Long-term scenarios for Norway for the fall and winter 2021–2022

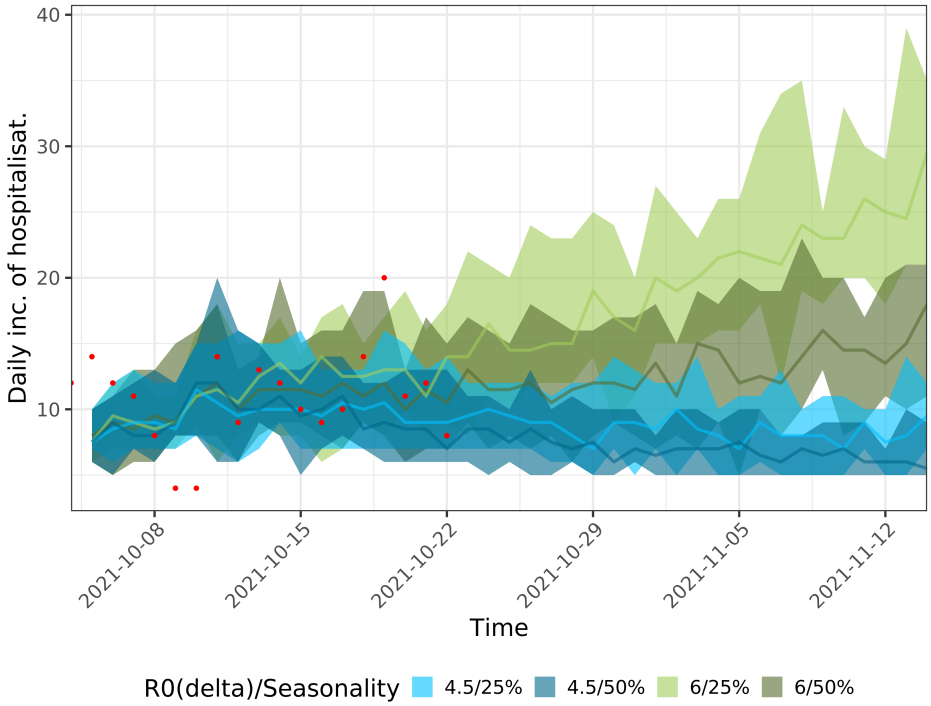
COVID-19 Modelling Team

October 28, 2021

Oppdatering før publisering

Modelleringa til denne rapporten vart ferdigstilt i første halvdel av oktober. Sidan då har epidemien utvikla seg. Vi har difor gjort ei samanlikning av modellresultata vist i rapporten med data på innlagte COVID-19-pasientar for dei første par vekene sidan 4. oktober. Figuren under viser dagleg insidens[1] av innleggingar i fire scenario: $R_0 = 4.5$ eller 6, kombinert med sesongvariasjon på anten 25 % eller 50 %. Data på dagleg insidens av nyinnlagte er vist som raude prikkar.

Vi ser at trenden i insidens er ganske flat i både data og alle fire scenario i perioden der det finst data i skrivande stund. Basert på dette er det enno for tidleg å seie noko sikkert om kva for eit scenario som peiker seg ut som mest sannsynleg. I løpet av dei kommande vekene skil scenarioa seg meir frå kvarandre, og vi reknar med at trenden i dataene etter kvart vil gjere det mogleg å skilje mellom meir og mindre sannsynlege scenario.



Update before publication

The modelling work presented in this report was finalised during the first part of October. Since then, the epidemic has evolved. We have therefore made a comparison between the modelling results shown in the report, and data on hospitalisations due to COVID-19 from the first couple of weeks after October 4th. The figure above shows the daily incidence[2] of hospitalisations in four scenarios: $R_0 = 4.5$ or 6, combined with either 25% or 50% seasonal variation. Data on daily incidence of newly admitted patients is shown as red dots.

We see that the trend of the incidence is qute flat both in data and all four scenarios during the period where there is data at time of writing. Based on this, it is still too early to say which scenario seems most likely. During the coming weeks, the scenarios begin to diverge in their incidence numbers, and we expect that the trend in the data will begin to enable discrimination between more and less likely scenarios.

[1] I figuren har vi forskjøvet modellens insidenstal opp med ein konstant (5 per dag) for å lette samanlikninga med data. Dette er naudsynt fordi startverdiane i modellen ikkje passar perfekt med verkelegheita. Figuren må berre nyttast for å samanlikne *trenden* i sjukehusinsidens.

[2] In the figure, the modelled incidence numbers have been shifted by a constant (5 per day) to ease the comparison with data. This is necessary due to non-perfect matching of the model's starting conditions to reality. The figure may only be used to compare *trends* of hospitalisation incidence.

Samandrag på norsk *(For english, please see the next page)*

Denne rapporten dreier seg om langtidsmodellering av moglege scenario for COVID-19-epidemien i Noreg for vintersesongen 2021/2022. Desse scenarioa er usikre fordi dei er avhengige av fleire ukjende faktorar, slik som den naturlege spreiingstakta til delta-varianten i Noreg, og korleis folk kjem til å oppføre seg. Vi understrekar difor at scenario ikkje er det same som prediksjonar – scenarioa viser moglege forløp av epidemien i framtida, under spesifikke føresetnadar.

Vi viser to scenario med ulike hypoteser for det basale reproduksjonstalet R_0 til viruset. R_0 er eit mål på det maksimale smittepotensialet viruset har. R_0 er eit teoretisk tal basert på ein heilt uvaksinert folkesetnad og utan smitteverntiltak i det heile, og seier kun noko om teoretisk smittepotensial. I denne rapporten fungerer R_0 i praksis som eit mål på kor høg smitteraten mellom folk er i kvar simulering. Dess høgre R_0, dess større er avstanden mellom dagens smitterate og smitteraten i eit heilt opent samfunn. I byrjinga av kvar simulering "gjenopnar" vi Noreg ved å auke smitteraten til nivået som svarer til R_0, og denne auken er større dess større R_0. Scenarioet med $R_0 = 4.5$ har ein smitterate etter gjenåpning som ligg nær den estimerte smitteraten i Noreg før gjenåpninga 25. september. I følge dette scenarioet har dermed gjenopninga hatt liten effekt på smittespreiinga. I det andre scenarioet med $R_0 = 6$ så auka derimot smitteraten med 60 % ved gjenåpning. I begge R_0-scenarioa antar vi at 50 % av dei smitta som utviklar symptom, held seg heime frå dag ein etter symptomstart til dag seks, og vi antar minst 90 % vaksinedekning i alle aldersgrupper over 12 år. Vi antar òg at vaksinene ikkje tapar effekt med tida. Vi tolkar scenarioa med $R_0 = 4.5$ og 6 til å representere eit spenn av plausible forløp for epidemien.

Scenarioet med $R_0 = 4.5$ viser at dersom vi greier å nå minst 90 % vaksinasjonsdekning i alle aldersgrupper over 12 år, og samtidig reduserer smitte ved at 50 % av dei symptomatisk sjuke held seg heime, så ser modellen knapt nokon smittebølgje i det heile gjennom vinteren. Scenarioet med eit høgre basalt reproduksjonstal viser derimot at dersom den naturlege spreiingstakta til viruset er vesentleg høgre, så ventar modellen ei betydeleg bølgje frå seinhausten og utover vinteren. Denne bølgja kan potensielt nå 60-70 innleggingar per dag på det meste. Det er på nivå med dei 60 nye innlagte vi såg 25. mars 2020, som er det høgste daglege talet på innlagte så langt i epidemien i Noreg. Det er vanskeleg å vurdere sannsynet for kvart av desse scenarioa, så det er naudsynt å førebu oss både på scenario med ein ganske godt kontrollert epidemi, og på scenario med høgre sjukdomsbyrde i vintermånadane. Som med tidlegare bølgjer vil det også her vere mogleg å stanse eller bremse bølgjene ved å innføre tiltak, og desse tiltaka vil i så fall ikkje trenge å vere på langt nær så drastiske som ved tidlegare bølgjer for å få smitta under kontroll. Vi følger nøye med på utviklinga sidan gjenopninga, og kjem til å bruke nye data fortløpande til å innsnevre estimata for smitteevne/R_0 i kommande rapportar.

Dei viktigaste faktorane som påverkar scenarioa for vintersesongen er den naturlege smittetakta til deltavarianten, etterleving av råd om testing og sjølvisolering ved sjukdom, vaksinasjonsdekning og storleiken på sesongvariasjonen. Det å nå ei høgre vaksinasjonsdekning enn det noverande nivået kan ha stor positiv effekt på epidemien, og kan anten gjere ei vinterbølgje vesentleg mindre eller gjere det mogleg å halde epidemien under kontroll sjølv med dårlegare etterleving av smittevernråd. Den største effekten av meir vaksinasjon blant yngre aldersgrupper er å redusere reproduksjonstalet og talet på infeksjonar i alle aldersgrupper. At folk held seg heime når dei er sjuke kan ha ein vesentleg effekt på epidemien, og dersom mange nok følger dette rådet kan det vere tilstrekkeleg til å halde epidemien under kontroll gjennom vinteren.

Oppsummert: Høg vaksinasjonsdekning, og noko reduksjon i symptomatisk smitte ved at folk held seg heime ved sjukdom, kan vere nok til å halde epidemien under kontroll gjennom vintersesongen i Noreg. Samstundes er det ein reell moglegheit for utfall der det kjem ei relativt stor vinterbølgje.

Summary in English

We present long-term COVID-19 scenarios for Norway for the winter season 2021/2022. Long-term scenarios are uncertain due to unknown factors including the natural rate of spread of the Delta variant in Norway and how the population will behave. We therefore emphasise that the scenarios are not predictions – they are the modelled outcomes of a specific set of assumptions about the future course of the epidemic.

We present two scenarios with different underlying basic reproduction numbers, R_0. R_0 quantifies how transmissible the virus is in the absence of any vaccine or interventions in a fully susceptible population. The higher R_0 is, the larger is the discrepancy between today's transmission rate, and the transmission rate in a fully open society. At the start of each simulation, we increase the transmission rate to the level corresponding to R_0, to simulate full reopening, and this increase is larger the larger R_0. We assume that 50% of those that develop symptoms stay at home for 5 days since the day after the onset of symptoms. Both scenarios reach at least 90% vaccine coverage in all age groups above 12 years old. We assume no waning of immunity from the vaccines with time. We interpret the scenarios with $R_0 = 4.5$ and $R_0 = 6$ as representing a range of plausible courses for the epidemic. The low scenario with $R_0 = 4.5$ has a transmission rate that is similar to the one in Norway prior to the reopening on 25th of September 2021. In this scenario, therefore, the reopening did not have a large effect on the spread. In the other scenario with $R_0 = 6$, on the other hand, the transmission rate increased by 60% at reopening, because the virus has a larger intrinsic transmissibility in this scenario.

The scenario with $R_0 = 4.5$ shows that if we can reach at least 90% vaccination coverage in all age groups over 12 years and are able to reduce symptomatic transmission by having 50% of symptomatic individuals staying home, the model expects hardly any winter wave at all. On the other hand, the scenario with a higher basic reproduction number $R_0 = 6$ shows that if the natural transmissibility is significantly higher, the model sees a sizeable wave during the late autumn and early winter. This wave could potentially reach 60-70 admissions per day at the peak. This is comparable to the 60 new admissions observed on the 25th of March 2020, which is the highest daily number of admissions until now. It is difficult to asses the likelihood of the different scenarios, so it is necessary to prepare both for scenarios with a fairly well controlled epidemic and scenarios with higher burden of disease during the winter. As with earlier waves in Norway, new waves can be suppressed or mitigated through interventions, and these interventions would not need to be as drastic as in previous waves in order to reduce the size to manageable levels. We are monitoring closely the development since the reopening, and will continuously update our models to obtain a more precise range of the estimates in future reports.

The main factors that influence the scenarios for the winter season are the natural transmissibility of the Delta variant, compliance with testing and home isolation when symptomatic, vaccination coverage and the amount of seasonal variation. Reaching a higher vaccination uptake than current levels can have a significantly positive effect on the epidemic and can either make a winter wave significantly smaller or allow us to keep the epidemic under control with less behavioural change. The main effect of additional vaccination in the younger age groups is to reduce the reproduction number and the number of infections in all age groups. Home isolation of symptomatic individuals can have a significant effect on the epidemic, and a high compliance to this from the public may have a major role in keeping the pandemic under control during winter.

High vaccination coverage, together with some reduction in symptomatic transmission by means of home isolation, may be sufficient to keep the epidemic under control during the winter season in Norway. There is, however, a realistic possibility of scenarios where there can be a sizeable winter wave.

1 Scenarios

It is very challenging to predict the COVID-19 epidemic over long time periods. This is due both to uncertainties in the natural transmissibility of the Delta variant in Norway, and because the disease transmission depends on people's behaviour, which is very hard to predict. Therefore, we present scenarios of what might happen given specific assumptions about policy implementation, people's behaviour, and about other factors governing the epidemic such as the effectiveness of vaccines and the duration of immunity. *Note that the future course of the epidemic will depend on the national and local control measures that the authorities impose to curb the transmission in the current and future waves of the epidemic, as well as on human behaviour. These future factors cannot be anticipated by the model. In addition, the epidemiological situation is highly uncertain. Therefore,* **the scenarios shown are not predictions on how the epidemic is likely to develop in the future** *but are the modelled outcomes of a specific set of assumptions.*

1.1 Reopening scenarios

In this report, we present a set of modelled scenarios where we assume that society was fully reopened on September 25th. This means that we do not assume any changes in behaviour or non-pharmaceutical interventions during the simulation period. The only non-pharmaceutical intervention we include in the model is home isolation when symptomatic, which remains constant throughout the simulations.

The reproduction number, R, is the number of secondary cases generated per infected individual on average. If R is greater than 1, the epidemic is expected to grow; otherwise the incidence of infections will drop. It is still too early to say exactly what the reproduction number is after the reopening, both due to the short time frame and to large changes in the testing regime. Therefore, we assume here that contacts between people returned to normal levels, which means that the potential for viral transmission between people increased to the levels that it was *before the pandemic* apart from home isolation when symptomatic.

It is very difficult to know exactly what the rate of spread of COVID-19 would be with no immunity and with pre-pandemic contact rates. The best we can do is to look at the early history of the epidemic in Norway, in February and early March of 2020. This was before any interventions were put in place by the government, and when only very few in the population had been exposed to the virus, meaning that the entire population was susceptible to infection. Our models estimate that the *basic reproduction number* (R_0) of the virus, which is the rate of spread of the virus in the Norwegian population in this period, was somewhere between 2 and 3 [1]. This is a highly uncertain estimate, partly because we do not know precisely how many imported cases there were from abroad.

An additional difficulty arises due to new variants. Since the start of the epidemic new variants of the virus have become dominant in Norway. It has been estimated that the Delta variant, currently dominating in Norway, has as about 1.5-2 times as large reproduction number as the original virus. This gives us an estimate for the R_0 of Delta, denoted by R_0^δ, in the range of about 3 to 6. For the scenario modelling presented here, we have thus chosen to operate with the values $R_0^\delta = \{4.5, 6\}$. We consider this to be a range of plausible scenarios. While R_0 values closer to the lower end of this range might be more plausible, an R_0 value of 6 is a possibility, and something we must plan for.
Based on the above estimates for R_0^δ, we calibrate our model to estimate what value for the model's transmission rate parameter corresponds to pre-pandemic level in a population with no immunity and no pharmaceutical and non-pharmaceutical interventions. We then start the simulation with this transmission rate, but with current levels of vaccination and assuming that some fraction of the infected individuals home-isolates when developing symptoms. For the calibration, we have used a home-isolation proportion of 50% for all scenarios, which is a slight simplification. This leads to the *effective* reproduction number (R_{eff}) at the current time to be much lower than R_0^δ. This is because a large part of the population has been vaccinated and/or has undergone the disease and acquired immunity, because sick people home-isolate to some degree, and because of seasonal variation in the transmission.

1.2 Vaccination scenarios

We use data from the Norwegian Immunisation Registry (SYSVAK) [2] to initialise the model with the correct number of people who have been vaccinated prior to the start of the simulation in each 1-year

age-group and municipality. We then run the model forward in time with three different scenarios for future vaccination. The first scenario is that no more first-doses are given, but everyone who has received a first dose, apart from 12-15 year olds, will receive their second dose. The second scenario is that we continue giving first doses until each age group has received at least 90% coverage. In the final scenario we investigate the effect of having 100% vaccination coverage for all eligible groups. We also assume no waning of immunity – this assumption covers both a scenario where there is no significant waning and a scenario where there is waning but the vaccination program is extended with booster shots such that protection is kept high.

1.3 Home isolation scenarios

We have implemented home isolation of symptomatic people in the model. For scenarios with 50% home isolation this is implemented such that 50% of people isolate at home from one day after symptom onset until 6 days after onset. While they are isolated they can spread the disease in the household, but not outside. The effect of home isolation is very dependent on the fraction of transmission that is due to people without symptoms, either from people who are asymptomatic or pre-symptomatic, which are still quite uncertain. Moreover there is little evidence on the level of home isolation among symptomatic cases. In order to take into account all these uncertainties, in alternative scenarios we vary the proportion of infected individuals adhering to home isolation by reducing it to 0% or 20% or increasing it to 70%.

2 Results

We present results from an individual-based model (IBM) which simulates the spread of the epidemic considering individual-level interactions in households, workplaces, schools, universities and the community setting [1]. The results for each scenario are based on 100 stochastic simulations of the IBM. In Section 3 we show a comparison of the IBM results to results from a metapopulation model to asses how much the scenarios depend on the specifics of the models.

2.1 Baseline scenario

In Figure 1, we show the outcomes of our simulations in terms of daily incidence of cases, hospital admissions and number of patients on ventilator treatment, in our *baseline* scenario. We have taken the baseline scenarios to have 50% adherence to home isolation among symptomatic individuals, 25% seasonality and a 90% vaccination coverage in all age groups 12 years and older. Table 1 shows the total number of cases, hospital admissions and ventilator treatments throughout the simulation period from October 4th until June 30th 2022.

The baseline scenarios show a plausible range of scenarios for the winter. For the low R-values we are in situation where the current effective R-value is less than one and we get a shrinking epidemic and no winter wave. For $R_0 = 6$ we find that the effective reproduction number is above one now, and even with some additional effect of the vaccination program we get an increasing epidemic from the start that peaks around the start of 2022.

The different scenarios have effective reproduction numbers R_{eff} in the range 0.8-1.4 at the beginning of the simulation, as detailed in Table 2. The R_{eff} is slightly lower under the higher seasonality assumption (50%), because a larger seasonal variation means that a larger share of the contact rate increase is taken care of by the seasonal factor. Hence, the model starts out with a comparatively lower contact rate (and thus also lower R_{eff}) for higher seasonality, as indicated by the reopening factors that are also shown in the table. We note that with the higher seasonality assumption (50%) and $R_0 = 4.5$, the reopening factor is in fact slightly under one. The interpretation of this is that the model believes the current state of transmission in Norway to correspond to an R_0 that is slightly above 4.5, given a seasonal variation of 50%. At the other end of the spectrum, with lower seasonality and $R_0 = 6$, the factor is 1.6 – a 60% increase in the contact rate at reopening was required to bring Norway back to pre-pandemic level. Tables 3 and 4 show breakdowns by age and vaccination status of the total number of cases and hospitalisations, respectively, in the baseline scenarios.

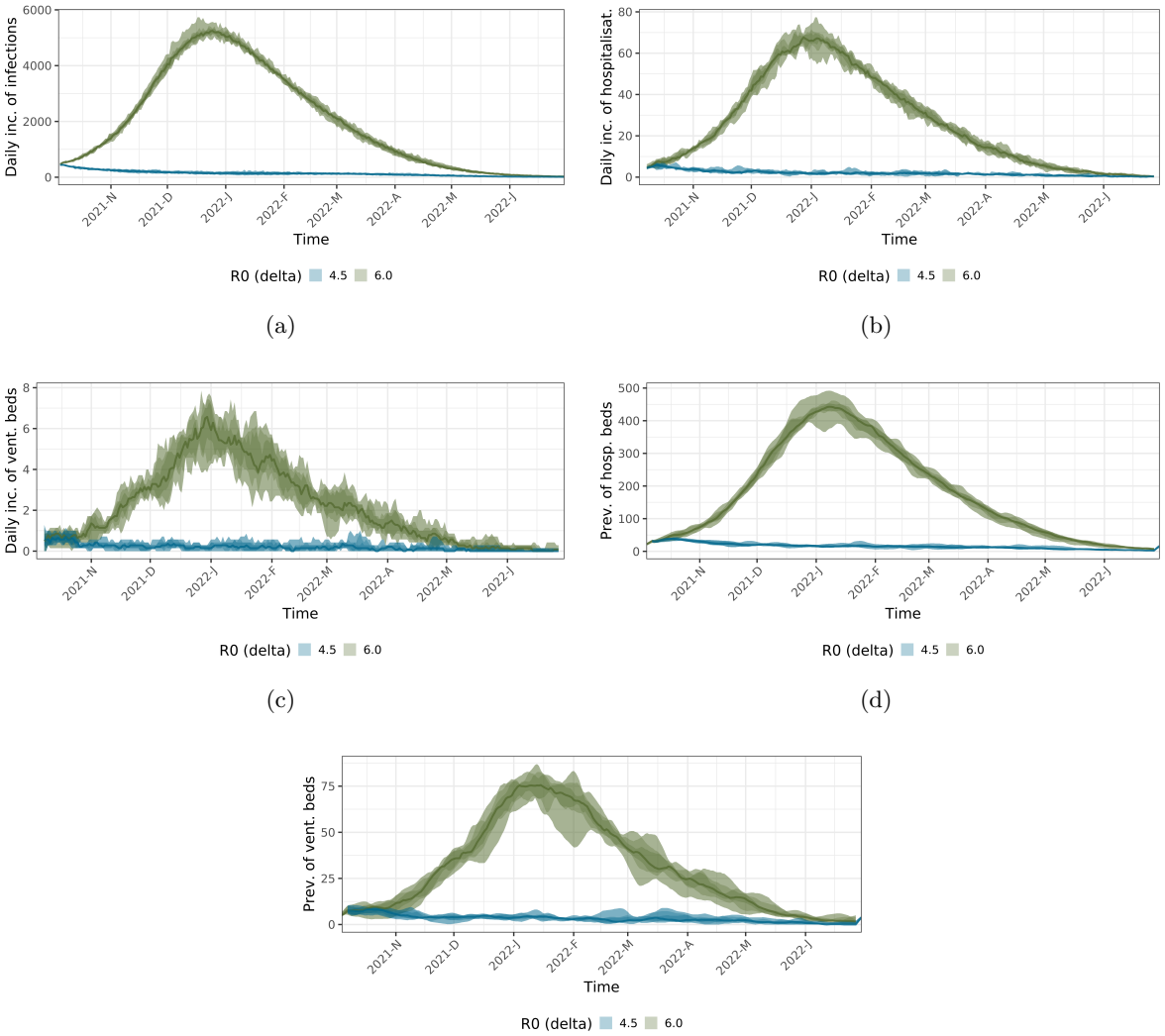


Figure 1: Long-term predictions from the baseline scenario, which assumes 90% vaccine coverage, 25% seasonality and 50% adherence to home isolation among symptomatic individuals, for daily incidence of infections (a), hospital admissions (b) and patients on ventilator treatment (c), as well as prevalence of hospital admissions (d) and ventilator treatment (e). A 7-day moving average has been applied to the incidence curves of hospitalisation and ventilator treatment in order to reduce fluctuations. The prevalence estimates are uncertain due to lack of data on length of stay for vaccinated individuals.

Seasonality	Vacc. uptake	Home isolation	R_0^δ	Infections	Hospitalisations	Ventilator
25 %	Current	0%	4.5	317551 (303339-332865)	3932 (3849-4175)	349 (333-381)
25 %	Current	0%	6	1103280 (1091733-1114418)	14030 (13788-14402)	1116 (1065-1131)
25 %	Current	20%	4.5	225934 (209615-239585)	2881 (2661-3067)	264 (210-287)
25 %	Current	20%	6	964654 (957865-977218)	12162 (12035-12403)	966 (911-1057)
25 %	Current	50%	4.5	104893 (84777-115211)	1322 (1076-1476)	108 (87-144)
25 %	Current	50%	6	744216 (734518-759022)	9366 (9127-9576)	782 (744-795)
25 %	Current	70%	4.5	47937 (36794-60003)	609 (482-789)	62 (47-88)
25 %	Current	70%	6	597672 (588820-614332)	7450 (7209-7637)	624 (572-644)
25 %	90%	0%	4.5	161605 (146445-177308)	2170 (1955-2429)	193 (178-241)
25 %	90%	0%	6	878634 (864304-891169)	11380 (11070-11652)	914 (860-954)
25 %	90%	20%	4.5	96340 (76379-103622)	1328 (1063-1402)	124 (104-137)
25 %	90%	20%	6	749712 (744836-756378)	9556 (9400-9979)	782 (754-824)
25 %	90%	50%	4.5	36998 (27480-44123)	529 (428-638)	54 (41-67)
25 %	90%	50%	6	533812 (528113-561557)	6872 (6542-7202)	574 (511-601)
25 %	90%	70%	4.5	20728 (18133-25002)	307 (266-377)	32 (27-47)
25 %	90%	70%	6	392550 (375086-404234)	4902 (4748-5108)	430 (401-456)
25 %	100%	0%	4.5	29738 (23517-36148)	296 (241-362)	22 (10-28)
25 %	100%	0%	6	327574 (300341-334656)	2760 (2603-2873)	134 (111-153)
25 %	100%	20%	4.5	21452 (17868-24763)	240 (208-266)	18 (9-28)
25 %	100%	20%	6	247067 (236381-256642)	2080 (1941-2155)	94 (80-120)
25 %	100%	50%	4.5	14370 (12438-15898)	179 (171-196)	16 (11-20)
25 %	100%	50%	6	147658 (137678-158367)	1237 (1149-1330)	66 (52-73)
25 %	100%	70%	4.5	11796 (10729-13013)	164 (135-175)	14 (7-20)
25 %	100%	70%	6	93988 (82326-107665)	782 (737-855)	42 (37-53)
50 %	Current	0%	4.5	286836 (249713-299348)	3697 (3171-3771)	321 (262-344)
50 %	Current	0%	6	1083440 (1072489-1099703)	13830 (13633-14178)	1080 (1018-1107)
50 %	Current	20%	4.5	194018 (166574-208185)	2422 (2149-2602)	209 (193-253)
50 %	Current	20%	6	957781 (942203-968408)	12058 (11714-12386)	938 (929-980)
50 %	Current	50%	4.5	78182 (61450-95926)	1051 (787-1297)	104 (74-137)
50 %	Current	50%	6	743178 (717093-753032)	9260 (8883-9442)	748 (704-809)
50 %	Current	70%	4.5	30567 (22119-36808)	450 (338-504)	46 (39-59)
50 %	Current	70%	6	578436 (566222-589495)	7145 (6963-7215)	582 (553-627)
50 %	90%	0%	4.5	119811 (113276-142175)	1647 (1565-1848)	157 (138-170)
50 %	90%	0%	6	867154 (860670-880388)	11148 (11003-11473)	882 (860-946)
50 %	90%	20%	4.5	64880 (48137-78266)	860 (677-1105)	80 (62-113)
50 %	90%	20%	6	734518 (725700-753415)	9431 (9200-9667)	768 (701-786)
50 %	90%	50%	4.5	19934 (17520-23624)	296 (251-347)	33 (24-43)
50 %	90%	50%	6	515566 (506687-533815)	6588 (6366-6742)	545 (513-580)
50 %	90%	70%	4.5	12058 (10536-15034)	206 (171-263)	24 (11-30)
50 %	90%	70%	6	362682 (345016-381907)	4624 (4345-4778)	385 (368-410)
50 %	100%	0%	4.5	19162 (13490-23510)	218 (183-272)	16 (13-22)
50 %	100%	0%	6	297293 (286304-310118)	2477 (2337-2661)	116 (107-146)
50 %	100%	20%	4.5	12968 (11646-16827)	177 (148-220)	14 (9-20)
50 %	100%	20%	6	220502 (209453-225657)	1845 (1712-1915)	86 (78-104)
50 %	100%	50%	4.5	9852 (9076-11733)	152 (134-163)	14 (8-20)
50 %	100%	50%	6	121994 (106225-127887)	998 (856-1035)	50 (37-62)
50 %	100%	70%	4.5	8653 (8097-9772)	138 (123-157)	14 (8-17)
50 %	100%	70%	6	65373 (59249-80638)	572 (501-703)	35 (24-46)

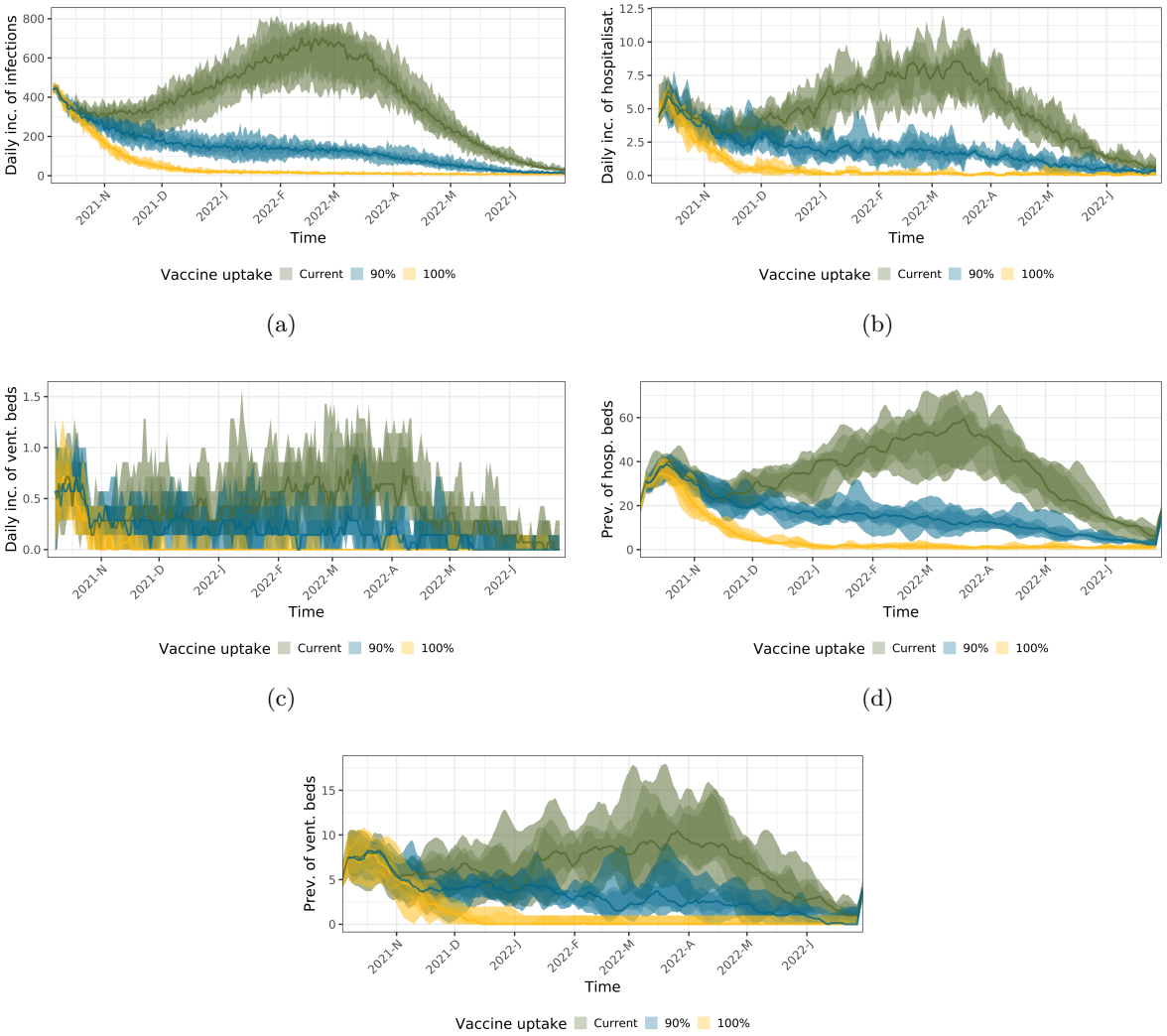
Table 1: Total number of cases, hospitalisations and patients on ventilator treatment during the simulation period, for different assumptions on seasonality, home-isolation adherence, vaccination coverage and reopening R_0^δ. Numbers shown are median (95 % CI).

2.2 Effect of vaccine coverage

Figure 2 shows the effect of varying vaccine uptake. Increasing vaccine uptake from the current level is an effective way of reducing the disease burden of a winter wave both in terms of infections, but also for hospitalisations. Increasing to 90% coverage mainly increases the coverage in the 12-45 year age groups. This can provide a strong indirect effect on the epidemic and reduce hospitalisations and deaths in all ages. Figure 12 shows the distribution of the additional vaccines given in the model in the 90% and 100% scenarios.

2.3 Effect of home isolation when symptomatic

We investigate different scenarios varying the proportion of the population adhering to the advice of staying home during symptoms. We assume a 50% adherence to home isolation in the baseline scenario shown above. Here we show results where this percentage is varied from 0% to 70%. The resulting epidemiological curves are shown in Figure 4 and 5, for $R_0^\delta = 4.5$ and 6, respectively. We see that home isolation has a major effect on the size of the wave, and thus illustrates the importance of this non-pharmaceutical intervention measure and individual behaviour for the containment of the disease.



(a) (b) (c) (d) (e)

Figure 2: The same plots as Figure 1, but for varying vaccination coverage: Current (vaccination level as of October 4th 2021), 90% or 100%. Here it is assumed $R_0^\delta = 4.5$, 50% adherence to home isolation and seasonality 25%.

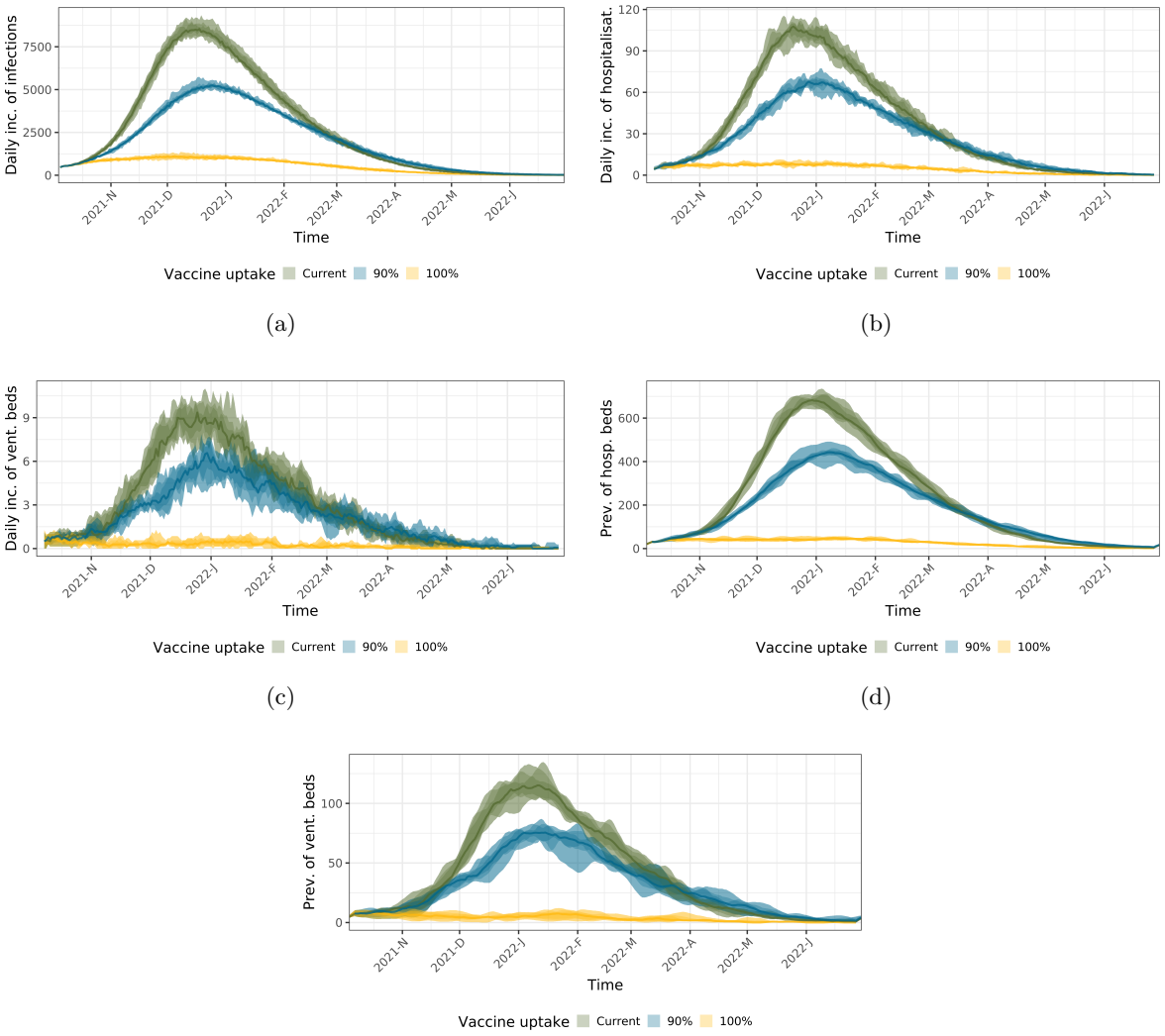


Figure 3: The same plots as Figure 1, but for varying vaccination coverage: Current (vaccination level as of October 4th 2021), 90% or 100%. Here it is assumed $R_0^\delta = 6$, 50% adherence to home isolation and seasonality 25%.

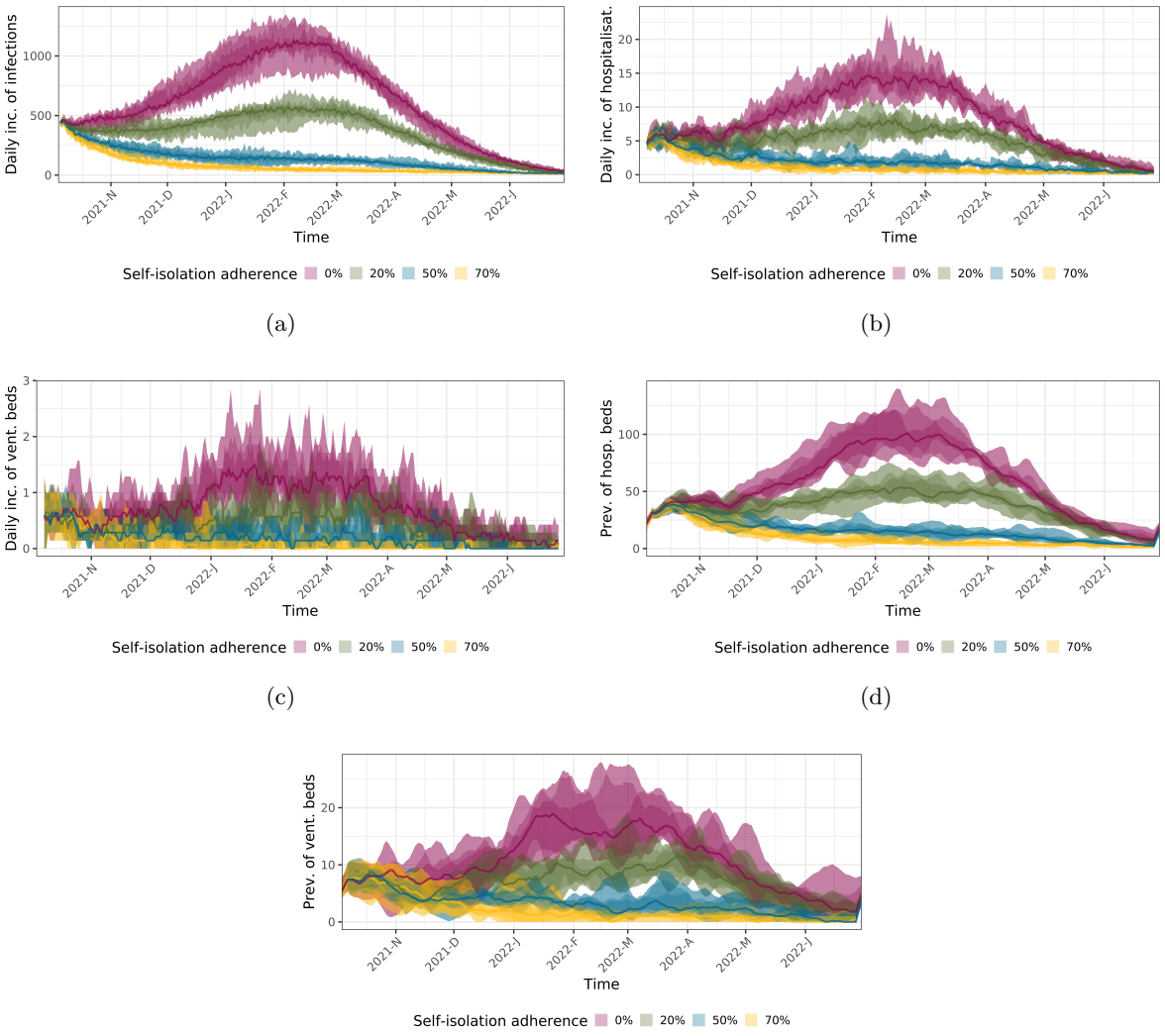


Figure 4: The same plots as Figure 1, but for varying degree of adherence to home isolation recommendations. Here it is assumed $R_0^\delta = 4.5$, vaccine coverage 90% and 25% seasonality.

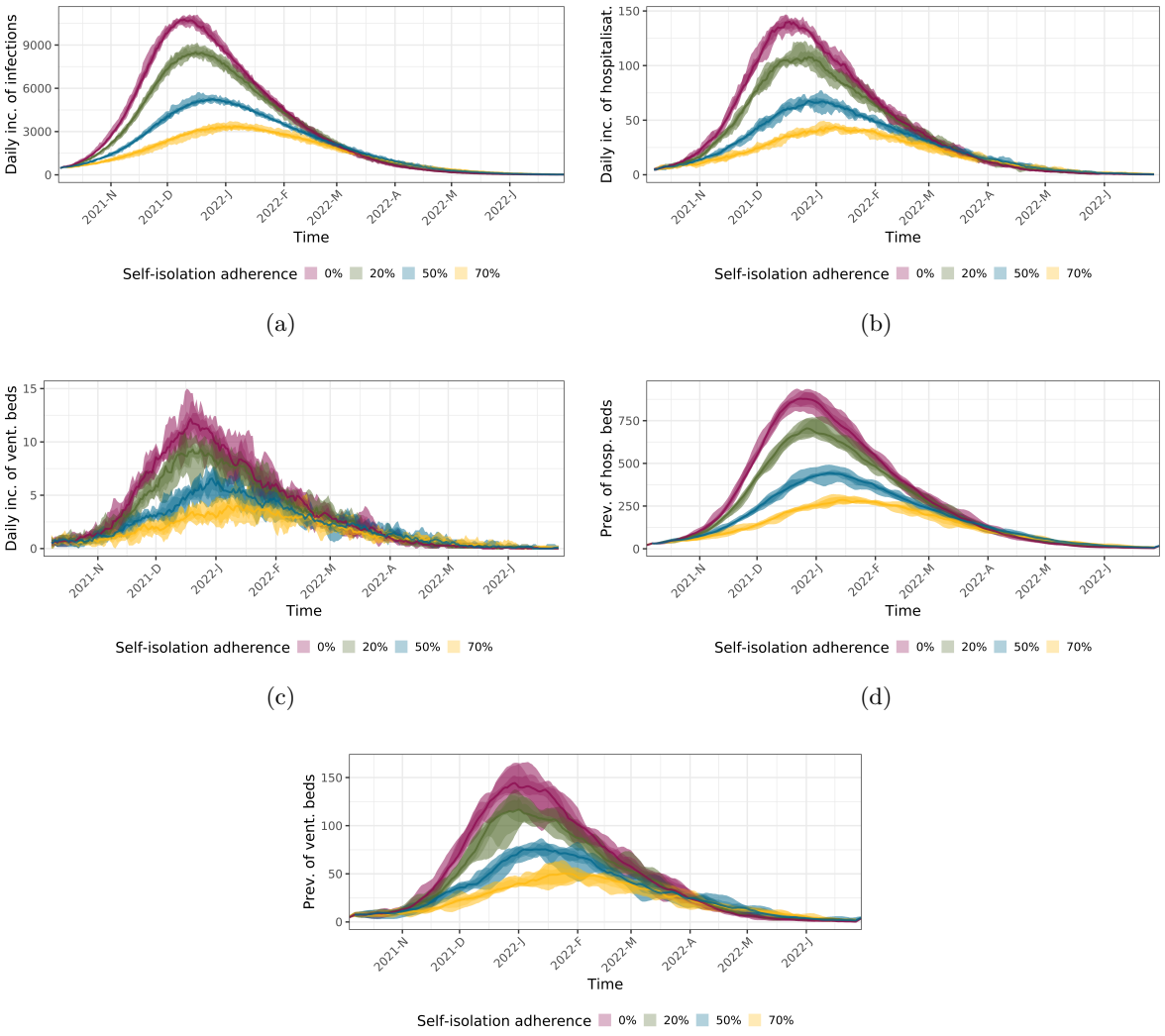


Figure 5: The same plots as Figure 1, but for varying degree of adherence to home isolation recommendations. Here it is assumed $R_0^\delta = 6$, vaccine coverage 90% and 25% seasonality.

R0	Home isolation	Seasonality	R_{eff}	Reopening factor
4.5	0%	25	1.01 (0.95-1.08)	—
4.5	20%	25	0.97 (0.91-1.04)	—
4.5	50%	25	0.9 (0.83-0.96)	1.12 (1.07-1.16)
4.5	70%	25	0.85 (0.78-0.92)	—
6	0%	25	1.36 (1.31-1.41)	—
6	20%	25	1.3 (1.26-1.35)	—
6	50%	25	1.21 (1.16-1.26)	1.61 (1.55-1.68)
6	70%	25	1.13 (1.09-1.19)	—
4.5	0%	50	0.93 (0.86-1)	—
4.5	20%	50	0.87 (0.8-0.94)	—
4.5	50%	50	0.82 (0.74-0.89)	0.93 (0.89-0.97)
4.5	70%	50	0.76 (0.69-0.83)	—
6	0%	50	1.25 (1.21-1.3)	—
6	20%	50	1.19 (1.14-1.25)	—
6	50%	50	1.09 (1.04-1.15)	1.34 (1.28-1.4)
6	70%	50	1.04 (0.98-1.1)	—

Table 2: Effective R values after reopening, and reopening factors (the relative change in contact rate from the initially calibrated value corresponding to $R_{\text{eff}} = 0.9$, to the reopening contact rate). The effective R values are calculated by averaging over the month of October. The values shown are median (interquartile range)

R0	Vaccination status	0–11	12–17	18–64	65+
4.5	total	9782 (6966-11975)	3550 (2581-4221)	20530 (15357-24243)	3152 (2492-3684)
4.5	unvaccinated	9782 (6966-11975)	1165 (835-1411)	4313 (3125-5280)	789 (603-890)
4.5	vaccinated	0	2384 (1746-2810)	16218 (12232-18963)	2364 (1889-2794)
6	total	143032 (140885-149385)	52778 (51540-56041)	291690 (288979-307646)	46508 (45224-48602)
6	unvaccinated	143032 (140885-149385)	18288 (17700-19461)	56708 (56160-59684)	8660 (8253-9094)
6	vaccinated	0	34490 (33840-36580)	234982 (232819-247962)	37848 (36971-39508)

Table 3: Total number of cases during the simulation period, by age and vaccination status, in the baseline scenarios. Numbers shown are median (95 % CI).

2.4 Effect of seasonality

While it is believed that the transmissibility of the virus varies with season, being higher in the winter months (e.g. [3]), the magnitude of this variation remains unclear. In our baseline scenarios, we have chosen to vary the transmission rate by 25% between the coldest and warmest day of the year (measured by the daily average temperature for Norway). In this section we investigate the alternative scenario where the seasonal variation is 50% (Figures 6 and 7 for R_0^{δ}=4.5 and 6, respectively). Since the effective contact rate at the start of the outbreak is defined such that we would reach the given R_0 value on the 1st of March regardless of the magnitude of seasonal variation, the difference between the seasonality assumptions is not very large. With lower seasonality we must have a higher contact rate now in order to reach the given reproduction number. The main difference between the seasonality scenarios is in the timing of the peak of the wave: For $R_0 = 6$, in the alternative scenario of 50 % seasonality, the peak comes about a month later than in the baseline.

2.5 Additional results

In Figures 9, 10 and 11 we show results for the baseline scenarios broken down on age groups. As expected we see a large number of infections, but a low number of hospitalisations in the lower age groups. Figure 8 shows the incidence risk per 100 000 population of vaccinated and unvaccinated individuals. The plot shows a significant higher risk of infections and hospitalisation for unvaccinated people. Figure 12 displays the number of first doses given to individuals during the simulations (not including the data from SYSVAK, which are always included).

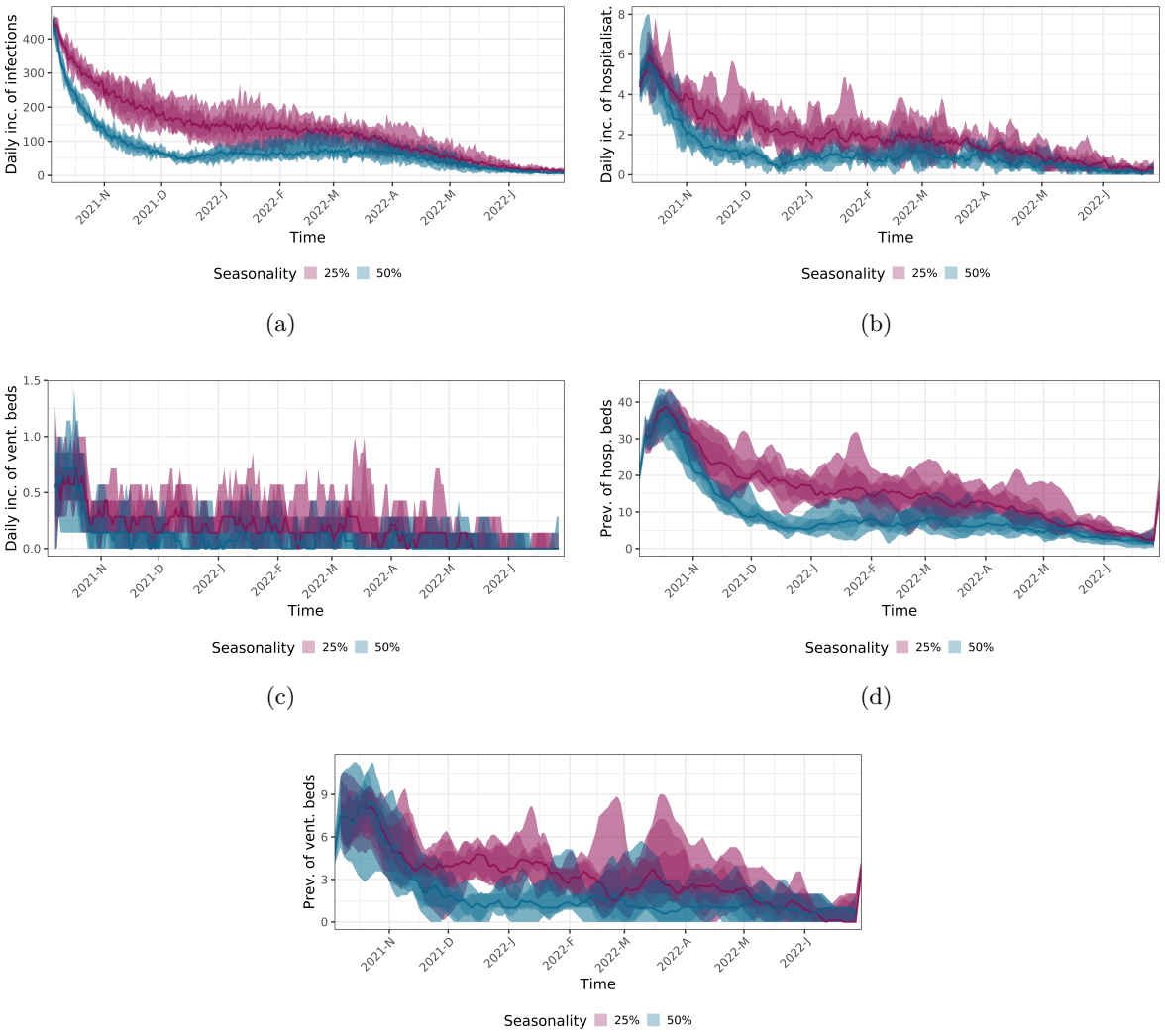


Figure 6: The same plots as Figure 1, but for varying seasonal variation in transmission. Here it is assumed $R_0^\delta = 4.5$, vaccine coverage 90% and 50% adherence to home isolation.

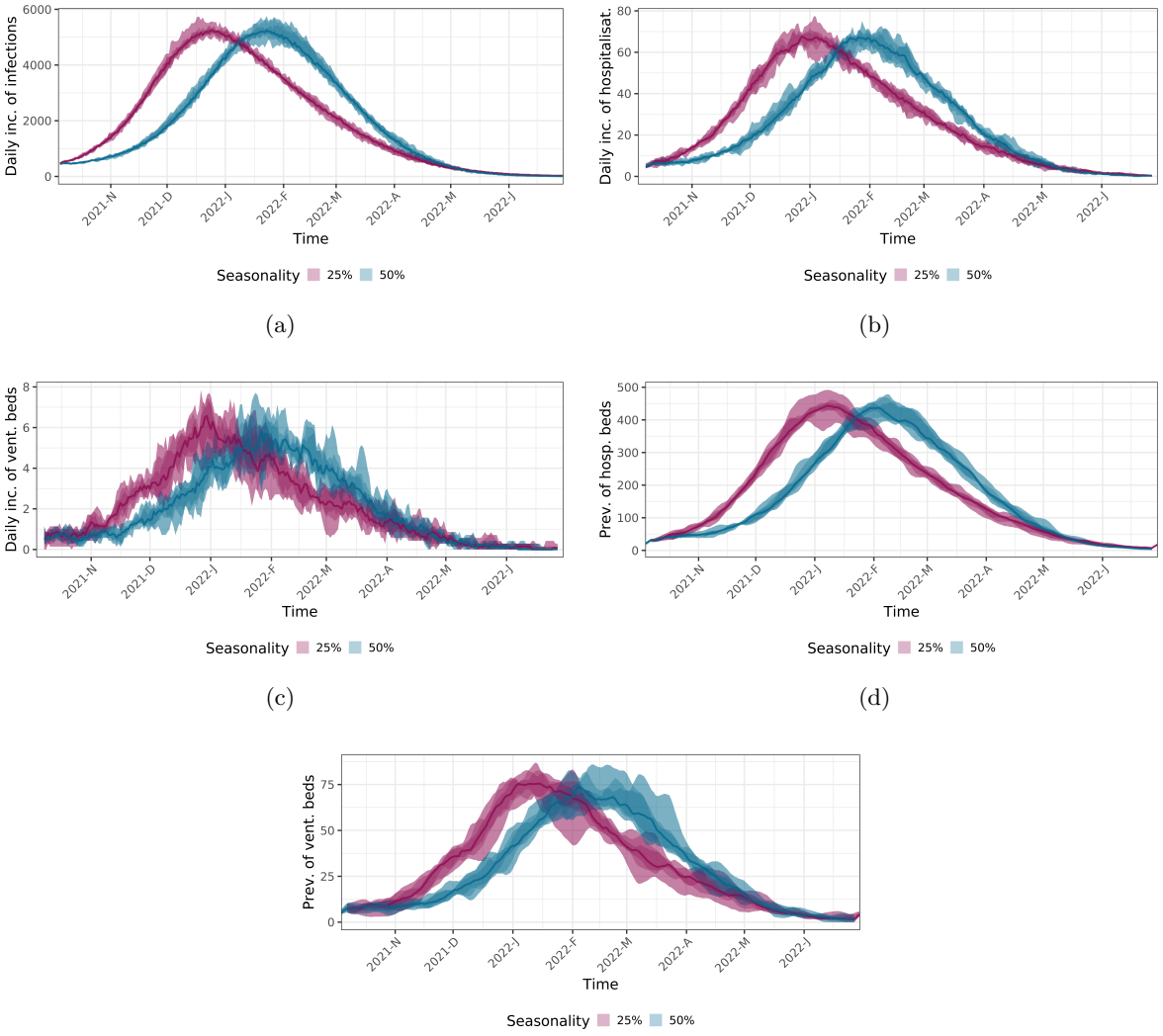
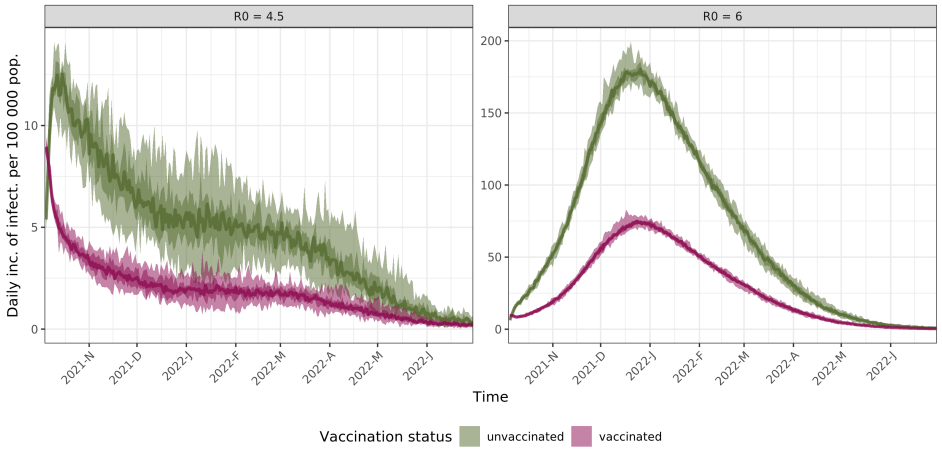
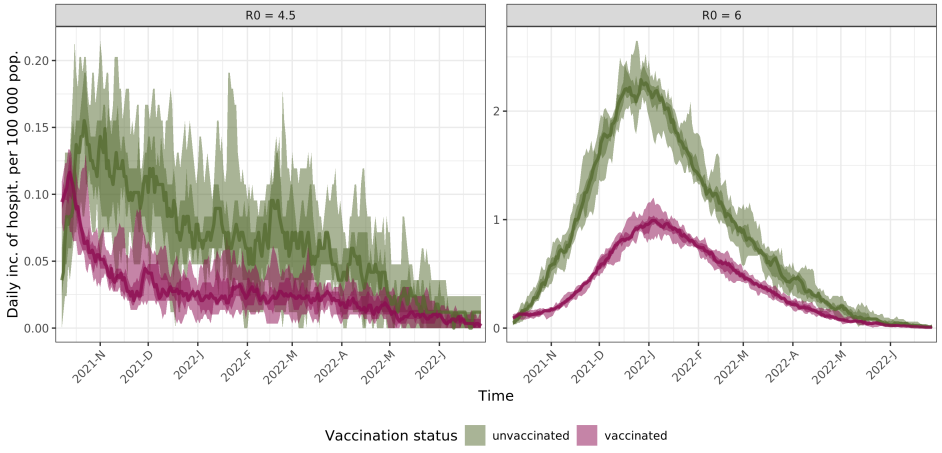


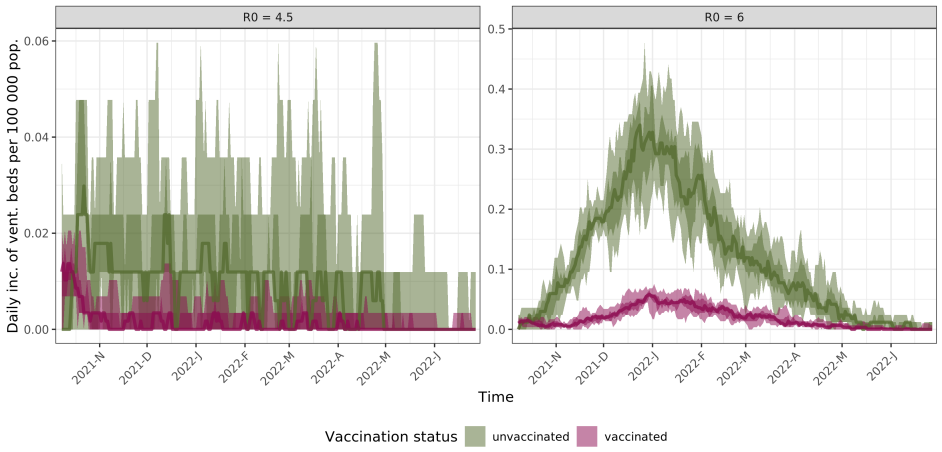
Figure 7: The same plots as Figure 1, but for varying seasonal variation in transmission. Here it is assumed $R_0^\delta = 6$, vaccine coverage 90% and 50% adherence to home isolation.



(a)



(b)



(c)

Figure 8: Incidence per 100 000 population for vaccinated and unvaccinated people from the baseline scenario, which assumes 90% vaccine coverage, 25% seasonality and 50% adherence to home isolation among symptomatic, for incidence of infections (a), hospital admissions (b) and ventilator treatments (c). A 7-day rolling average has been applied to the hospitalisation and ventilator bed curves.

R0	Vaccination status	0–11	12–17	18–64	65+
4.5	total	12 (5-17)	1 (0-4)	252 (195-316)	255 (213-302)
4.5	unvaccinated	12 (5-17)	0	97 (78-122)	94 (78-111)
4.5	vaccinated	0	1 (0-2)	155 (117-194)	160 (135-191)
6	total	174 (162-193)	31 (19-45)	3307 (3103-3479)	3339 (3219-3498)
6	unvaccinated	174 (162-193)	16 (10-20)	1308 (1170-1332)	1185 (1107-1262)
6	vaccinated	0	14 (9-25)	1999 (1933-2147)	2154 (2112-2236)

Table 4: Total number of hospitalisations during the simulation period, in the baseline scenarios, by age and vaccination status. Numbers shown are median (95 % CI).

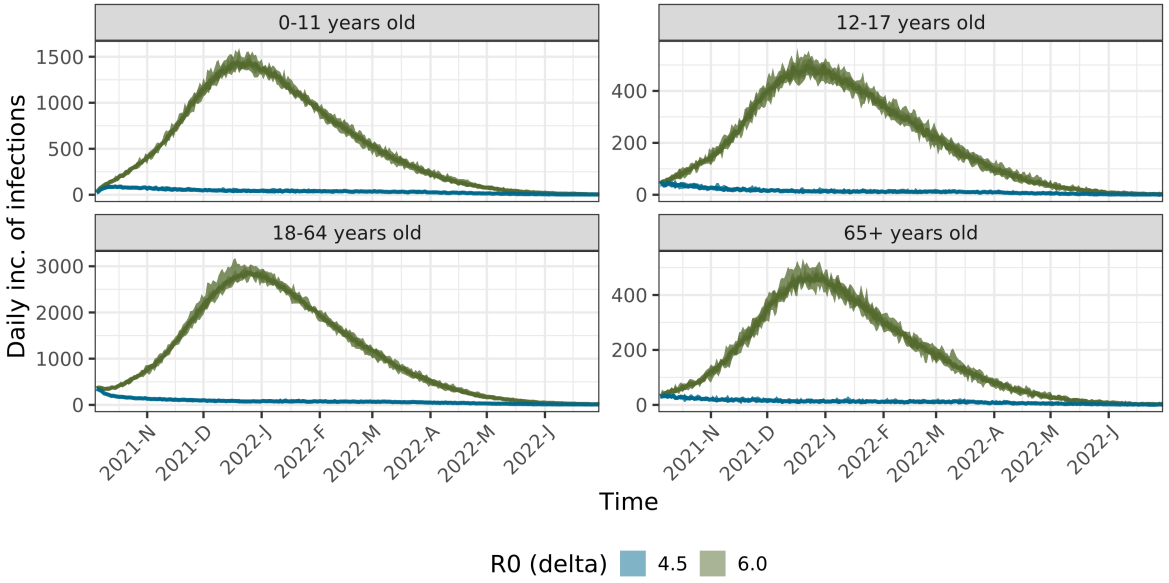


Figure 9: Daily incidence of cases. Panels show different age groups, lines show different assumptions for R_0^δ.

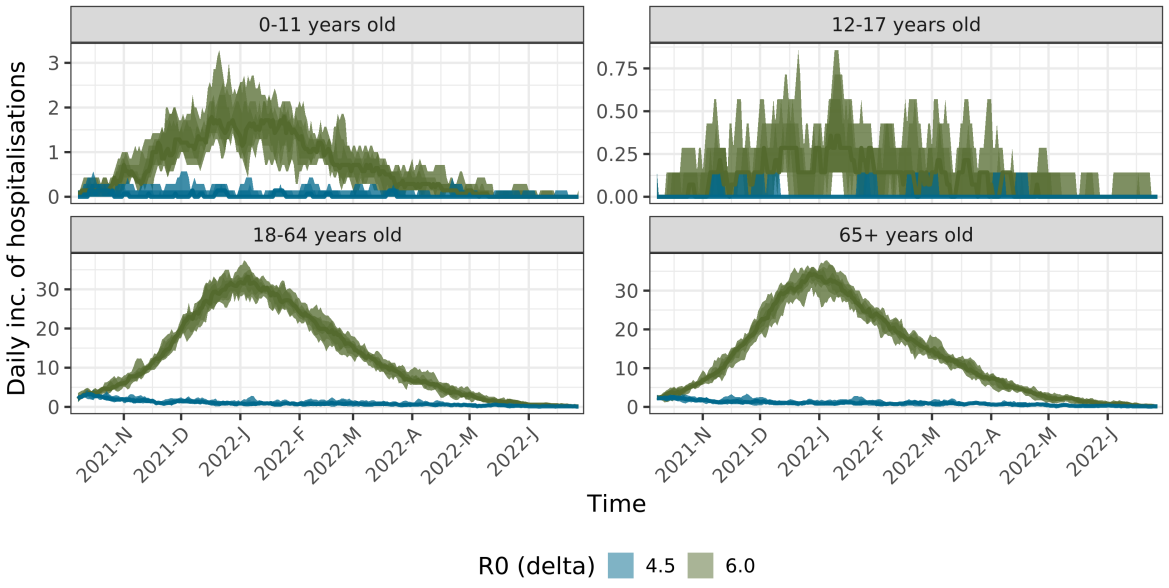


Figure 10: Daily incidence of hospitalisations. Panels show different age groups, lines show different assumptions for R_0^δ.

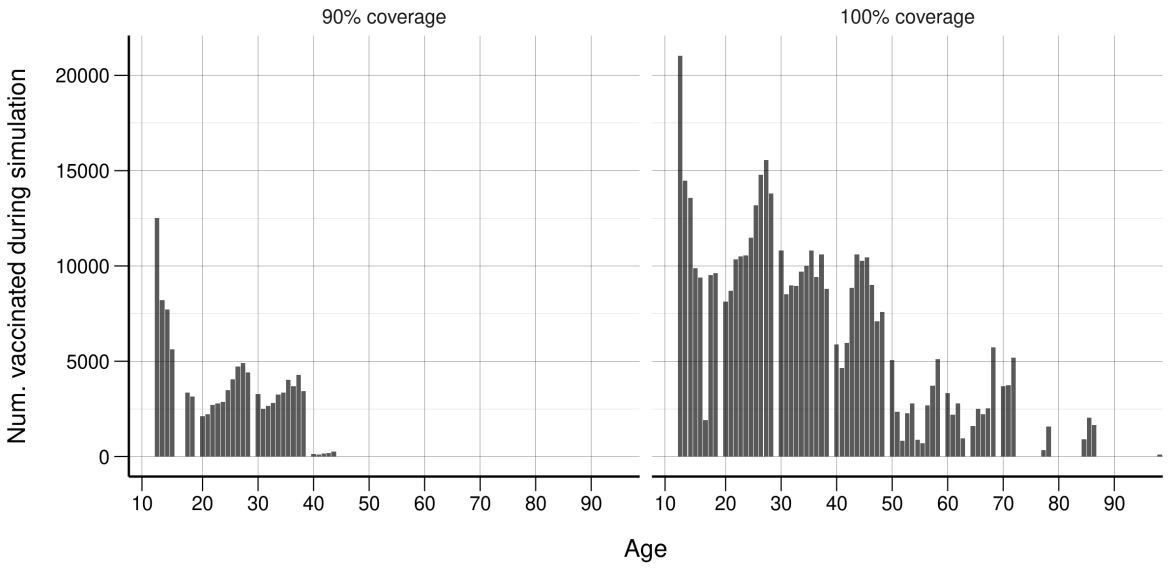


Figure 12: Number of doses distributed in the model during the simulations (not including the vaccination data from SYSVAK, which are always distributed during initialisation), by age, in the scenarios with 90% and 100% coverage.

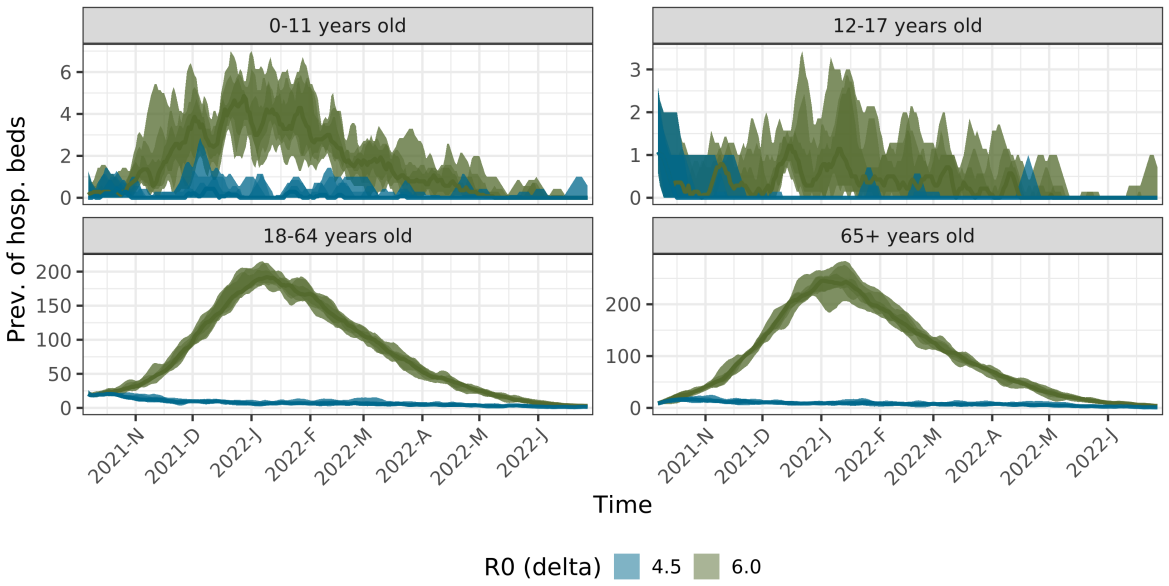
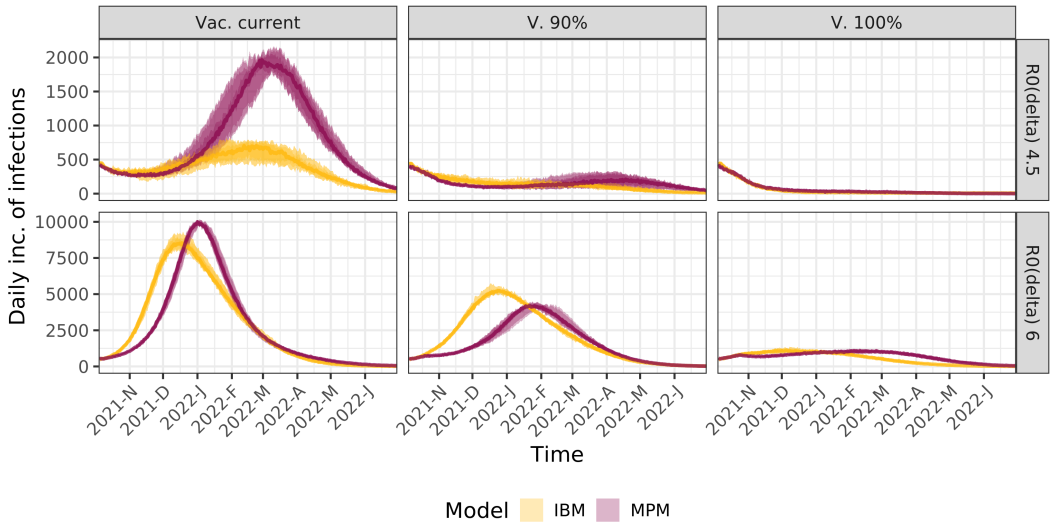


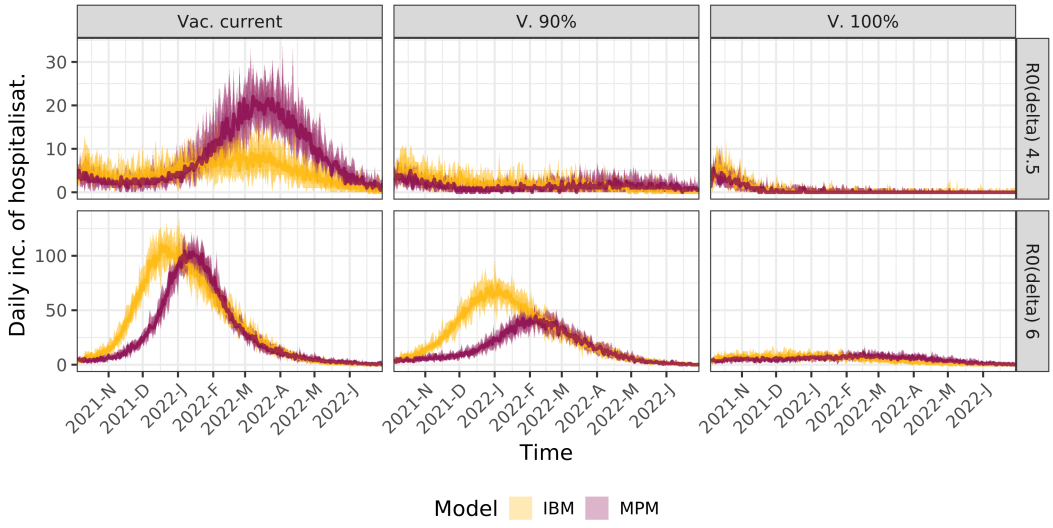
Figure 11: Prevalence of hospitalisations. Panels show different age groups, lines show different assumptions for R_0^δ.

3 Alternative model

To asses the robustness of the models we compared the IBM model results presented above to a metapopulation model (MPM) with 10-year age groups and 22 geographical divisions. Qualitatively the models give similar results, but there are some differences. These differences are due to differences in implementation of mobilty, geographical resolution, contact structure and calibration. The main difference in model structure is that the IBM model takes into account a more realistic contact structure in various settings and more realistically includes repeated contacts.



(a)



(b)

Figure 13: Comparison between the IBM and the MPM for incidence of cases (a) and hospitalisations (b). The different panels show varying R_0^δ values and vaccine coverages. It is assumed 50% adherence to home isolation and 25% seasonality.

4 Limitations and uncertainties

- There is large uncertainty in the value of the effective R-number upon reopening. There is a lack of knowledge about the precise effect of interventions and human behaviour on the spread of SARS-CoV-2, in particular which contact rate corresponds to a situation of "normal" social contact in society after reopening. Moreover there are large uncertainties on the value of the basic reproduction number of the Delta variant. The results are sensitive to these assumptions about the basic reproduction number and the contact rate when contact reducing measures are relaxed.

- The models do not take into account new virus variants imported into Norway or future genetic variations of the virus. Thus, our scenarios assume that the spreading potential remains constant in time (apart from seasonal variations).

- The model takes into account differences in the vaccine distribution at the municipality and age level based on historical data. However, we do not consider the effect of clusters of unvaccinated groups in the society. Small groups in the community with low vaccine coverage, might lead to the emergence of local outbreaks.

- Assumptions about vaccine effects and vaccine deliveries are uncertain.

- The estimated prevalence of patients in hospital and on ventilator treatment depend on the assumed length of stay. The effect of vaccination on length of stay is uncertain due to limited data. We have assumed that vaccinated individuals have a 20% shorter length of stay. The prevalence numbers in this report should be viewed as crude estimates and used with caution.

- There is lack of data about the current level of adherence to individual control measures, such as home isolation. In the models we run the baseline scenarios assuming a 50% proportion of home isolation among symptomatic cases and we vary this parameter in sensitivity analyses. Adherence to home isolation is kept constant throughout each run, however this parameter might change in time, depending on the evolution of the pandemic and future changes in the infection-control policies.

- The relative importance of transmission by asymptomatic and pre-symptomatic individuals is not well known, and these factors have a large impact on the transmission dynamics in the model.

- Reproduction numbers in Norway's municipalities and districts are changing continuously during the pandemic. We have made an assessment of where in the country there have been persistently high and low infection rates and how large the variance is. In the simulations, we use a constant scaling factor for each municipality/district during the entire simulation period. This means that the results must be interpreted carefully because they depend on the fact that the level of infection in the country's regions is predictable in the future and follows the previous developments. Due to time constraints, we have not carried out sensitivity analyses that could shed light on the importance of variability in infection pressure between regions.

- There are uncertainties on the seasonal variation of the COVID-19 spread. In the baseline scenarios we assumed a seasonality of 25%, varying this number to 50% in additional analyses. However, there are limited empirical data to asses the seasonal variation in the infection rate of the Delta variant.

- The risk of serious illness for the youngest age groups is difficult to estimate since there have been few cases of serious illness in these groups in Norway.

- The results of the models are based on current knowledge and there will be a need for ongoing updates when new information and knowledge become available. Results may also change as a result of the model continuing to be developed.

- We assume that vaccinated individuals suffer no waning of immunity.

5 Methods

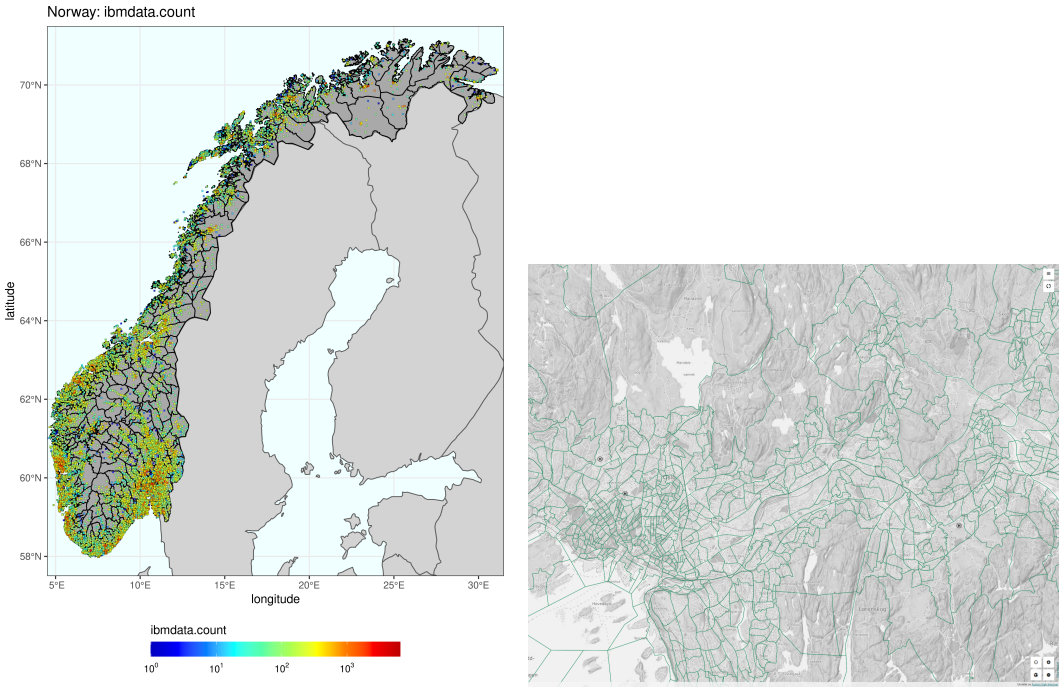
5.1 Individual-based model structure

We developed a stochastic individual-based model (IBM) simulating the spread of COVID-19 in Norway at the individual level, taking into account different factors such as specific places of transmissions, age and vaccination status of the population.

Synthetic population

The model consists of a population of approximately 5.3 million individuals distributed on a geo-located grid of 13521 cells (Figure 14a) at the grunnkrets resolution in Norway (Figure 14b) [4]. Each individual is characterized by specific features:

- age, ranging between 0 and 100;
- type of occupation (student, teacher, generic worker, healthcare worker, retired or unemployed);
- health status; (COVID-19 positive or negative)
- epidemiological status (see description of compartment model below);
- hospitalisation status (not hospitalised, hospitalised, hospitalised in ICU);
- vaccination status;
- geographic location.



(a) (b)

Figure 14: Geo-spatial resolution of the Individual-based model. The model consists of 13521 cells (grunnkrets) defining the territory of Norway. Figure (a) shows the distribution of the population on the grid at the national level. Figure (b) shows an example of the grunnkrets divisions for the Oslo municipality taken from kart.ssb.no.

Persons live in households and, depending on age, are associated to schools (different school levels are considered in the model, from kindergartens to high-schools), universities or to workplaces, if not unemployed or retired. The household size and age distribution of people in the household have been calibrated on Norwegian census data in order to obtain the real socio-demography of Norway [5].

Mobility patterns

Transmission in the community depends on location of individuals and their mobility, which may contribute to long distance transmission. The travel distance of individuals in the model is governed by a probability distribution that is estimated from mobility data from Telenor, for the single day of Monday January 25th 2021. Specific mobility distributions have been defined for each municipality. These define a probability distribution of the distance people travel from their home, estimated as a radius of gyration using length-of-stay as the mass parameter. The probability distributions are hence isotropic, dependent only on radial distance. We see empirically that the mobility distributions resemble χ^2 distributions, so the probability mass functions used in the model are a fit of the mobility data (which has a non-optimal spatial resolution) to a χ^2 distribution, separately for each municipality. The degrees of freedom and scale are free parameters in the fit. Figure 15 shows the probability distributions for a selection of municipalities. The probability distribution has an exponential-like

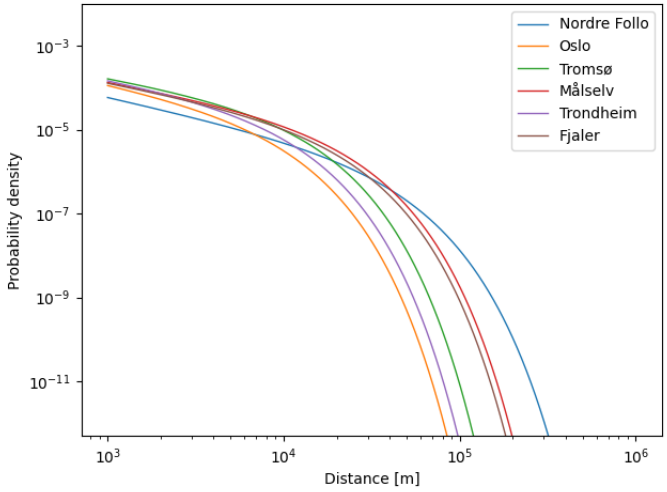


Figure 15: Mobility distribution for selected municipalities.

drop as function of distance, meaning that within-city transmission is much more likely than intercity transmission and, for example, the probability of transmitting from Oslo to Sandvika is much higher than transmission to Bergen.

Epidemiological model and parameters

Individuals in the model are characterised by different epidemiological states, namely susceptible (S), exposed and non-infectious (E1), pre-symptomatic (E2), symptomatic (I), asymptomatic (Ia) or recovered (R). The progression between these compartments follows the epidemiological SEIR diagram in Figure 16. The time spent in each compartment has been modelled with gamma distributions. The parameters of the gamma distributions are reported in Table 5 together with the relative infectiousness of each compartment.

	Time duration			
Compartment	shape	scale	mean (days)	Relative infectiousness
E1 (exposed)	5	0.4	2	0
E2 (presymptomatic)	5	0.4	2	1.25
I (symptomatic)	3.7	0.8	3	1.0
Ia (asymptomatic).	3.7	0.8	3	0.1

Table 5: Compartments and parameters. The time duration of each compartment follows gamma distribution. The mean value is a product of shape and scale parameters.

.

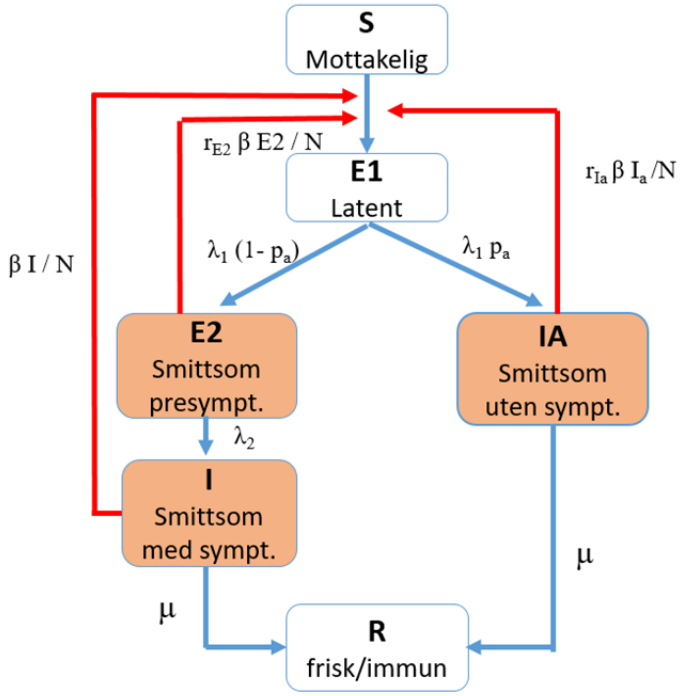


Figure 16: Compartment model. Taken from FHI website.

Since the start of the epidemic different studies have suggested an age-dependent susceptibility to COVID-19 infections [6, 7]. In the model we have taken into account these differences defining specific levels of susceptibility by age-group based on [7] (Table 6).

age	Susceptibility
0-9	0.23
10-19	0.45
20-59	0.68
60-69	0.83
70-100	1.00

Table 6: Susceptibility parameters. Younger individuals with lower susceptibility are less likely to be infected compared to the older individuals.

In the model described above a fraction of the infected individuals do not develop symptoms and, after being exposed to the virus, progress towards an asymptomatic infected state (Ia). Based on the study of Sah *et al.* [8] we defined age-dependent probabilities of remaining asymptomatic as normally distributed variables (Table 7).

Age-group	Fraction of asymptomatic cases	
	Mean	SD
0-18	0.47	0.08
19-59	0.32	0.06
60+	0.20	0.05

Table 7: Probabilities of asymptomatic infections. Younger individuals have a lower probability of developing symptoms compared to the older individuals.

Transmission dynamics

In the IBM people are in contact in various settings: households, educational institutions, workplaces and the community. All these places are characterized by specific networks and type of contacts that affect the probability of transmission. In the model we take into account these differences by having specific transmission risks for each setting. These parameters are calibrated on the observed number of infections by setting, with about 40% of the infection occurring in the community, 35% in households and the rest in schools and workplaces.
Regional differences in the transmission have been included in the model by estimating a scaling factor for the national reproduction number in each municipality (see section Model initialisation below)

Hospitalisation parameters

Symptomatically infected individuals (I) have a probability of hospitalisation that depends on their age and whether they have underlying diseases. These probabilities are listed in Table 8. From hospitalisation, they have a probability of being admitted to ventilator treatment. The death model operates separately from the hospitalisation model, *i.e.* an individual might die without first being admitted to hospital, but the probability of death is significantly increased for hospitalised and ventilator patients. Vaccinated individuals have a 65% reduction in the risk of needing ventilator treatments.

Age	Prob (%) hospitalization	ventilator	death
0-9	0.27 (0.72)	0	0.000068 (0.00012)
10-19	0.27 (0.72)	6.5	0.00032 (0.00059)
20-29	1.1 (2.8)	3.2	0.0012 (0.0023)
30-39	2.3 (6.1)	8.5	0.006 (0.011)
40-49	2.8 (7.3)	9.4	0.029 (0.052)
50-59	5.2 (13.6)	15.1	0.14 (0.25)
60-69	7.5 (19.9)	18.4	0.51 (0.89)
70-79	10.1 (27.8)	19.1	2.2 (4.1)
80-100	21.9 (59.8.0)	9.3	9.7 (17.9)

Table 8: Probabilities of hospitalization, ventilator treatment given hospitalization and death. The numbers in parentheses are the higher probabilities for individuals with underlying diseases, i.e. risk groups.

The length of stay in hospital depends on the age of the infected individuals and it has been modelled as a random variable with a negative binomial distribution, whose parameters have been fitted to Norwegian data [9, 10] (Table 9). Vaccinated individuals have an average LOS that is approximately 20% lower than unvaccinated patients [11].

Age-group	Length of stay in hospital	
	Mean (days)	Size
0-9	1.8	3.9
10-19	3.5	1.1
20-29	3.6	1.4
30-39	3.4	2.1
40-49	4.7	2.0
50-59	5.5	2.3
60-69	6.4	2.6
70-79	6.4	2.0
80-89	6.4	2.4
90+	5.1	1.6

Table 9: Length of stay in hospital (LOS). The LOS for each patient is drawn from age-dependent negative binomial distributions. The values of the parameters reported in the table (mean and size) have been estimated from Norwegian data.

The length of ventilator treatments is defined through age-dependent negative binomial distributions whose parameters are reported in Table 10.

Age-group	Length of ventilator treatment	
	Mean (days)	Size
0-9	3.3	0.5
10-19	3.3	0.5
20-29	3.3	0.5
30-39	9.2	1.1
40-49	9.5	2.6
50-59	16	1.2
60-69	14	1.5
70-79	14	1.5
80+	18	1.1

Table 10: Length of ventilator treatments. The length of ventilator treatments is drawn from age-dependent negative binomial distributions. The parameter of the negative binomial distributions reported in the table (mean and size) have been estimated from Norwegian data.

5.2 Metapopulation model

The metapopulation model uses the same epidemiological model as the IBM, but instead of simulating each individual we follow groups of people over time. In the metapopulation model we assume random mixing in each of the combined 18 age/risk groups and 22 geographical regions, giving a total of 396 population groups. In the model we have a separate copy of the epidemiological model for each of these 396 groups, but where the force of infection in one group is related to the number of infectious people in all groups through the "who-infects-who"-matrix. This is a 396x396 matrix that is defined as an outer product of the age-based mixing from a 2017 study in Norway with a geographical contact matrix based on the mobility data.

The MPM model uses the same parameters as the IBM model apart from that all transition times between compartments are exponentially distributed.

5.3 Vaccination

The vaccination model includes the vaccines from Pfizer and Moderna, which are currently in the vaccination programme in Norway. In the model, the vaccines are offered to everyone 12 years or older, in line with government policy.

We assume a six-week interval between the first and second mRNA vaccine doses, for people older than 18 years of age. A ten-week interval is used for 16-17-year olds. Only one dose is given to the age-group 12-15. The values of the vaccine efficacy (VE) are reported in Table 11. We assume that the vaccines are effective against all variants in the same way. The estimates take into account the effect of the Delta variant and data collected for Comirnaty and Spikevax.

Vaccine effectiveness	**Value % (1st dose/2nd dose)**
Against asymptomatic disease	50/63
Against symptomatic disease	62.5/82
Against severe disease requiring hospitalisation	85/92.5
Against death	90/92.5
Against transmission	65

Table 11: Vaccine effectiveness estimates

5.4 Infection-control measures

The model takes into account individual-control measures against the spread of COVID-19. The current policies in Norway require individuals presenting newly-arisen symptoms of infection to stay at home until negative COVID-19 test results are received [12]. In order to simulate these control measures, in the model we assume that 50% of individuals infected and presenting symptoms stay at home and do not mix with others in schools, workplaces or in the society. Moreover we assume that this home-isolation measure occurs 1 day after the onset of symptoms and it lasts for 5 days. In the absence of data that could inform the model's home-isolation parameters, the values above, used as a baseline scenario, reflects a situation that is believed to better represent reality. To assess the variability of the epidemiological dynamics under different assumptions, in additional scenarios we explore the effect of varying the proportion of symptomatic people adhering to home isolation.

5.5 Importation

We assume the following total number of imported cases per month (the imported cases are then evenly distributed over the days of the month): October 152; November 91; December 72; 100 from January through June 2022.

5.6 Model initialisation

The initial conditions with the number of exposed, pre-symptomatic, asymptomatic, symptomatic and recovered individuals in each Norwegian municipality are set using the results of the regional change-point model run until the most recent time point [13]. We assume regional differences in the reproduction number by estimating a scaling factor for the national reproduction number in each municipality. The scaling factor is calculated from the proportion of the population in each municipality who has tested positive, compared to the national one.
We use data from SYSVAK on the number of vaccinations carried out up until 4th October 2021 to initialise the model with the real number of vaccinations by time, 1-year age-group and municipality. This includes 4174120 first doses administered in total. Between October 4th and October 19th, 17860 additional first doses have been administered according to SYSVAK. We only use first-dose data from SYSVAK, and assume that everyone who receives the first dose also receives the second dose.

References

[1] FHI COVID-19 modelling team, "Situational awareness and forecasting for Norway, week 40, 6 October 2021." https://www.fhi.no/sv/smittsomme-sykdommer/corona/koronavirus-modellering/.

[2] "Norwegian Immunisation Registry SYSVAK." https://www.fhi.no/en/hn/health-registries/norwegian-immunisation-registry-sysvak/.

[3] Ekspergruppe for matematisk modellering af covid-19, Statens Serum Institut, "Ekspertrapport af 20. september 2021. Scenarier for udviklingen i smitte, nyindlæggelser og gennembrudsinfektioner med covid-19." https://www.ssi.dk/-/media/cdn/files/ekspertrapport-af-d-20-september-2021_scenarier-for-udviklingen.pdf.

[4] "Statistics Norway. Classification of statistical tract and basic statistical unit." https://www.ssb.no/en/klass/klassifikasjoner/1.

[5] F. Di Ruscio, G. Guzzetta, J. V. Bjørnholt, T. M. Leegaard, A. E. F. Moen, S. Merler, and B. F. De Blasio, "Quantifying the transmission dynamics of mrsa in the community and healthcare settings in a low-prevalence country," *Proceedings of the National Academy of Sciences*, vol. 116, no. 29, pp. 14599–14605, 2019.

[6] N. G. Davies, P. Klepac, Y. Liu, K. Prem, M. Jit, and R. M. Eggo, "Age-dependent effects in the transmission and control of covid-19 epidemics," *Nature medicine*, vol. 26, no. 8, pp. 1205–1211, 2020.

[7] J. Zhang, M. Litvinova, Y. Liang, Y. Wang, W. Wang, S. Zhao, Q. Wu, S. Merler, C. Viboud, A. Vespignani, *et al.*, "Changes in contact patterns shape the dynamics of the covid-19 outbreak in china," *Science*, vol. 368, no. 6498, pp. 1481–1486, 2020.

[8] P. Sah, M. C. Fitzpatrick, C. F. Zimmer, E. Abdollahi, L. Juden-Kelly, S. M. Moghadas, B. H. Singer, and A. P. Galvani, "Asymptomatic sars-cov-2 infection: A systematic review and meta-analysis," *Proceedings of the National Academy of Sciences*, vol. 118, no. 34, 2021.

[9] "Norsk intensiv- og pandemiregister (NIPaR)." https://www.kvalitetsregistre.no/register/skade-og-intensiv/norsk-intensiv-og-pandemiregister.

[10] "Norsk pasientregister (NPR)." https://www.helsedirektoratet.no/tema/statistikk-registre-og-rapporter/helsedata-og-helseregistre/norsk-pasientregister-npr.

[11] M. Ramakrishnan and P. Subbarayan, "Impact of vaccination in reducing hospital expenses, mortality and average length of stay among covid 19 patients. a retrospective cohort study from india," *medRxiv*, 2021.

[12] "FHI web page: Coronavirus - facts, advice and measures ." https://www.fhi.no/en/op/novel-coronavirus-facts-advice/facts-and-general-advice/advice-when-you-or-your-household-members-have-respiratory-infections-but-a/.

[13] "Coronavirus modelling at the NIPH." https://www.fhi.no/en/id/infectious-diseases/coronavirus/coronavirus-modelling-at-the-niph-fhi/.