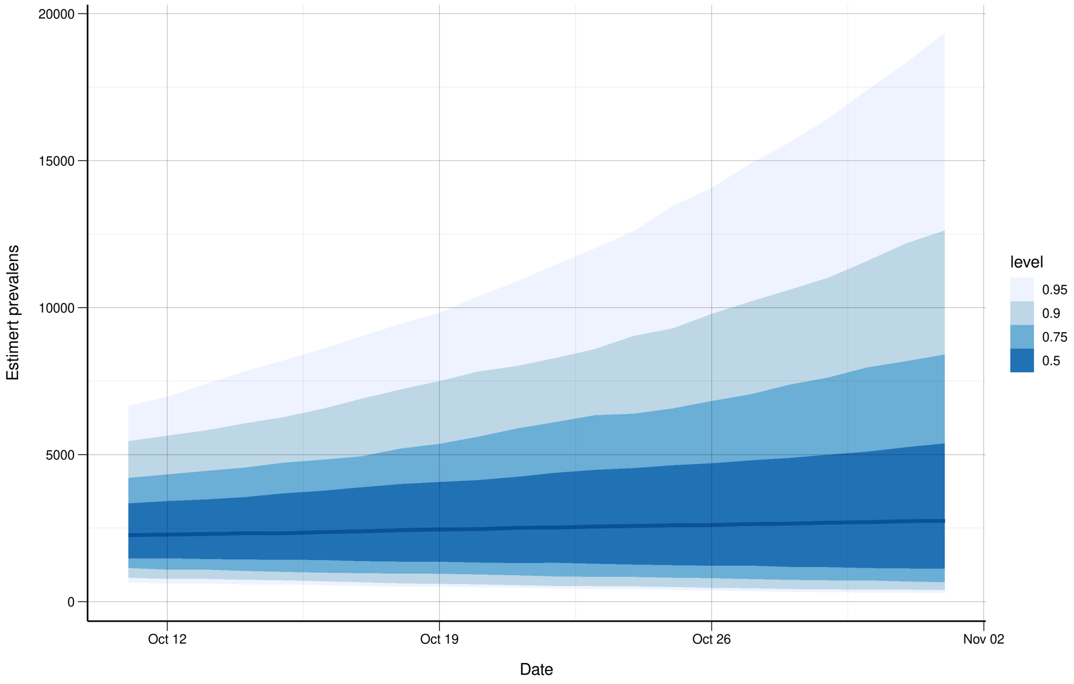


Figure 10: Predicted daily prevalence of asymptomatic, presymptomatic and symptomatic individuals, aggregated, whole Norway, (95% confidence interval).

7 Predicting prevalence on municipality level

The model is predicting prevalence on municipality level. Absolute prevalence and trend from last week are shown in figure 11. According to the mean of our simulations, today's prevalence in 275 municipalities is estimated to be equal or larger than 1.0.

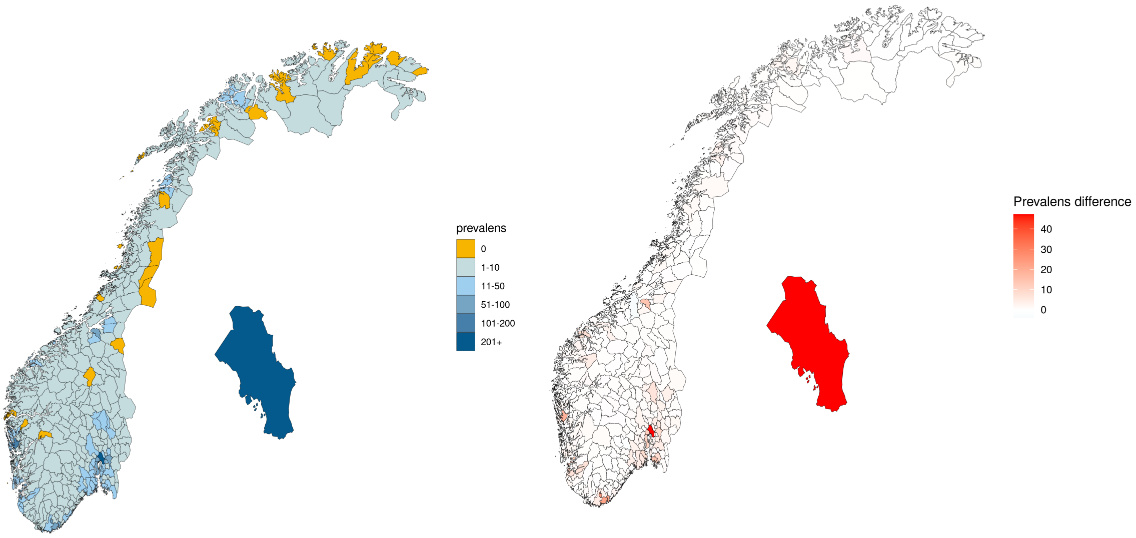


Figure 11: (Left) Map of predicted prevalence. Number of infectious individuals (asymptomatic plus presymptomatic plus symptomatic) today in each municipality. (Right) Prevalence difference compared to the previous week. Decreasing trends are shown in blue.

8 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, see Figure 12 for the 20 largest municipalities and Figure 13 for Norway's counties (fylker).

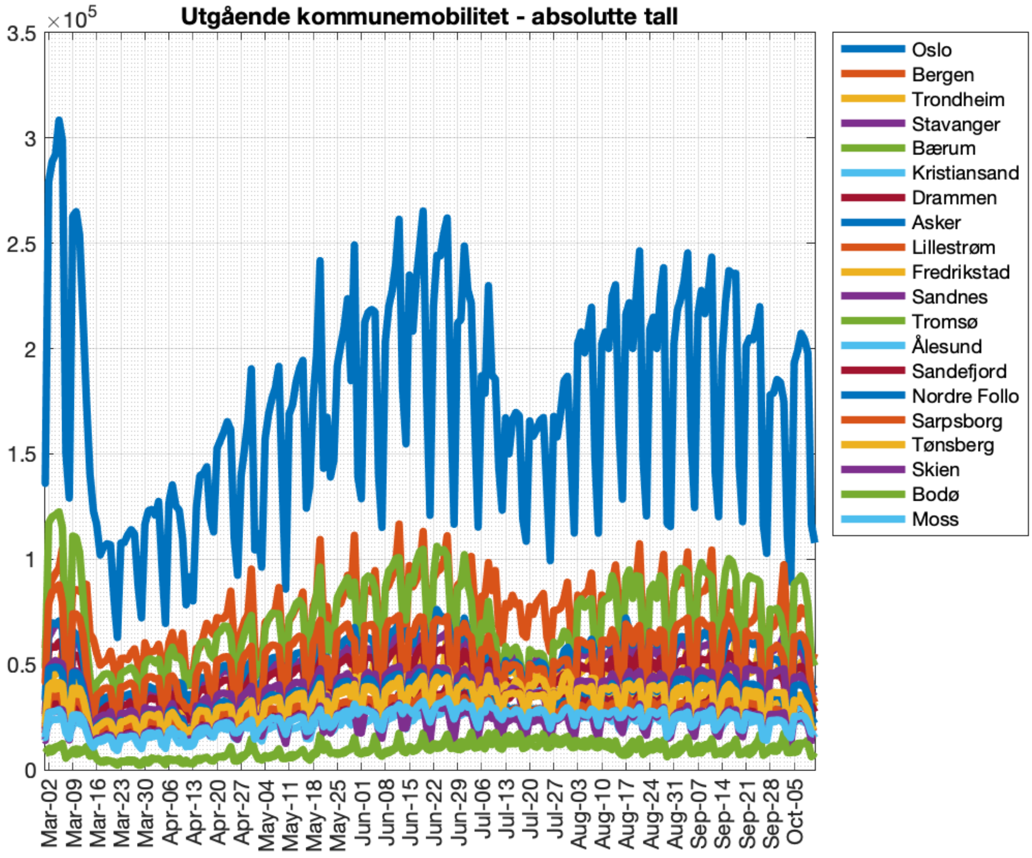


Figure 12: Inter-municipality mobility from week 10 until today.

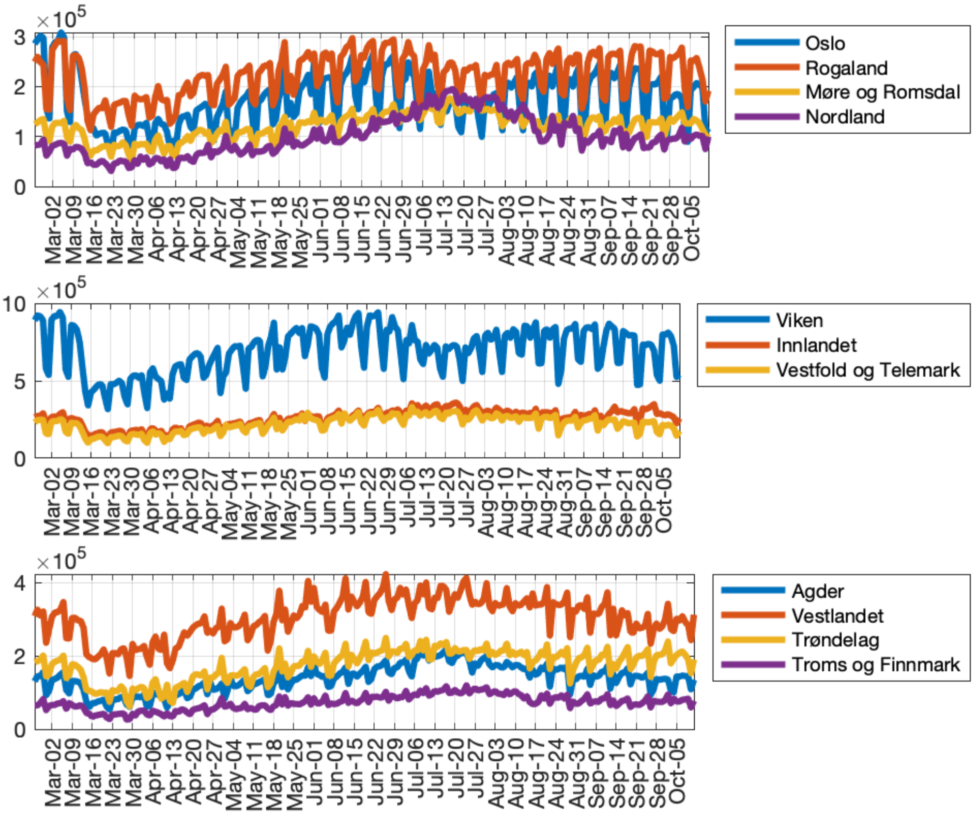
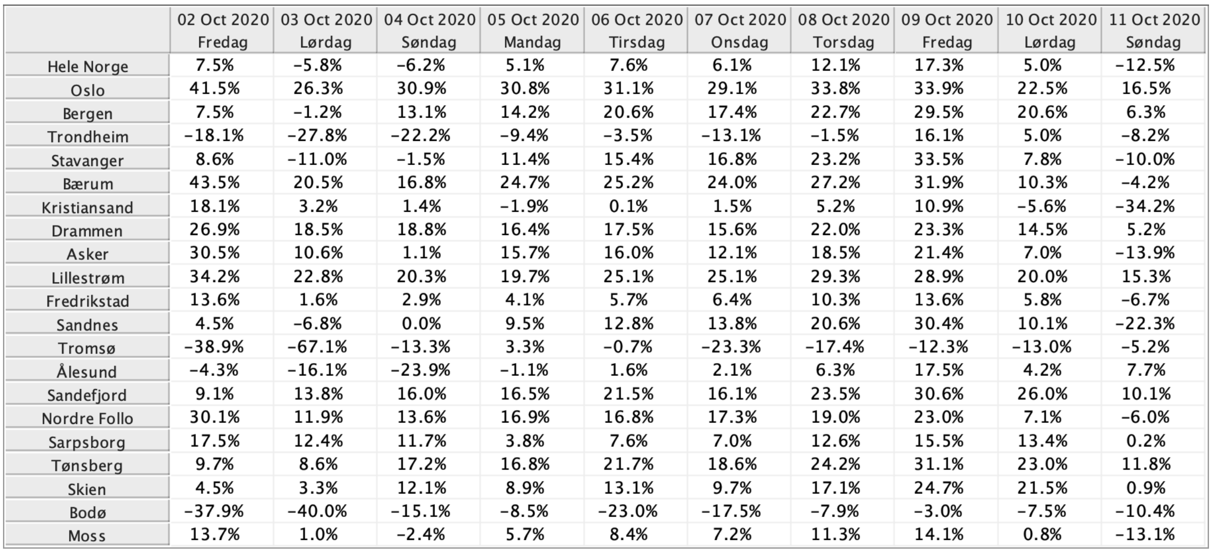


Figure 13: Inter-county mobility from week 10 until today.

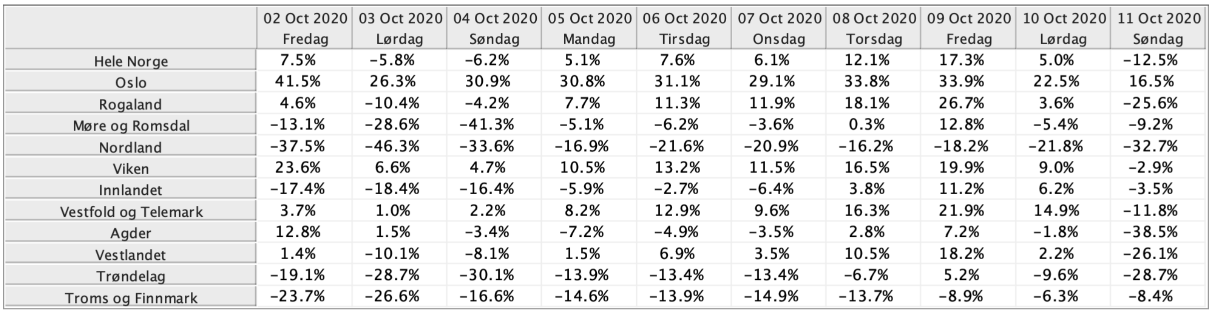
The reduction in movements the last ten days is compared to movements in week 10: Mondays are compared to Monday March 2nd (last Monday before restrictions); Tuesdays are compared to Tuesday March 3rd, etc. until Sundays are compared to Sunday March 8th. For municipalities see Table 8, and for counties see Table 9.

Table 8: Percentage reduction in total mobility out from each municipality.



	02 Oct 2020	03 Oct 2020	04 Oct 2020	05 Oct 2020	06 Oct 2020	07 Oct 2020	08 Oct 2020	09 Oct 2020	10 Oct 2020	11 Oct 2020
	Fredag	Lørdag	Søndag	Mandag	Tirsdag	Onsdag	Torsdag	Fredag	Lørdag	Søndag
Hele Norge	7.5%	-5.8%	-6.2%	5.1%	7.6%	6.1%	12.1%	17.3%	5.0%	-12.5%
Oslo	41.5%	26.3%	30.9%	30.8%	31.1%	29.1%	33.8%	33.9%	22.5%	16.5%
Bergen	7.5%	-1.2%	13.1%	14.2%	20.6%	17.4%	22.7%	29.5%	20.6%	6.3%
Trondheim	-18.1%	-27.8%	-22.2%	-9.4%	-3.5%	-13.1%	-1.5%	16.1%	5.0%	-8.2%
Stavanger	8.6%	-11.0%	-1.5%	11.4%	15.4%	16.8%	23.2%	33.5%	7.8%	-10.0%
Bærum	43.5%	20.5%	16.8%	24.7%	25.2%	24.0%	27.2%	31.9%	10.3%	-4.2%
Kristiansand	18.1%	3.2%	1.4%	-1.9%	0.1%	1.5%	5.2%	10.9%	-5.6%	-34.2%
Drammen	26.9%	18.5%	18.8%	16.4%	17.5%	15.6%	22.0%	23.3%	14.5%	5.2%
Asker	30.5%	10.6%	1.1%	15.7%	16.0%	12.1%	18.5%	21.4%	7.0%	-13.9%
Lillestrøm	34.2%	22.8%	20.3%	19.7%	25.1%	25.1%	29.3%	28.9%	20.0%	15.3%
Fredrikstad	13.6%	1.6%	2.9%	4.1%	5.7%	6.4%	10.3%	13.6%	5.8%	-6.7%
Sandnes	4.5%	-6.8%	0.0%	9.5%	12.8%	13.8%	20.6%	30.4%	10.1%	-22.3%
Tromsø	-38.9%	-67.1%	-13.3%	3.3%	-0.7%	-23.3%	-17.4%	-12.3%	-13.0%	-5.2%
Ålesund	-4.3%	-16.1%	-23.9%	-1.1%	1.6%	2.1%	6.3%	17.5%	4.2%	7.7%
Sandefjord	9.1%	13.8%	16.0%	16.5%	21.5%	16.1%	23.5%	30.6%	26.0%	10.1%
Nordre Follo	30.1%	11.9%	13.6%	16.9%	16.8%	17.3%	19.0%	23.0%	7.1%	-6.0%
Sarpsborg	17.5%	12.4%	11.7%	3.8%	7.6%	7.0%	12.6%	15.5%	13.4%	0.2%
Tønsberg	9.7%	8.6%	17.2%	16.8%	21.7%	18.6%	24.2%	31.1%	23.0%	11.8%
Skien	4.5%	3.3%	12.1%	8.9%	13.1%	9.7%	17.1%	24.7%	21.5%	0.9%
Bodø	-37.9%	-40.0%	-15.1%	-8.5%	-23.0%	-17.5%	-7.9%	-3.0%	-7.5%	-10.4%
Moss	13.7%	1.0%	-2.4%	5.7%	8.4%	7.2%	11.3%	14.1%	0.8%	-13.1%

Table 9: Percentage reduction in total mobility out from each county.



	02 Oct 2020	03 Oct 2020	04 Oct 2020	05 Oct 2020	06 Oct 2020	07 Oct 2020	08 Oct 2020	09 Oct 2020	10 Oct 2020	11 Oct 2020
	Fredag	Lørdag	Søndag	Mandag	Tirsdag	Onsdag	Torsdag	Fredag	Lørdag	Søndag
Hele Norge	7.5%	-5.8%	-6.2%	5.1%	7.6%	6.1%	12.1%	17.3%	5.0%	-12.5%
Oslo	41.5%	26.3%	30.9%	30.8%	31.1%	29.1%	33.8%	33.9%	22.5%	16.5%
Rogaland	4.6%	-10.4%	-4.2%	7.7%	11.3%	11.9%	18.1%	26.7%	3.6%	-25.6%
Møre og Romsdal	-13.1%	-28.6%	-41.3%	-5.1%	-6.2%	-3.6%	0.3%	12.8%	-5.4%	-9.2%
Nordland	-37.5%	-46.3%	-33.6%	-16.9%	-21.6%	-20.9%	-16.2%	-18.2%	-21.8%	-32.7%
Viken	23.6%	6.6%	4.7%	10.5%	13.2%	11.5%	16.5%	19.9%	9.0%	-2.9%
Innlandet	-17.4%	-18.4%	-16.4%	-5.9%	-2.7%	-6.4%	3.8%	11.2%	6.2%	-3.5%
Vestfold og Telemark	3.7%	1.0%	2.2%	8.2%	12.9%	9.6%	16.3%	21.9%	14.9%	-11.8%
Agder	12.8%	1.5%	-3.4%	-7.2%	-4.9%	-3.5%	2.8%	7.2%	-1.8%	-38.5%
Vestlandet	1.4%	-10.1%	-8.1%	1.5%	6.9%	3.5%	10.5%	18.2%	2.2%	-26.1%
Trøndelag	-19.1%	-28.7%	-30.1%	-13.9%	-13.4%	-13.4%	-6.7%	5.2%	-9.6%	-28.7%
Troms og Finnmark	-23.7%	-26.6%	-16.6%	-14.6%	-13.9%	-14.9%	-13.7%	-8.9%	-6.3%	-8.4%

9 Long-term prediction results

Predicted daily number of COVID-19 patients in hospital and receiving ventilator treatment in Norway until the end of April 2021, in addition to prevalence. The figures are made using 200 candidate models, where the reproductive numbers are varying according to their estimated uncertainty as estimated today with the changepoint model. There are some candidate models for which $R_6 > 1$ which result in a peak in the future. The interpretation of the figures should be made with this in mind.
The confidence intervals reflected in the plots are two-tailed around the median, and therefore the upper 95 % level shows the 97.5 % boundary, see figure 14 for estimated prevalence, figure 15 for estimated number of hospitalisations, and figure 16 for estimated number of patients needing ventilator treatment.

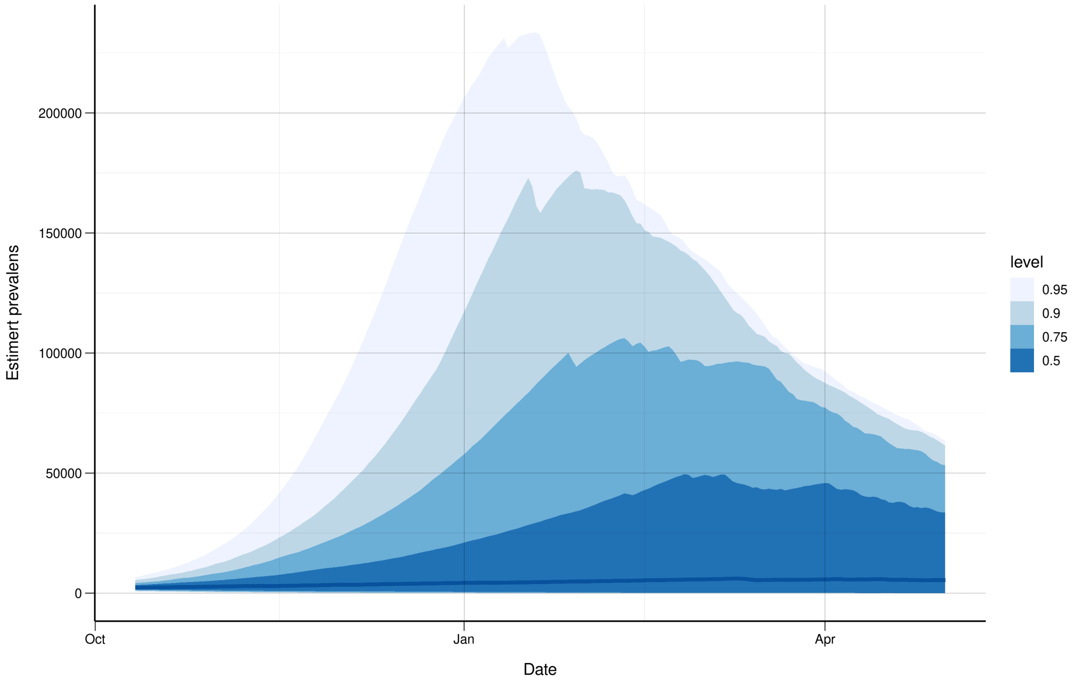


Figure 14: Predicted prevalence of COVID-19 based on 200 candidate models where the reproductive number used for simulation varies according to the estimated uncertainty.

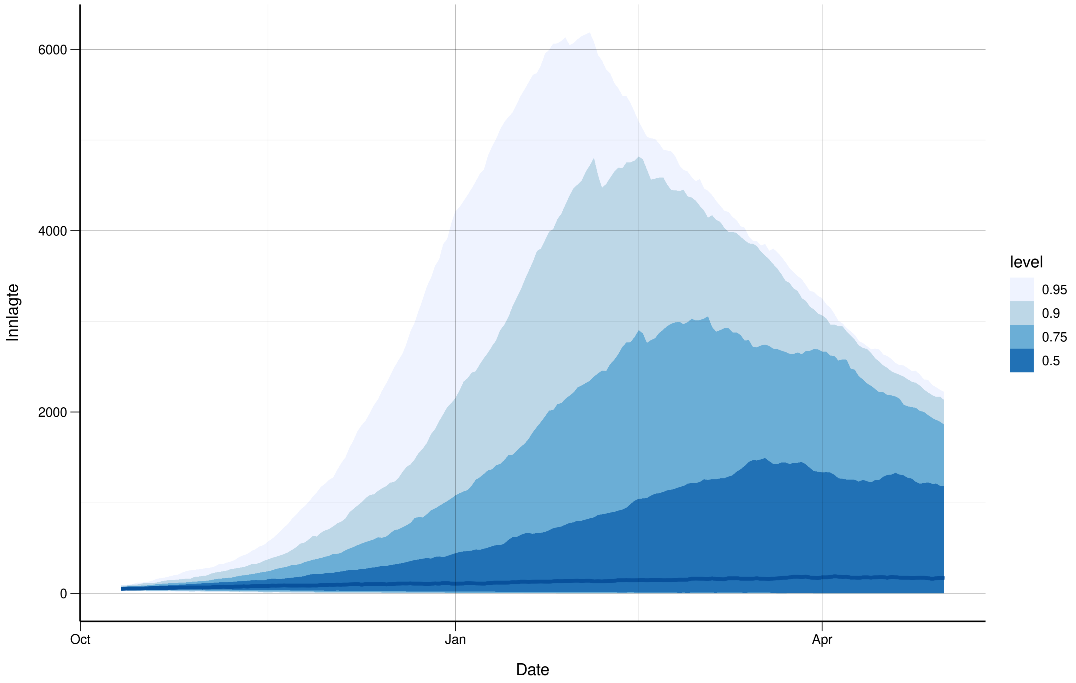


Figure 15: Predicted number of COVID-19 patients in hospital based on 200 candidate models where the reproductive number used for simulation varies according to the estimated uncertainty.

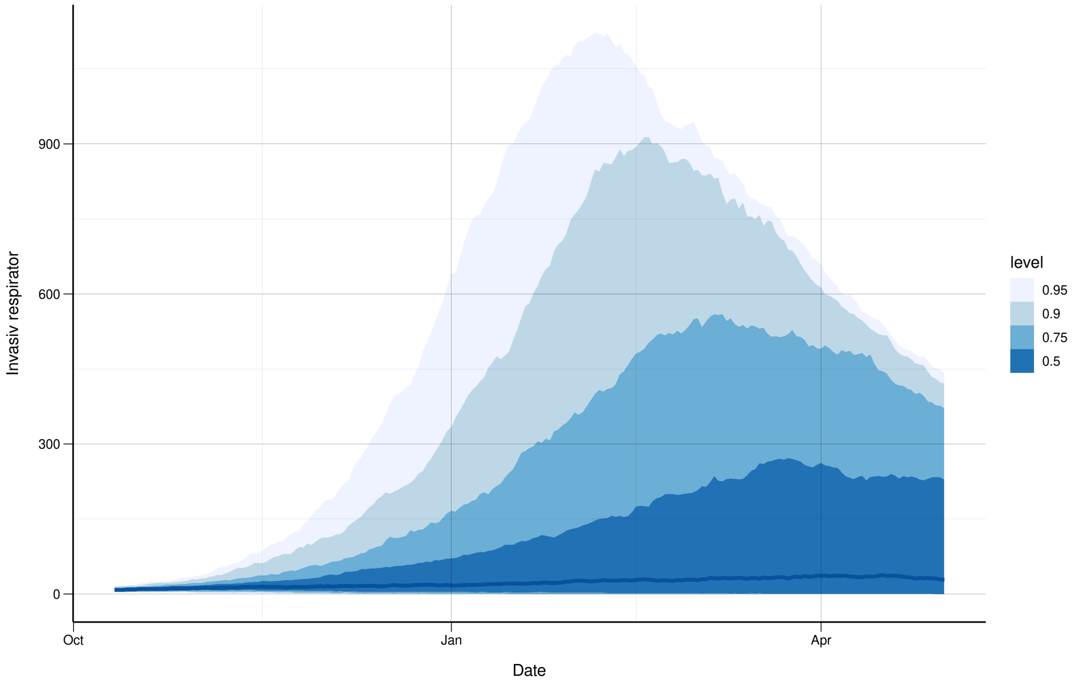


Figure 16: Predicted prevalence of COVID-19 patients needing ventilator treatment based on 200 candidate models where the reproductive number used for simulation varies according to the estimated uncertainty.

The probability of a surge capacity need above **500 ICU** beds is **18 %**. We estimate the probability of a surge capacity need above **1000 ICU** beds to be equal to **5 %**.

10 Long-term scenario results

Here we show how the epidemic will develop, from July 23rd, under three assumed scenarios. We assume that until July 23rd we follow our estimated reproductions numbers, but from July 24th, 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), see figure 17, and the daily number of patients with ventilator treatment, figure 18. In table 10 we also report 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 the probability of being hospitalised and the probability of needing ventilator treatment.

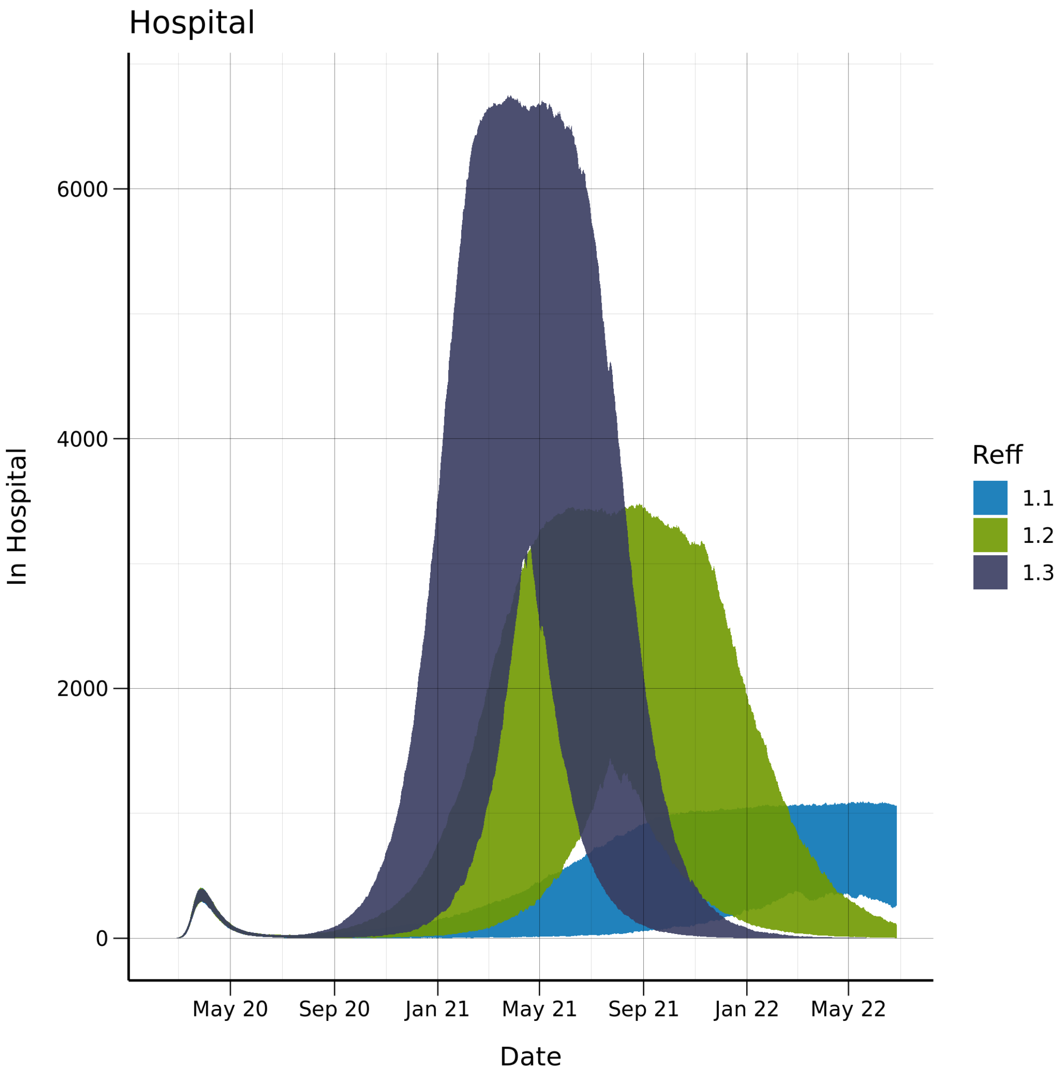


Figure 17: Predicted number of COVID-19 patients in hospital based on three different scenarios with R effective equal to 1.1, 1.2 and 1.3.

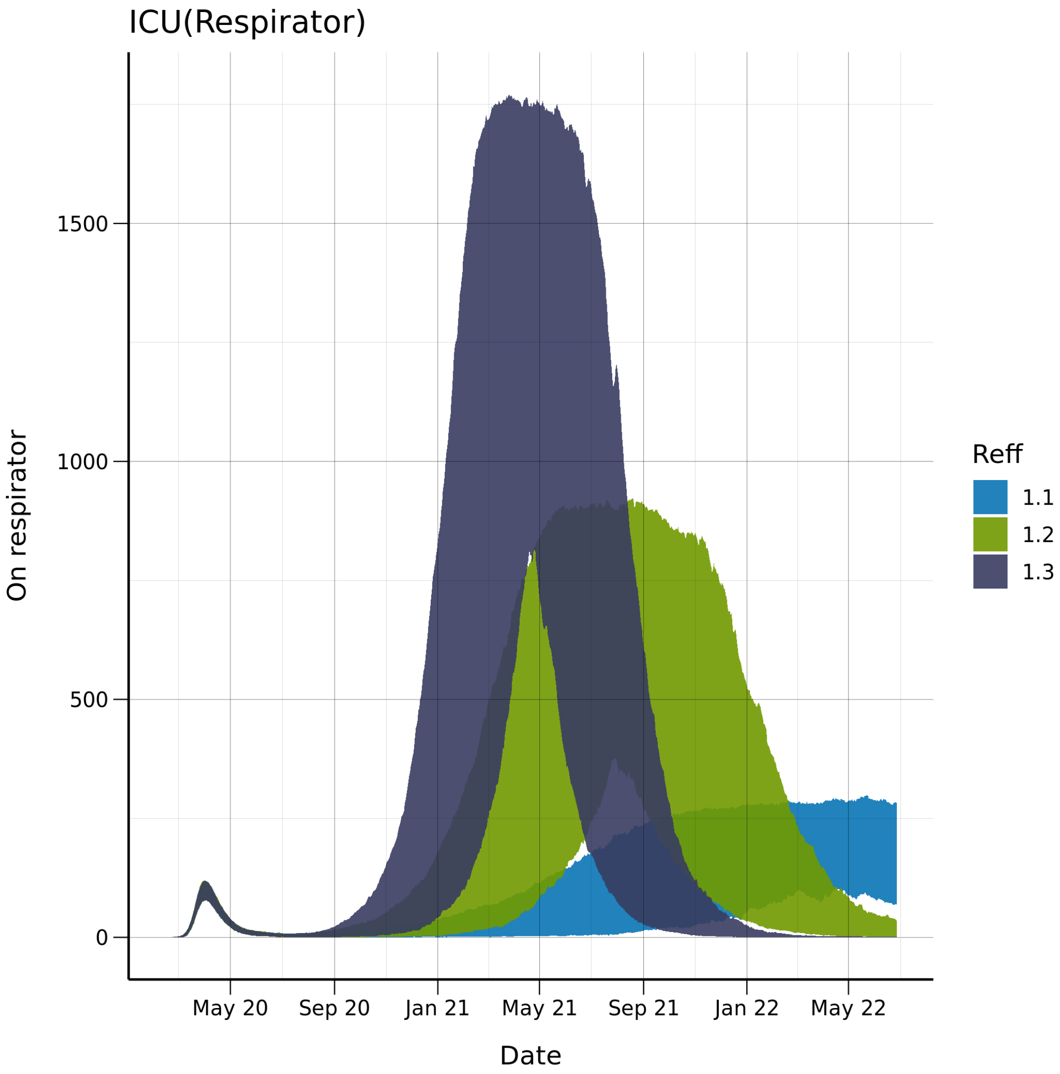


Figure 18: Predicted number of COVID-19 patients needing ventilator treatment based on three different scenarios with R effective equal to 1.1, 1.2 and 1.3.

Table 10: Predicted numbers of total infected, total number of hospitalisations, total number needing ventilator treatment, and the predicted peak number in ward (not in respirator), hospitalised (both with and without ventilator treatment) and ventilated treatments based on three different scenarios with R effective equal to 1.1, 1.2 and 1.3.

	Reff=1.1	**Reff=1.2**	**Reff=1.3**
Total infected	849.000(376.000 - 981.000)	1.790.000(1.760.000 - 1.840.000)	2.380.000(2.350.000 - 2.420.000)
Total Hospital	33.100(14.100 - 38.300)	69.700(68.200 - 72.200)	92.100(90.900 - 94.300)
Total on respirator	4.980(2.060 - 5.770)	10.600(10.200 - 11.000)	13.900(13.700 - 14.300)
Ward[1] at peak	802(660 - 867)	2.560(2.440 - 2.680)	4.990(4.800 - 5.130)
Hospital[2] at peak	1.070(884 - 1.160)	3.440(3.300 - 3.610)	6.710(6.450 - 6.900)
Respirator at Peak	285(222 - 316)	912(857 - 964)	1.760(1.680 - 1.830)

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[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 to be 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: Susceptible (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 in figure 19.

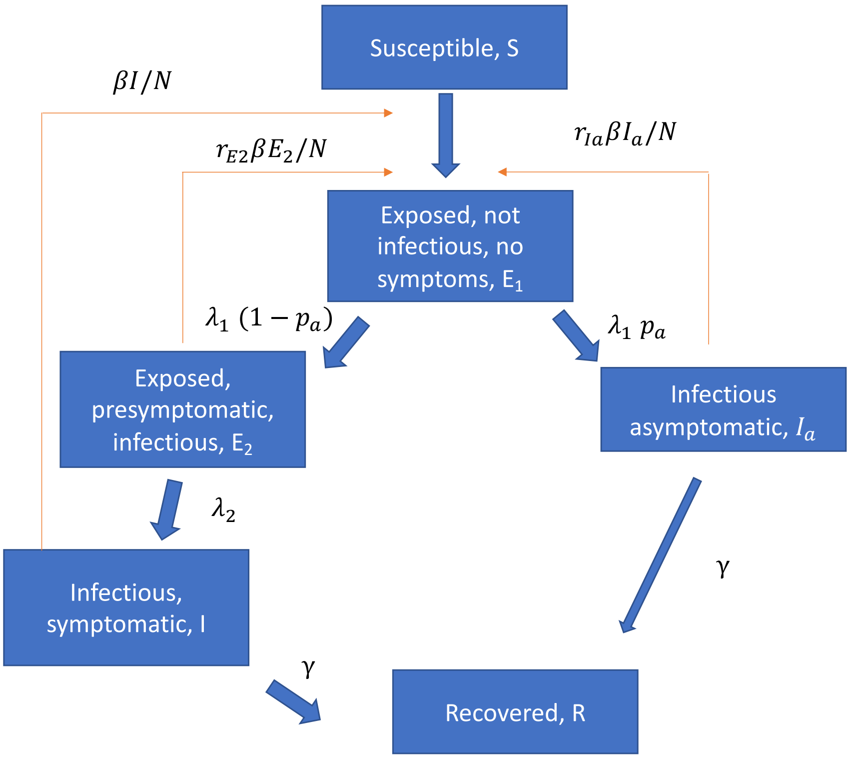

Figure 19: Schematic overview of the model.

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 to be 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 necessary.

Healthcare utilisation

Based on the estimated daily incidence data from the model and the population age structure in each municipality, we calculated the hospitalisation using a weighted average. We correct these probabilities by a factor which represents the over or under representation of each age group among the lab confirmed positive cases. The hospitalisation is assumed to be delayed relative to the 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, using the data available until yesterday. 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 otherwise missed. We denote this by the 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, a third reproduction number R_2 until May 10, a fourth reproduction number R_3 until June 30, R_4 until July 31, and a sixth reproduction number until today. This last reproduction number is used for the future. The changepoints follow the change in restrictions introduced. We estimate the reproduction numbers so that the predicted number of hospitalised individuals is closest to the true number of hospitalised individuals, from March 10 until the last available data point. We use a method called sequential ABC which tests thousands of combinations of R_0, R_1, R_2, R_3, R_4, R_5, R_6, and the amplification factor, to determine the 200 ones that lead to the best fits to the hospitalisation incidence. The algorithm is described in Engebretsen et al. (2020) https://royalsocietypublishing.org/doi/10.1098/rsif.2019.0809.

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 2. The estimated hospital prevalence (Figure 3) 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.

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[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

- 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.
- 26 June: **New reproduction number active from 11 May:** We introduce a new change point in the reproduction number, so that R_2 is active until 10 May and R_3 from 11 May. This is the day of the last ease of restrictions before summer.
- 29 June: **Time-varying reproduction number and Sequential Monte Carlo estimation** We assume a daily varying reproduction number (after March 9). In this way we are able to automatically detect changes in the reproduction number with no need to introduce changepoints explicitly. However, estimating many more parameters (one for each day) is much harder than the three reproduction numbers we assume in the changepoint model. We developed a method and an algorithm to estimate the daily reproduction numbers based on Sequential Monte Carlo (Doucet and Johansen, A tutorial on particle filtering and smoothing: Fifteen years later, Handbook of nonlinear filtering, 2009). To stabilise our estimates, we run a 7-days moving window, so that R_t is the average of the reproduction numbers over the 7 previous days. We quantify the uncertainty of our estimates by simulation. The disadvantage of this approach is that the estimated R_t for the last two weeks, and in particular for the last days, is very uncertain. Therefore we look two weeks back in time to determine sensible reproduction numbers. We compute the posterior probability of the time-varying reproduction number and plot the central 50% of this distribution to sketch the uncertainty. This band can be interpreted as the one which we predict to contain the daily reproduction number with 50% of posterior probability. We also compute the posterior probability that the reproduction number is above 1.
- 1 July: **Imported cases until June** We incorporate confirmed imported cases now until June 26. They are placed in their municipality of residence. We assume a unique amplification factor for all imported cases during the whole epidemic, and estimate it.
- 10 August: **Imported cases until yesterday** We incorporate confirmed imported cases until the day before ("yesterday") and continue to assume a single amplification factor which is re-estimated every time we have new data.
- 10 August: **New reproduction number active from 1 July:** We introduce a new change point in the reproduction number, so that R_3 is active until 11 May and R_4 from 1 July. We plan to add a new change point every first day of the month, but start to estimate it only from the 21 of the same months, as we need three weeks of data to get a good estimate.
- 10 August: **Improved Sequential Monte Carlo estimation** We have reported an estimate of the daily reproduction number (7-days moving window average) R_t in the last month and observed that our estimate was too sensitive to small changes in the daily hospital incidence. This produced visible oscillations in R_t, which we think are not realistic. We have therefore changed the likelihood of the hospital incidence, so that small variations can more easily seen as noisy variations. We use now a beta-binomial likelihood (with $\alpha = 8$, but will optimise this parameter further in the next days).
- 12 August: **Reporting expected probability that the total number of new cases per 100.000 inhabitants will exceed 20** For each county, we estimate this probability in the next two weeks, using estimated number of cases.
- 17 August: **New seeding data set** We change the source of the seeding data. Before, we used the first day with symptoms for every imported case. Now instead, we use the date of positive testing. The reason is that most imported cases might have been abroad when the symptoms appeared, while we are sure that they are in Norway on the day they test. The positive test data is also a more sure data point, compared to the first day with symptoms. This change makes a difference in March and April, as can be seen in the figure 20, where we show a comparison between the previous seeding (red) and the new one (black).

- 24 August: **New reproduction number active from 1 August:** We introduce a new changepoint in the reproduction number, so that R_4 is active until July 31 and R_5 from August 1. We start to estimate the new reproduction number approximately three weeks after, when some data informing it are available.
- 24 August: **Predicted medians instead of means** We report posterior medians as point predictions, instead of means, because of the strong skewness of the posterior distributions.
- 1 September: **Revised hospitalisation probabilities** We have changed the probability that an infected individual (symptomatic or asymptomatic) is hospitalised. In the last weeks it has become apparent that the age profile of the individuals who test positive does not follow the demography of the Norwegian population, with a much stronger representation of the age group between 20 and 29 years. Therefore we had to change our assumptions, namely that age of infected individuals was following the demographic age profile of the Norwegian population. Instead we learn the distribution of ages of the infected from the Norwegian data of who tested positive. We computed a correction factor for each age group, consisting of the ratio between the proportion tested of each group divided by the demographic proportion in the overall Norwegian population. We computed the percentage of each age group among all positive tests taken from May 1 until the last available data. For the age group 20-29 this percentage was on 1 September 26%, while in the general population, this age group consists of only 15%, and is therefore highly overrepresented. This correction influences the overall probability for an infected individual to be hospitalised. Before we used 3.9%. This percentage becomes now 2.26% using the new correction factors. The correction factors multiplied by the hospitalisations probabilities from Saljie at al 2020, in the 9 age groups are: $0.459 * 0.002, 0.874 * 0.002, 1.954 * 0.006, 1.480 * 0.013, 1.128 * 0.017, 1.005 * 0.035, 0.479 * 0.071, 0.331 * 0.1130, 0.373 * 0.27$.
- 1 September: **Percentage of detected cases each month** We add a new figure in section 2, where we represent the percentage of detected cases, among the positive cases that our model estimates. This is done for the whole period in Table 2, and for each month in the figure.
- 10 September: **New probabilities of being hospitalised when infected, per age group** Salje at al. 2020 updated their results on the basis of better outcomes of some of the patients in their cohort. Therefore their estimates of the probability of being hospitalised if infected per age group are reduced. We use the new values from today. For the 9 age groups, the new (and old) probabilities are: 0.1% (0.092%), 0.1% (0.2%), 0.5% (0.6%), 1.1% (1.3%), 1.4% (1.7%), 2.9% (3.5%), 5.8% (7.1%), 9.3% (11.3%), 22.3% (27%).
- 14 September: **New probability of requiring ventilator treatment if hospitalised**, from May 1 updated to 8.7% from previously 15.1% based on analysis of registry data on patients hospitalised in Norway from May-September.
- 21 September: **New reproduction number active from 1 September:** We introduce a new changepoint in the reproduction number, so that R_5 is active until August 31 and R_6 from September 1. We start to estimate the new reproduction number approximately three weeks after, when some data informing it are available.
- 5 October **Updated hospitaliastion parameters:** We have updated the hospitalisation parameters (time to hospitalisation, length of stay, etc.) based on more recent data. In particular, we introduce a changepoint in the hospitalisation parameters on 1 April, where the data before and after 1 April are used to estimate the different parameters. See figures in the next section.
- 12 October **Included reporting delay for hospital admissions:** We have implemented a reporting delay of new hospitalisations. We estimated it from all data since April using time from admissions to reporting in the BeredtC19 registry. The reporting delay is implemented as a probability that an admission which happened on a certain day is actually reported with a delay of one to four days. We estimated these delay probabilities for the last four days from "today" and have different delay probabilities on Monday compared to the rest of the week, because the delay is more pronounced for admissions happening in the weekend. The probabilities are listed in Table 12, Assumptions.

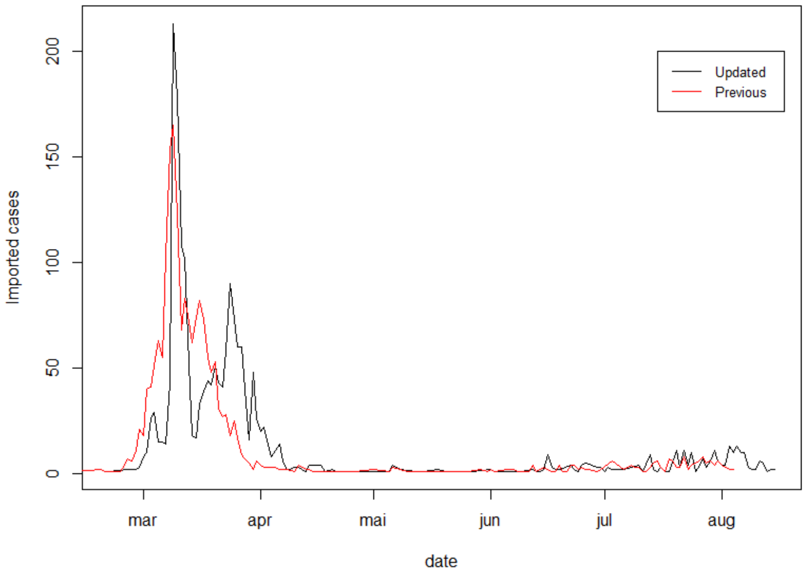

Figure 20: Comparison between the number of imported cases on the day of declared appearance of symptoms (red) and on the date of positive test, which is used from now on (black).

Parameters used today

Figures 21 and 22 indicate 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.

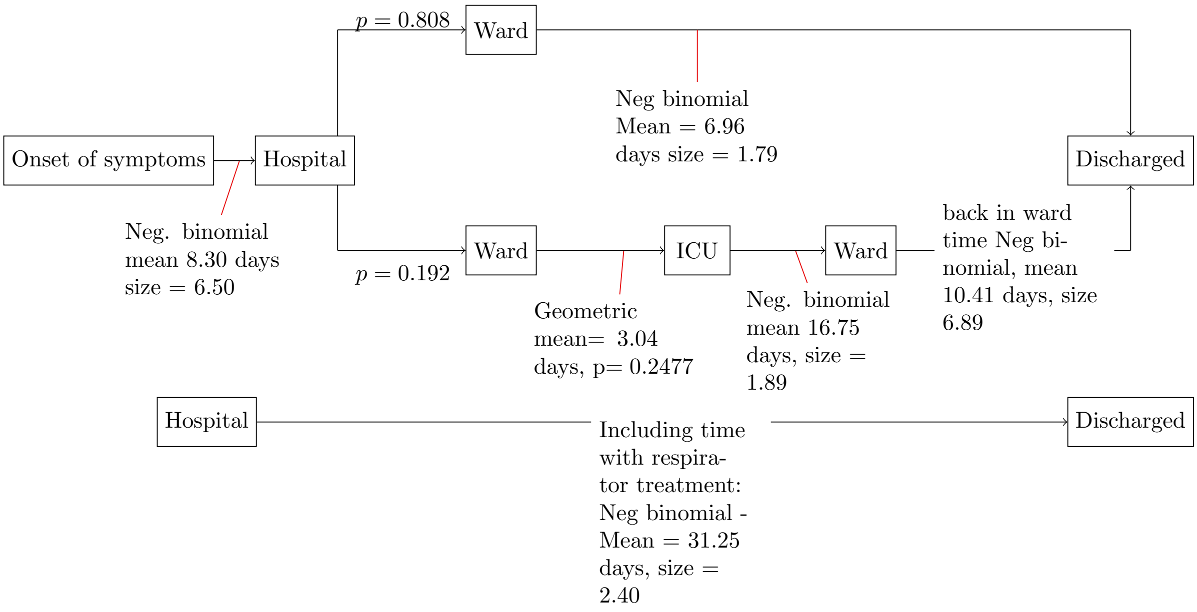

Figure 21: Hospital assumptions and parameters used before 1 April

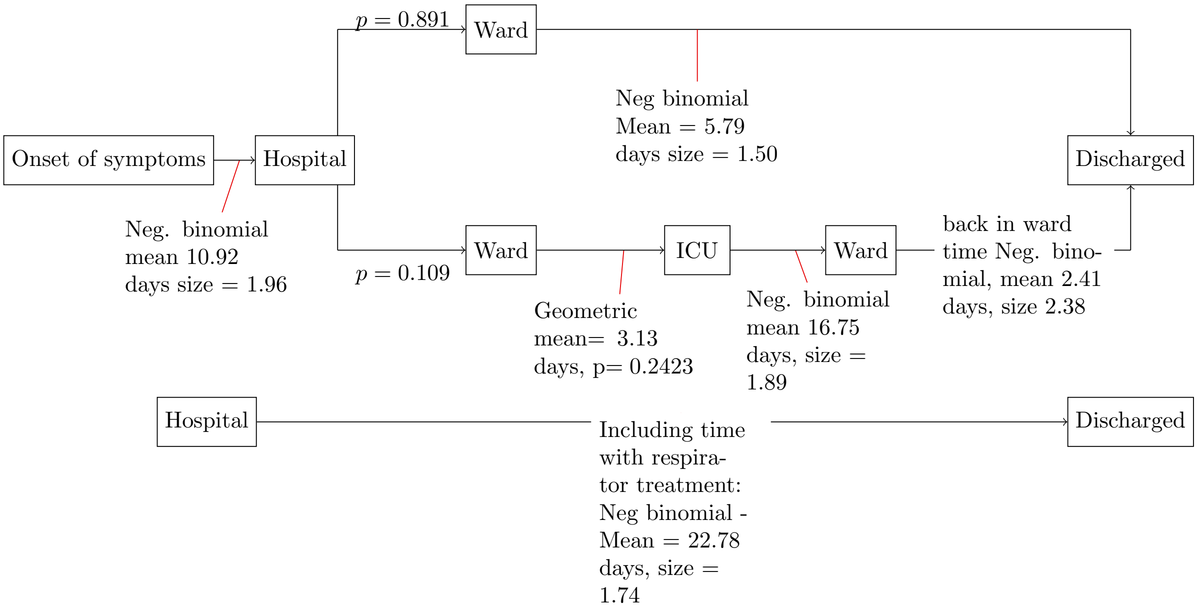

Figure 22: Hospital assumptions and parameters used after 1 April

Table 11: Estimated reproductive numbers

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	Period
R0s	1.94	3.16	3.466	3.482	3.773	4.755	Until March 14
R1s	0.393	0.514	0.543	0.545	0.578	0.667	From March 15 to April 19
R2s	0.021	0.366	0.531	0.523	0.665	1.074	From April 20 until May 10
R3s	0.329	0.732	0.868	0.852	0.993	1.257	From May 11 until June 30
R4s	0.007	0.417	0.682	0.715	1.011	1.945	From July 1 until July 31
R5s	0.23	0.601	0.78	0.783	0.946	1.343	From August 1 until August 31
R6s	0.476	0.907	1.081	1.076	1.237	1.749	From September 1
AMPs	1.761	3.739	4.545	4.596	5.479	8.016	From February

Table 12: Assumptions I

Assumptions	Mean	Distribution	Reference
Seeding			
Telenor coverage	48%		https://ekomstatistikken.nkom.no/
Model parameters			
Exposed period $(1/\lambda_1)$	3 days	Exponential	Feretti et al 2020
Pre-symptomatic period $(1/\lambda_2)$	2 days	Exponential	Feretti et al 2020
Symptomatic infectious period $(1/\gamma)$	5 days	Exponential	Feretti et al 2020
Asymptomatic, infectious period $(1/\gamma)$	5 days	Exponential	Feretti et al 2020
Infectiousness asympt. (r_{I_a})	0.1	Fixed	Feretti et al 2020
Infectiousness presymp (r_{E_2})	1.25	Fixed	guided by Feretti et al 2020
Prob. asymptomatic infection (p_a)	0.4		Feretti et al 2020
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:		Fixed	Saljie et al 2020 corrected for: % of elderly living in elderly homes in Norway (last two age groups) and corrected for presence among positive tested since May 1.
0-9 years	0.476*0.1%		
10 - 19 years	0.896 *0.1%		
20 - 29 years	2.044 *0.5%		
30 - 39 years	1.45*1.1%		
40 - 49 years	1.098*1.4%		
50 - 59 years	0.975*2.9%		
60 - 69 years	0.468*5.8%		
70 - 79 years	0.337*9.3%		
80+ years	0.346*22.3%		
% hospitalized patients requiring ICU		Fixed	Estimated from ”Beredskapsregistret BeredtC19”
Feb - March	20%		
April	10%		
May -	8.7 %		
Overall hospitalization risk	2.26%	Fixed	Corrected Saljie et al 2020 (adapted to Norwegian population and adapted to positive tested)
Probability that an admission has been reported on Monday		Fixed	Estimated from ”Beredskapsregistret BeredtC19”
From Sunday	32%		
From Saturday	49%		
From Friday	68%		
From Thursday	86%		
Probability that an admission has been reported		Fixed	Estimated from ”Beredskapsregistret BeredtC19”
From one day before	53%		
From two days before	77%		
From three days before	82%		
From four days before	91%		
Mobile phone mobility			
Until October 10th	Measured Telenor mobility		
Data used in the predictions	October 9th	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 laboratory-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 hospitalisation data are a less biased information source for 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, see figure 23. 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 to be 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.

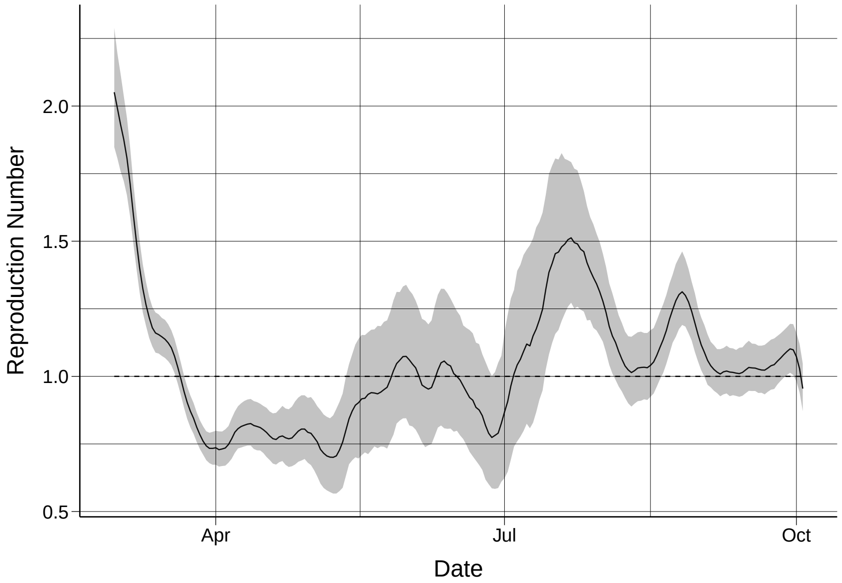

Figure 23: Reproduction number estimated using the R package EpiEstim.

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