Modelling scenarios for the SARS-CoV-2 Omicron VOC (B.1.1.529) in Norway during the winter 2021—2022

The FHI COVID-19 modelling group[1], Folkehelseinstituttet (FHI, Norwegian Institute of Public Health)

December 22nd, 2021

Samandrag

For english, please see next page

I denne rapporten presenterer vi ein modelleringsstudie om spreiinga av Omikron-varianten (B.1.1.529) av sars-COV-2 i Noreg. Vi viser ulike scenario for korleis den framtidige utviklinga av epidemien kan bli under spesifikke føresetnadar om Omikron sin ibuande spreiingsevne, samt endring i kor effektive vaksinane er mot den nye varianten. Vi set opp kombinasjonar av ulike scenario for å forstå korleis ulike nivå av samfunnstiltak mot smittespreiing, vaksineeffektar og oppslutning om vaksinasjonsprogrammet, spelar seg ut i lag med ulike epidemiologiske profilar for Omikronvarianten.

I den noverande, tidlege fasen av Omikron sin utbreiing er det mykje uvisse omkring Omikron sine eigenskapar, og dette kjem til syne i eit breitt spenn av moglege epidemiske forløp. Det er viktig at desse simuleringane ikkje vert tolka som prediksjonar eller varsel, men som illustrasjonar av moglege forløp gitt spesifikke føresetnadar, inkludert meir pessimistiske scenario.

Det er særleg to veldig viktige kjelder til usikkerheit som påverkar modelleringa vi viser her, og kvar av dei har stor påverknad på den framtidige spreiinga av Omikron i Noreg. Den første er kor smittsam Omikronvarianten er – på grunn av auka ibuande smitteevne og/eller dårlegare effekt av vaksinane – og dermed kor fort han greier å spreie seg. Den andre er kor effektive dei noverande tiltaka i samfunnet er mot smittespreiing. Hovudmålet med denne rapporten er å gi innsikt i korleis desse faktorane speler saman og formar Omikronepidemiens utvikling.

Modelleringa indikerer at dersom spreiingstakta til Omikron svarer til ein doblingstid på fire dagar, slik vi antar i dei meir optimistiske scenarioa våre, og tiltaka mot smittespreiing samstundes greier å redusere smitteraten med 40 prosent eller meir, så kan det vere nok til å halde utbruddet under kontroll gjennom den komande perioden. På den andre sida, i eit meir pessimistisk scenario der Omikron spreier seg med ei raskare doblingstid på 2.4 dagar, så kan vi stå overfor ei stor bølgje av infeksjonar med eit overvelda helsevesen som resultat, sjølv med dei noverande tiltaka på plass. I eit slikt scenario vil det vere naudsynt med endå meir inngripande tiltak for å få epidemien under kontroll. Ei samanlikning av simuleringane med andelen omikron som vert rapportert, kan sjå ut til å peike mot at den noverande doblingstida ligg ein stad i mellom dei to scenarioa, men dette er veldig usikkert enno.

Det er òg andre faktorar som påverkar utfallet i modellane. Det er førebels uklart kor alvorleg sjukdom Omikronvarianten gjev samanlikna med Delta. Viss Omikron viser seg å vere vesentleg mildare enn Delta, så vil det bidra til å redusere trykket på helsevesenet for eit gitt nivå av smittespreiing. Vi modellerer òg effekten av oppfriskingsdoser, og viser at å tilby dei til alle over 18

[1] See the end of the document for a list of all contributing authors

år kan ha stor påverknad på å redusere smittespreiinga og flate ut kurva. Effekten av oppfriskingsdosane heng nøye saman med kor mange som takkar ja til dei, og modellen finn stor forbetring på epidemiens storleik i scenario der oppslutnaden om vaksinasjonsprogrammet er høgre. For at oppfriskingsdosene skal ha effekt er det naudsynt at epidemien vert halde under kontroll gjennom dei kommande vekene fram til ein har hatt tid til å distribuere og setje vaksinene.

I dei neste dagane og vekene kjem det til å vere stort tilfang av ny informasjon og nye data som vil setje oss i stand til å innskrenke og forbetre estimata frå modellane. Vi kjem til å følgje nøye med på korleis epidemien utviklar seg, og planlegg å oppdatere desse resultata i framtidige rapportar.

Summary

In this report we present a modelling study of the spread of the Omicron (B.1.1.529) variant in Norway. We show different scenarios of the future development of the epidemic under specific assumptions on the Omicron's intrinsic transmissibility and changes in the vaccine effectiveness against the new variant. We thus investigate a combination of various scenarios to clarify how different levels of control measures, vaccine efficacies and uptake, would interact with specific epidemiological profiles of the Omicron variant.

During this early phase of the Omicron emergence, there are significant uncertainties in the characteristics of Omicron that are reflected in a broad range of possible epidemic outcomes. Thus, the simulations should not be interpreted as predictions or forecasts of the future development of the epidemic, but as illustrations of the possible outcomes, given specific assumptions including more pessimistic scenarios.

There are two main, very important sources of uncertainty influencing the modelling presented here, each of which has a decisive impact on the future course of the Omicron wave in Norway. One is the transmissibility of the Omicron variant compared to Delta – due to increased intrinsic transmissibility and/or evasion of prior immunity – and hence how fast it will be able to spread. The other is the effectiveness of the current non-pharmaceutical interventions in reducing transmission in the society. The main focus of the modelling presented here, is to say something about how these factors interact to shape the future course of the epidemic.

The present modelling results indicate that if the growth rate of Omicron corresponds to a doubling time of 4 days, as we assume in our more optimistic scenarios, and the interventions currently in place are effective and able to reduce the transmission rate by 40% or even more, then the measures can be enough to keep the outbreak under control through the coming period. On the other hand, in a more pessimistic scenario where Omicron has a faster doubling time of 2.4 days, we may face a significant wave of infections with a resulting overload of the healthcare sector even with the current measures in place. Under this scenario, an even stronger level of interventions would be needed to bring the epidemic under control. A comparison of the simulations with the fraction of Omicron cases reported, might indicate that the current growth rate is between the two scenarios, but this is still very uncertain at present.

Other factors also influence the outcomes. It is at present not known how severe disease Omicron gives compared to Delta. Should Omicron turn out to be significantly milder than Delta, then this would reduce the burden on hospitals for a given level of infections. In this report we assume that Omicron has the same severity as Delta. We also model the effect of the booster program and show that the effect of offering booster doses to everyone 18 and above can have a significant impact on reducing the transmission and flattening the curve. The effect of the booster program depends crucially on coverage, and the model finds large improvements on the overall epidemic size in scenarios with a higher uptake. For the boosters to have an effect, however, the transmission must be kept sufficiently slow in the coming weeks so that booster shots can be administrated before a large share of the population becomes infected.

In the next days, additional data and information will be gathered enabling to narrow down and improve our modelling estimates. We will continuously follow the course of the epidemic, and plan to update these results in future reports.

Table of contents

How we model Omicron

We study the spread of COVID-19 using a stochastic individual-based model (IBM) that explicitly models the spread of the Omicron and Delta variants as two separate strains of SARS-CoV2. This means that the model will keep track of who is infected with what variant, and upon transmission to other individuals, they inherit the variant from their infector.[2]

The IBM contains detailed socio-demography of the Norwegian population combined with exact information about the number of vaccine doses administered by date, municipality and age. It simulates human contacts in different settings including households, schools, workplaces and in the community. It has been used extensively in the past to model and monitor the COVID-19 epidemic in Norway.[i]

We seed the Omicron variant by introducing 100 positive cases randomly in the population on November 24, 2021. The index cases will become infectious, either symptomatically or asymptomatically, and begin to infect others. Depending on what assumptions we make for the transmissibility and vaccine evasion of Omicron compared to Delta, Omicron may outcompete Delta and become dominant over time.

Determining Omicron parameters

The main uncertainties for the Omicron variant are its ability to evade vaccine-induced immunity from infection and its intrinsic transmissibility relative to Delta. These two parameters together determine the observed doubling time of Omicron cases in a population. To estimate them, we use two sources of data:

1. Preliminary data from the United Kingdom[ii] on how well the vaccines protect against infection.
2. Data on how fast Omicron spreads internationally and in Norway so far. Using the number of cases detected in Norway, we estimate the growth rate (doubling time) of Omicron in the time period before interventions were put in place on December 8th.

Norwegian data of the first reported Omicron cases up to the implementation of the first infection-control measures at the end of the first week of December, suggest a doubling time of about 2.4 days. In an initial phase of an epidemic, these estimates are surrounded by a high level of uncertainties, being affected by the sampling activity and outbreak dynamics, such as super-spreading events (as reported in Norway), which might underestimate the value. In our baseline, we thus also run a scenario with a higher doubling time, 4 days. In future reports, additional data will enable us to refine our parameters.

Modelling scenarios

It is not possible to predict the COVID-19 epidemic over long time periods. This is due both to uncertainties in the epidemiological characteristic of the circulating virus variants, and because the disease transmission depends on intervention levels and people's behaviour, which is extremely hard to predict.

[2] In the present version of the model, we assume complete cross-immunity between the strains – meaning that a person who has undergone Delta infection cannot be reinfected by Omicron. This is a simplifying assumption at odds with the data we have on Omicron so far, and we aim to make this more realistic in the next version of the model.

Therefore, we present scenarios of how the epidemic might play out given specific assumptions about policy implementation, people's behaviour, and other factors governing the epidemic, such as the effectiveness of vaccines and the duration of natural and vaccine-derived immunity. We assume that the contact-measures implemented in each scenario do not change during the simulations. Similarly, we assume there are no changes in human behaviours affecting the contact rate. While it is possible to include in the model an effect of change of behaviour as a result of high levels of infection, this would require many assumptions on the size and thresholds of these effects for which we do not have any data. For this reason, we choose not to include such effects in the model. Because of these factors, 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.

Baseline scenarios

Based on the above considerations, we define our baseline scenarios with the following assumptions about Omicron's properties:

1. The **vaccine effectiveness (VE) against infection and onward transmission** is reduced by either
    a. 20 percentage points (e.g., from 90% (Delta) to 70% (Omicron)), or
    b. 35 percentage points (e.g., from 90% (Delta) to 55% (Omicron))
2. The **doubling time of Omicron** (in the early period before interventions implemented on 8th Dec 2021) in Norway is either
    a. 2.4 days, or
    b. 4 days

Our baseline thus consists of four different scenarios generated by the combinations of 1a, b and 2a, b. In addition to these Omicron properties, we make the following assumptions:

- **Effect of interventions:** We assume that due to measures introduced on December 8th, 2021, the contact rate was reduced by 15%, then reduced further to a total of 40% reduction due to stricter interventions imposed on December 15th. In the IBM model, a 40% reduction is consistent with changes seen in the model after previous interventions imposed on September 25th.
- **Vaccine protection against severe disease** (i.e., hospitalisation and death) is the same as for Delta.[3]
- **Severity:** There is large uncertainty about the severity of an Omicron infection. We assume that omicron has the same probability of hospitalisation or death per infection as Delta. It seems unlikely that omicron is more severe, but possible that it is less severe. Regarding severity the current scenarios can be viewed as conservative.
- **Vaccine uptake**: No further uptake of 1st and 2nd doses of vaccines than SYSVAK as of December 5th. Booster doses are offered to everyone **aged 18 and above**, with age-dependent uptake according to survey data (see the methods section for details).
- **Time delay between 2nd and 3rd (booster) dose** is set to minimum 4.5 months.
- **Home isolation** adherence rate is set to 70% for infected when symptomatically ill with COVID-19.
- **Vaccine effectiveness and waning** are based on data from the UK and assume a linear waning for 40 weeks (see the methods section for details)

[3] Note that we assume it is the *conditional* protection against severe disease *given infection* that is unchanged.

- The **Seasonal variation** of the transmission rate is 35% between the warmest and coldest days of the year.

Alternative scenarios

Having defined the baseline, we then explore alternative scenarios where we independently vary each of the parameters' assumptions as following:

1. **Effect of interventions**:
    a. **More effect of interventions**. 15% reduction on the 8th of Dec 2021, then reduce further to a total of 60% reduction due to stricter interventions imposed on December 15th.
    b. **Less effect of interventions.** 15% reduction on the 8th of Dec 2021, then reduce further to a total of 20**%** reduction due to stricter interventions imposed on December 15th.
2. **Vaccine protection against severe disease**:
    a. 10 percentage points lower than Delta. As an example, in the baseline vaccine effectiveness scenario, for people below 65 years and after dose 2, this corresponds to a 50% increase of the relative risk of hospitalisation, from 20% to 30%.
    b. 10 percentage points higher than Delta (to illustrate a scenario with milder illness for Omicron). In the baseline vaccine effectiveness scenario, for people below 65 years and after dose 2, this corresponds to a halving of the relative risk of hospitalisation, from 20% to 10%.
3. **Vaccine uptake**:
    a. No more 1st or 2nd doses, booster doses offered to people aged 45 and above with uptake according to survey.
    b. 95% uptake for all doses, boosters offered to people aged 18 and above.
4. **Vaccine effectiveness and waning**
    a. Higher waning of the vaccine effectiveness (see methods section for details).

Uncertainties, limitations and assumptions

- One of the main uncertainties in the simulations is represented by the epidemiological profile of the Omicron variant. In particular, the intrinsic transmissibility, severity and the capacity to escape vaccine protection are currently highly uncertain and different assumptions have a decisive impact on the future Omicron epidemic.
- Due to the uncertainty about intervention-induced and spontaneous, self-regulating behavioural changes in the population as well as properties of the virus and effect of vaccines, the results are very uncertain.
- The precise reduction in the contact rate resulting from the last bundle of measures implemented in December cannot be quantified from the current data. We thus ran simulations with different values to take into account a range of more optimistic and more pessimistic scenarios.
- The model simulates the spread of two strains, Omicron and Delta variant. We assume that individuals infected with one strain gain lifelong protection against COVID-19 reinfection by any strain. This assumption might potentially underestimate the spread potential of the new strain. The model estimates that ~10% of the population is infected with the Delta variant at the time of Omicron importation, reducing the number of susceptibles to Omicron. However, part of this effect will be adjusted by the calibration to the Omicron doubling time.

With a less-than-complete cross-immunity between strains, it is also possible that the two strains would co-exist in the long run.

- The estimated prevalence of patients in hospital and on ventilator treatment depend on the assumed length of stay (LOS). The length of stay of Omicron cases is unknown. In this report we assume the same LOS for patients infected with the Omicron and Delta variant. The prevalence numbers in this report are thus highly uncertain and should be viewed as crude estimates.
- The model takes into account differences in the vaccine distribution at the municipality and age level based on current Norwegian data. However, we do not consider the effect of clustering of unvaccinated individuals within households or in social mixing in the public setting. 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 policy of vaccinating population has been changing these days. In this version of the model, we take the current policy and do not consider giving 2nd doses to aged 12-15 and 1st doses to aged 5-11. The model will be updated if the current policy is changed.
- There is a lack of data about the current level of adherence to individual control measures, such as home isolation. We run the baseline scenarios in the model assuming a 70% proportion of home isolation among symptomatic cases. We varied this parameter to be 90% in sensitivity analyses; however, we found no significant differences compared to the baseline due to high transmissibility of the virus. Adherence to home isolation is kept constant throughout each run. In reality this parameter might change in time, depending on the evolution of the pandemic and future changes in the infection-control policies.
- No quarantine measures are included in the model currently. This means that contact rates of pre-symptomatic individuals remain at the levels before December 8th, which could be overestimated now. In the model, setting-specific measures including home quarantine, school closures and home office are now reflected by the overall intervention effect as one parameter. More detailed-specific implemented measures would be added in the next updated report.
- The relative importance of transmission by asymptomatic and pre-symptomatic individuals is not well known, and these factors have a significant impact on the transmission dynamics in the model.

Results

We present results of the spread of the Omicron and Delta variants for each scenario consisting of 9 stochastic simulations over the period between December 27, 2021, and June 30, 2022. In the main text we include figures showing results until the end of January only, to emphasise that the outcomes further ahead in time are even more uncertain. Figures showing the full simulations are included in the supplementary figures section.

1 - Baseline

The baseline plots compare the outcomes between the four different assumptions for Omicron parameters, in terms of number of infections, number of hospitalisations and patients requiring ventilator treatment. The other parameters are as defined in the baseline above. In particular, we assume that the non-pharmaceutical interventions put in place by the government on December 8th and December 15th have reduced the average contact rate, and thus transmission, by 40%.

The model indicates that, in the two most pessimistic scenarios where Omicron cases double every 2.4 days, a 40% reduction in overall contact rate will not be enough to prevent a big wave peaking already in early January. In these scenarios, more than three million people, i.e., more than 50% of the population, become infected before February. In total, between 30 000 and 40 000 people require hospitalisation, and the daily incidence of admissions peaks at ~1000. The scenario with 35% VE escape has a somewhat higher burden of hospitalisations than the 20% VE escape. The incidence of patients requiring ventilator treatment peaks at around 50 per day. The halfway and full takeover of the Omicron variant occurs at around mid-Dec 2021 and early-Jan 2022, respectively.

In the more optimistic scenarios with a doubling time of 4 days, the wave is delayed, and the peak is significantly reduced (outside time range shown here; see Supplementary figures). This is in large part due to the booster doses having time to be distributed and give protection against infection. The total number of infections is also much lower than for the pessimistic scenarios, but even here, more than 1 million people become infected with Omicron throughout the simulation time. In these scenarios, the hospitalisation admissions peak at ~125 patients per day, around May. The halfway and full takeover is around early-Jan and mid-Feb 2022, respectively.

A comparison of the fraction of Omicron cases simulated by the model with the current data, as of December 22, might indicate that the current growth rate of the epidemic is between our more optimistic and pessimistic scenarios. However, takeover dynamics in the early phase of the Omicron epidemic might be affected by assumptions on the seeding of the index cases, such as timing and size. In the coming days additional data will enable us to better calibrate the model on the data and to gain more robust insights into the takeover.

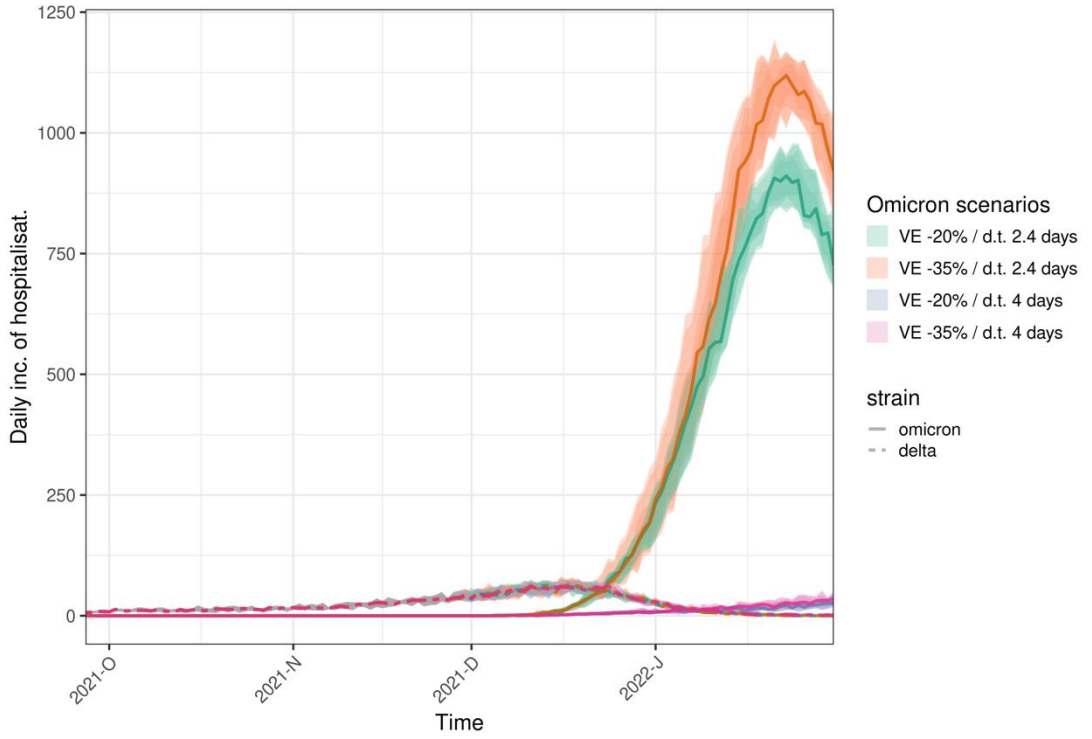


Figure 1: Daily incidence of hospitalisations in the baseline scenarios until end of January 2022. Whole lines indicate hospitalisations with Omicron, dashed lines indicate hospitalisations with Delta.

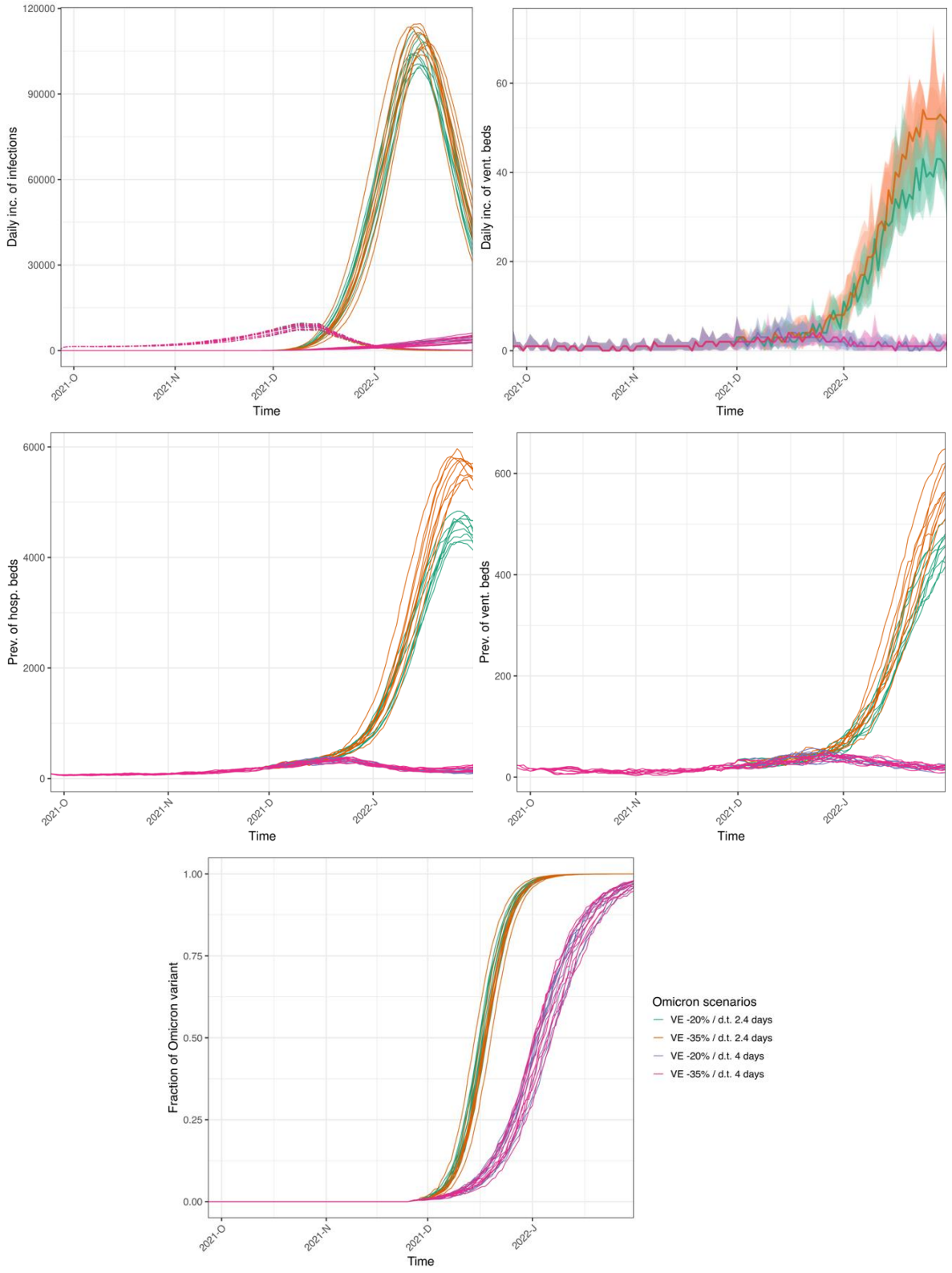


Figure 2: Daily incidence of infections (top left) and ventilator beds (top right), prevalence of hospital beds (central left) and ventilator beds (central right), and fraction of Omicron variant (bottom), in the baseline scenarios.

2 - Varying effect of interventions

Here, we show how different assumptions about the effectiveness of current interventions interact with the four assumptions for Omicron's doubling time and vaccine effectiveness against infection. The colours represent varying degrees of the effect of infection-control measures implemented on the 15th of December. We assume a total reduction of the contact rate of 40% (baseline, green), 20% (orange) or 60% (purple).

A larger reduction of the contact rate results in a significant decrease in the number of infections and hospitalisations. The final size of the winter wave strongly depends on the Omicron transmissibility. In the pessimistic scenarios with an initial Omicron doubling time of 2.4 days, even a 60% reduction in contact rate cannot prevent a sizeable wave, with hospitalisations peaking in February with around 300 admissions per day. In this scenario, more effective interventions will be needed to keep the outbreak under control throughout the winter months.

In the more optimistic scenario with an Omicron doubling time of 4 days and the baseline assumption of 40% reduction of the contact rate, the effective reproduction number is just above 1 during the winter months. If the interventions are more effective, at 60% reduction, the reproduction number is brought below the epidemic threshold, completely quenching the epidemic. Note that these results are contingent on a relatively successful booster program for everyone 18 and above (the baseline assumption).

We also found no difference in the takeover time of the Omicron variant between different levels of interventions as both variants are suppressed equally.

See the Supplementary figures section for additional figures.

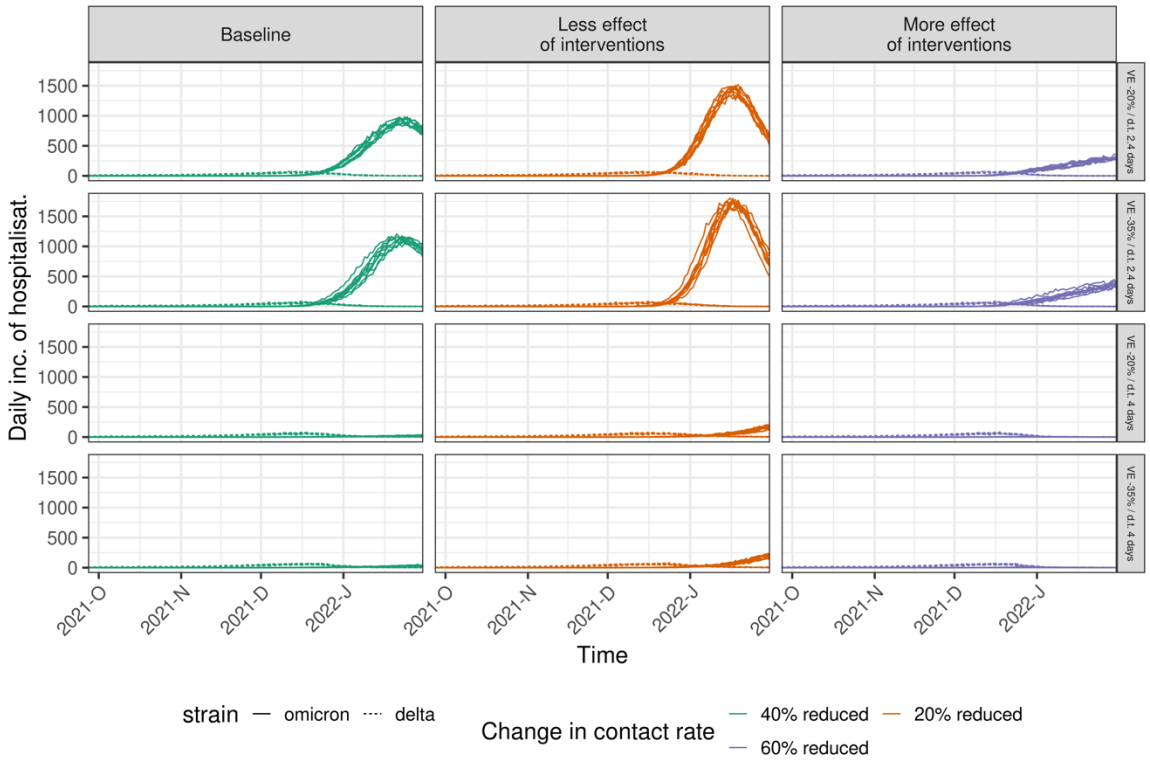


Figure 3: Daily incidence of hospitalisations for different levels of effect of the interventions. All other parameters are baseline.

3 - Varying vaccine protection against severe outcomes

In this section we show how different assumptions on the vaccine effectiveness against severe disease affects the number of hospitalizations. The results are shown in combination with different effects of interventions implemented on the 15th of December, namely 40% reduction in the contact rate (our baseline assumption) and 60% reduction.

In the scenarios with a doubling time of 2.4 days, considering a 40% reduction in the contact rate, there is a difference of ~500 cases at the peak of the daily incidence between the more optimistic scenarios (10% increase in VE against omicron) and the pessimistic scenario with 10% reduction of VE against Omicron severe disease.

See the Supplementary figures section for additional figures.

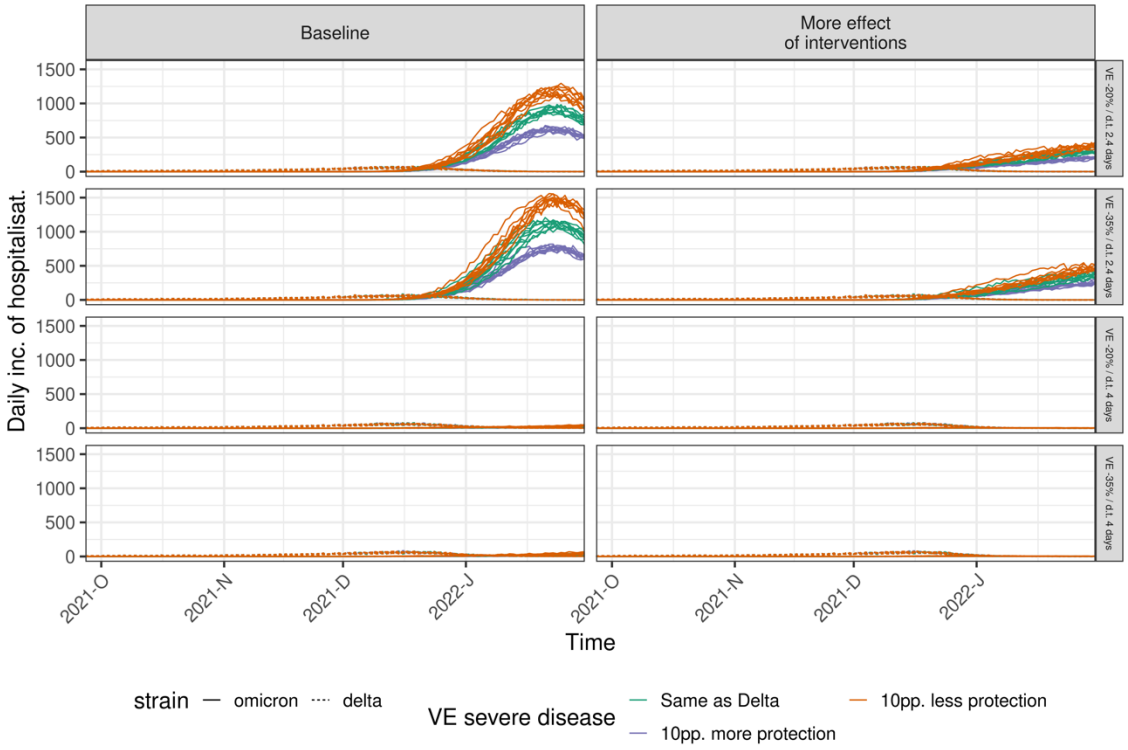


Figure 4: Daily incidence of hospitalisations for different effectiveness of the vaccines against severe disease. All other parameters are baseline.

4 - Vaccine uptake

In this section we explore the effect of different vaccination strategies varying the target population of booster doses (45+ vs. 18+) and the effect of a higher vaccine uptake (current coverage vs. 95% vaccine uptake). The other parameters are those of the baseline scenarios. The results are shown in combination with different effects of interventions implemented on the 15th of December, namely a 40% reduction in the contact rate (our baseline assumption) or a 60% reduction.

The administration of booster shots to a larger share of the population (18+) increases the level of immunisation in the population, resulting in a significant decrease of the burden on healthcare systems. This effect is particularly evident in the optimistic scenario with a higher Omicron doubling time. Based on this result, we expect that a higher uptake of vaccines in all age groups above 12 years would further increase the benefits with a higher reduction in the incidence of hospitalisations and infections.

The scenarios show that combining a higher level of vaccine-induced immunity in the population with more stringent infection-control measures can significantly reduce the wave of infections generated by an Omicron variant with a 2.4 doubling-time. This could even result in a fully controlled epidemic, assuming an Omicron's doubling time of 4 days.

See the Supplementary figures section for additional figures.

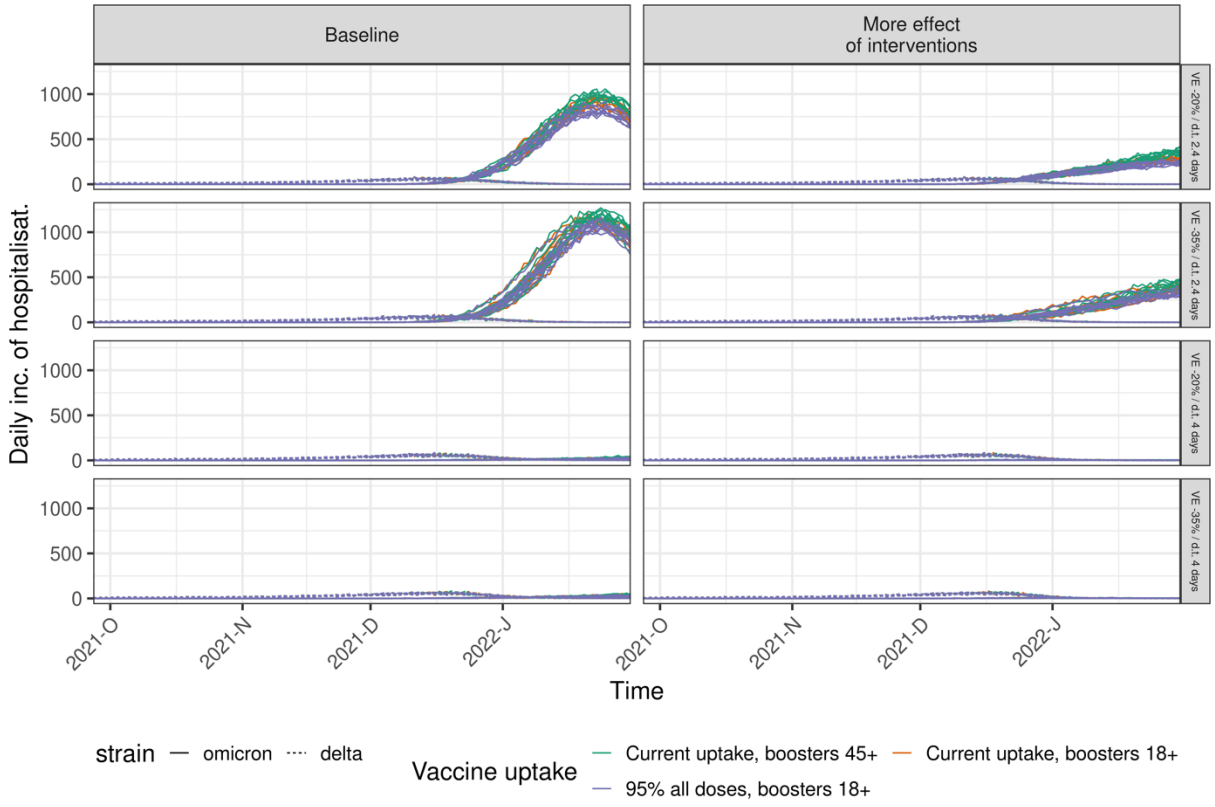


Figure 5: Daily incidence of hospitalisations for different vaccine uptake scenarios. All other parameters are baseline.

5 - Vaccine effectiveness profile

In this section we investigate how waning vaccine immunity affects the Omicron epidemic. We present two scenarios with two levels of waning, an optimistic scenario ("less waning") and a more pessimistic scenario with a higher degree of waning ("more waning"). A description of the assumptions in these two scenarios is reported in the Methods section. Similar to the previous sections, the results are shown in combination with different effects of interventions implemented on the 15th of December, namely 40% reduction in the contact rate (our baseline assumption) and 60% reduction.

See the Supplementary Figures section for additional figures.

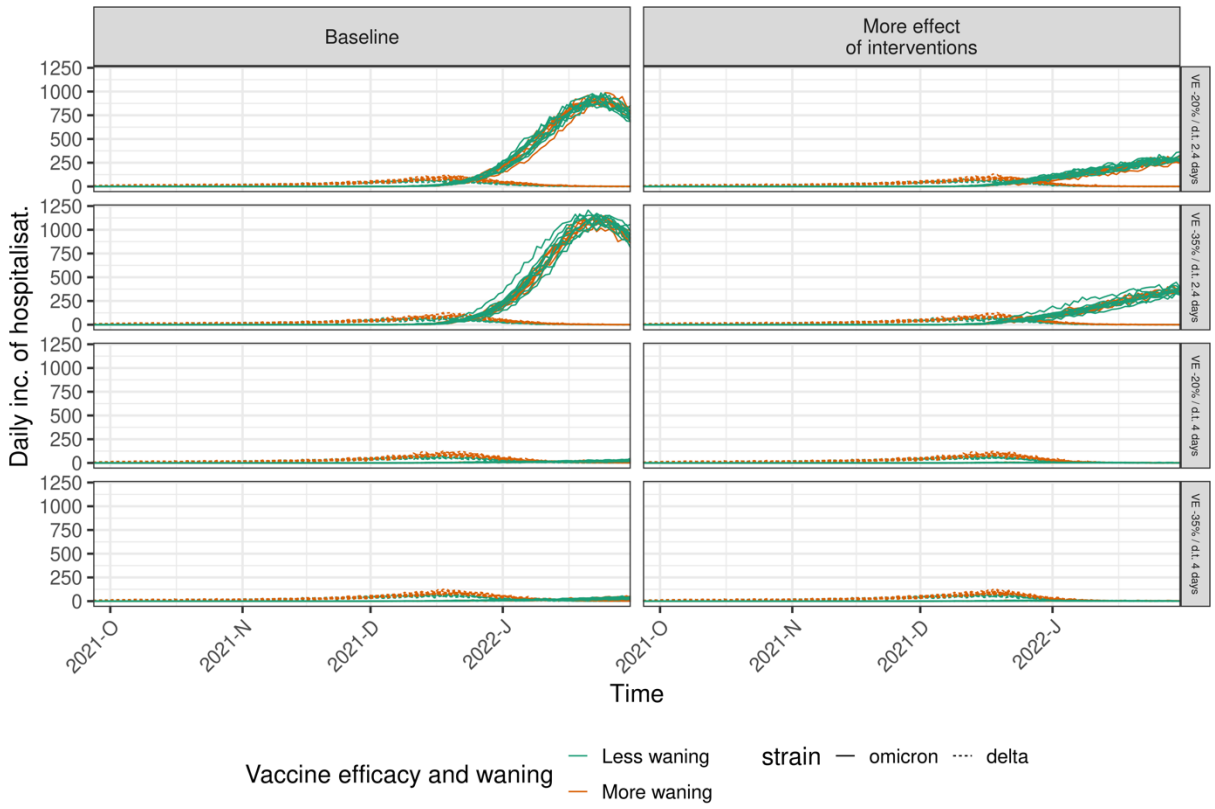


Figure 6: Daily incidence of hospitalisations for different vaccine profiles. All other parameters are baseline.

About the model and methodology

The model is described in detail in the Long-term scenario report from 28th October 2021[i]. The main changes from the previous long-term scenario report are the following:

1. The model simulates the spread of two different strains, the Omicron and Delta variant.
2. The calibration of the transmission rate of the Delta variant, β, is performed by fitting the hospitalization incidence from September 27th to December 5th. The transmission rate of the Omicron variant is calibrated to obtain specific doubling times.
3. We implemented a more detailed simulation of vaccines by explicitly modelling the effect of 1st, 2nd, and 3rd doses (see below for a more detailed description).

Two-strain model

The model used in this study explicitly simulates the circulation of both the Omicron and Delta variant as two different strains. This means that people can be infected by one of the two variants that they will potentially transmit to their contacts. We assume full cross-immunity between strains so that a person infected with one specific variant cannot be re-infected by the other variant.

The main differences between the Delta and the Omicron variant concern the transmission rate, β, and the level of escaping vaccine-derived immunity (see section Vaccinations below).

Calibration

We calibrate the transmissibility, β, of the Delta variant by fitting the hospital incidence between September 27 and December 8, through a maximum likelihood estimation approach. The following plot shows

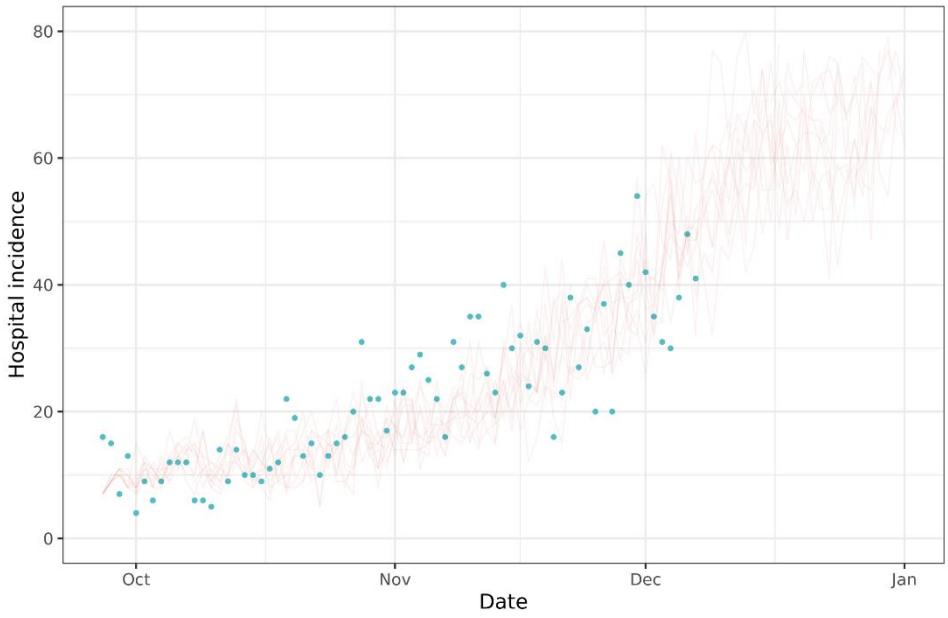


Figure 7: Comparison of the model's daily incidence of hospitalization (red curves) with the Norwegian data (blue dots) over the calibration period.

In a second step, the transmissibility of the Omicron variant is calibrated to a doubling time of either 2.4 or 4 days, in a simulation without interventions imposed. These two values enable us to consider variability related to the intrinsic transmissibility of the Omicron variant that is currently one of the biggest uncertainties.

The β parameters need to be calibrated separately for each assumption of how effective the vaccines are, because these assumptions influence the relationship between β and the incidence of hospitalization and growth rate of the strains.

Vaccination

Vaccination is modelled considering each dose separately. This means that each individual may take 0, 1, 2 or 3 doses of the mRNA vaccine in the model. We do not consider AstraZeneca vaccines in the model but assume everyone vaccinated and recorded in SYSVAK has gotten mRNA vaccines for simplicity.

Historical vaccinations in the IBM are based on SYSVAK data; from SYSVAK, the model is informed about how many first, second and third (booster) doses have been distributed by date, age, and municipality.

During the simulations, the distribution of vaccines depends on age-specific uptake values for each dose, vaccination capacity and with a minimum time interval between doses, which is 6 weeks between 1st and 2nd doses and 20 weeks between 2nd and 3rd doses. Given the latest vaccine delivery schedule, we let the model distribute up to 7000, 22000, and 400000 doses per week as the 1st, 2nd and 3rd doses, respectively. The model selects individuals at random from the population, and if they are eligible for a vaccine dose (fulfilling time interval requirement, etc.), then they are vaccinated.

The following table shows the uptake assumptions for the booster doses based on an internal FHI survey conducted in the days preceding the first Omicron cases. In different scenarios we explore the effect of giving the booster shot to all people above 45 years vs. giving the booster shot to all people above 18 years, and considering higher uptakes, 95% in all age-groups.

	Age 0-17	**Age 18-29**	**Age 30-39**	**Age 40-49**	**Age 50-59**	**Age 60+**
Dose 3	Not offered	76%	79%	81%	87%	89%

Each dose of vaccine is assumed to give a protection to an individual against 5 outcomes: asymptomatic and symptomatic disease, passing the disease on to others, hospitalisation and death. The vaccine effectiveness over time for each type of protection is shown in the figures below. The numbers are also reported in supplementary tables at the end of the document. The different panels show different assumptions for the VE values, as well as different delay times between dose 2 and 3.

We assume Omicron variant could reduce vaccine effectiveness (VE) in several ways including protection against severe diseases (i.e., hospitalization and death in our model), as shown in Section 3. For example, given the assumption of 0% reduce, we assume that the **conditional VE** given infection remains the same. However, the **overall VE** (given that individual is susceptible) could be reduced according to the assumed reduction in immune escape, which affects protection in symptomatic and asymptomatic infection and onwards transmission. The figures below show the overall VEs against the Delta variant, and the ones against Omicron are not shown.

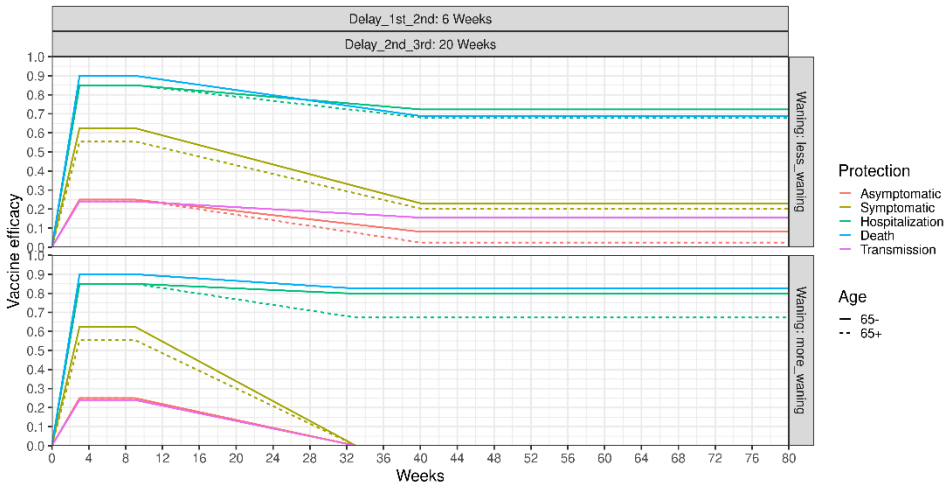


Figure 8: Vaccine effectiveness over time of the 1st dose only.

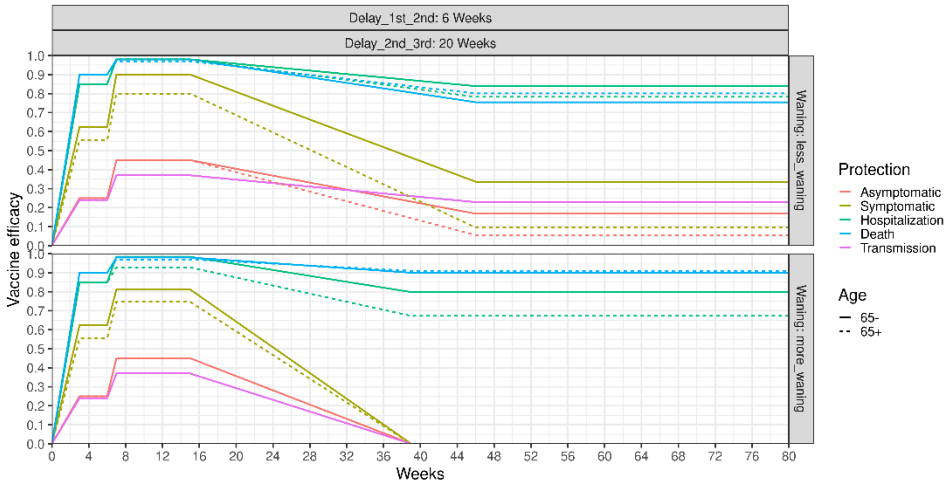


Figure 9: Vaccine effectiveness over time of the 2nd doses only.

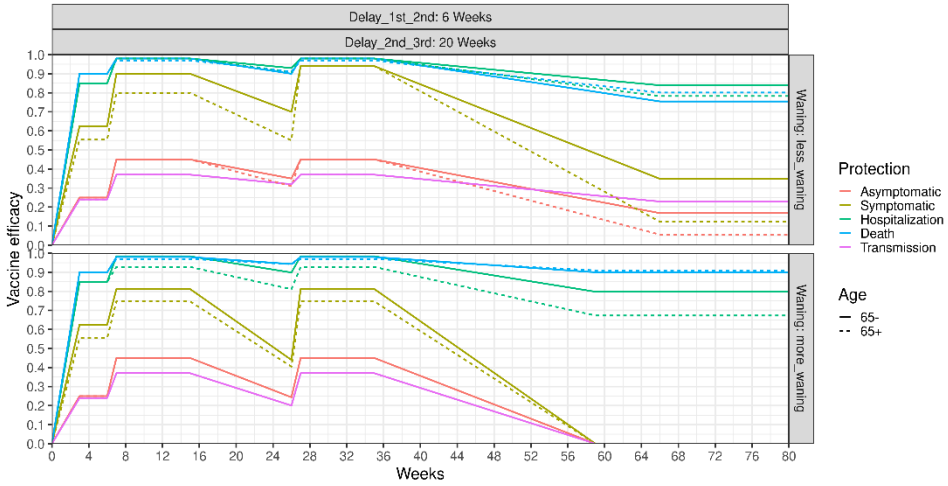


Figure 10: Vaccine effectiveness over time of all 3 doses.

Who contributed to this report

- Francesco di Ruscio*4
- Louis Yat Hin Chan*4
- Jørgen Eriksson Midtbø*4
- Gunnar Øyvind Isaksson Rø*
- Birgitte Freiesleben de Blasio*§
- Karin Marie Nygård*
- Preben Aavitsland*
- Sara Watle*
- Lene Kristine Juvet*
- Karan Golestani*
- Solveig Engebretsen^
- Arnoldo Frigessi§$
- Alfonso Diz-Lois Palomares*
- Anja Bråthen Kristoffersen*
- Kenth Engø-Monsen*
- Jonas Christoffer Lindstrøm*

*Folkehelseinstittuttet, Norwegian Institute of Public Health
^Norsk Regnesentral, Norwegian Computing Centre
§Oslo Centre for Biostatistics and Epidemiology, University of Oslo
$Oslo Universitetssykehus, Oslo University Hospital
4These authors contributed equally

Supplementary tables

Vaccine effectiveness scenario 1: "Less waning"

Vaccine effectiveness are compiled based on a wide range of international studies[iii]. The parameters for waning are compiled based primarily on data from the UK.[iv] The studies include data up until 20 weeks after vaccination. We assume the vaccines continue to wane until a total of 40 weeks and obtain number for this by extrapolating linearly from the UK data. Since we model waning of each dose independently, the required list of parameters is extensive. Where we have not found numbers in literature on, e.g., amount or duration of waning, we have made estimates based on similar numbers for other doses, or protection against other outcomes. The following tables should not be interpreted as a definitive set of best-estimates for vaccine efficacies but is an assumption that we believe gives a reasonable estimate of reality.

Table 1: Time parameters in "less waning" scenario

Dose nr.	*Time from shot to full effect (weeks)*	*Time from shot to start of waning (weeks)*	*Time from shot to end of waning (weeks)*
1	3	9	40
2	1	9	40
3	1	9	40

Table 2: Vaccine effectiveness (VE) parameters for the Delta variant in "less waning" scenario

	VE full effect (aged below 65)	*VE full effect (aged above 65 or risk group)*	*VE waned (age6 below 65)*	*VE waned (aged above 65 or risk group)*
Asymptomatic infection, dose 1	25%	25%	8.1%	2.5%
Asymptomatic infection, dose 2	45%	45%	16.8%	5.5%
Asymptomatic infection, dose 3 (booster)	45%	45%	16.8%	5.5%
Symptomatic infection, dose 1	62.5%	55.5%	23%	20.3%
Symptomatic infection dose 2	90%	80%	33.6%	9.5%
Symptomatic infection, dose 3 (booster)	94%	94%	34.8%	12.3%
Hospitalisation, dose 1	85%	85%	72.3%	68.1%
Hospitalisation, dose 2	98%	98%	83.9%	78.3%
Hospitalisation dose 3 (booster)	98%	98%	83.9%	78.3%
Death, dose 1	90%	90%	68.9%	68.9%

Death, dose 2	98%	97%	75.5%	80.1%
Death, dose 3 (booster)	98%	97%	75.5%	80.1%
Onward transmission dose 1	24%	24%	15.5%	15.5%
Onward transmission dose 2	37%	37%	22.9%	22.9%
Onward transmission, dose 3	37%	37%	22.9%	22.9%

Vaccine effectiveness scenario 2: "More waning"

The following table shows the VE parameters used in the alternative scenario, where some parameters, primarily for waning, have been updated based on an internal preliminary FHI study of Norwegian data. In this scenario, the vaccines generally wane faster, and the effectiveness against infection and onward transmission wanes all the way to zero protection.

Table 3: Time parameters in "more waning" scenario

Dose nr.	*Time from shot to full effect (weeks)*	*Time from shot to start of waning (weeks)*	*Time from shot to end of waning (weeks)*
1	3	9	33
2	1	9	33
3	1	9	33

Table 4: Vaccine effectiveness (VE) parameters for the Delta variant in "more waning" scenario

	VE full effect (aged below 65)	*VE full effect (aged above 65 or risk group)*	*VE waned (aged below 65)*	*VE waned (aged above 65 or risk group)*
Asymptomatic infection, dose 1	25%	25%	0%	0%
Asymptomatic infection, dose 2	45%	45%	0%	0%
Asymptomatic infection, dose 3 (booster)	45%	45%	0%	0%
Symptomatic infection, dose 1	62.5%	55.5%	0%	0%
Symptomatic infection dose 2	81.2%	74.7%	0%	0%
Symptomatic infection, dose 3 (booster)	81.2%	74.7%	0%	0%
Hospitalisation, dose 1	85%	85%	79.8%	67.3%
Hospitalisation, dose 2	98.4%	92.8%	79.8%	67.3%

Hospitalisation, dose 3 (booster)	98.4%	92.8%	79.8%	67.3%
Death, dose 1	90%	90%	82.5%	82.5%
Death, dose 2	98%	97%	90%	91%
Death, dose 3 (booster)	98%	97%	90%	91%
Onward transmission dose 1	24%	24%	0%	0%
Onward transmission dose 2	37%	37%	0%	0%
Onward transmission, dose 3	37%	37%	0%	0%

Length of stay in hospital

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. Vaccinated individuals have an average LOS that is approximately 20% lower than unvaccinated patients[v].

Table 5: 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.

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

Supplementary figures

In this section, we present additional figures to supplement the results shown in the sections above. The figures show the simulated epidemic up to the end of June 2022 to capture the development of the milder wave. It is impossible to predict the future development of the epidemic over a long

period of time. The model cannot anticipate future behavioural changes, the implementation of control measures or other epidemiological dynamics such as the emergence of new variants. Thus, simulations spanning over several months must be interpreted as illustrations of the development of the epidemic conditional on the fact that the scenarios assumptions are kept constant in the future.

1 – Baseline

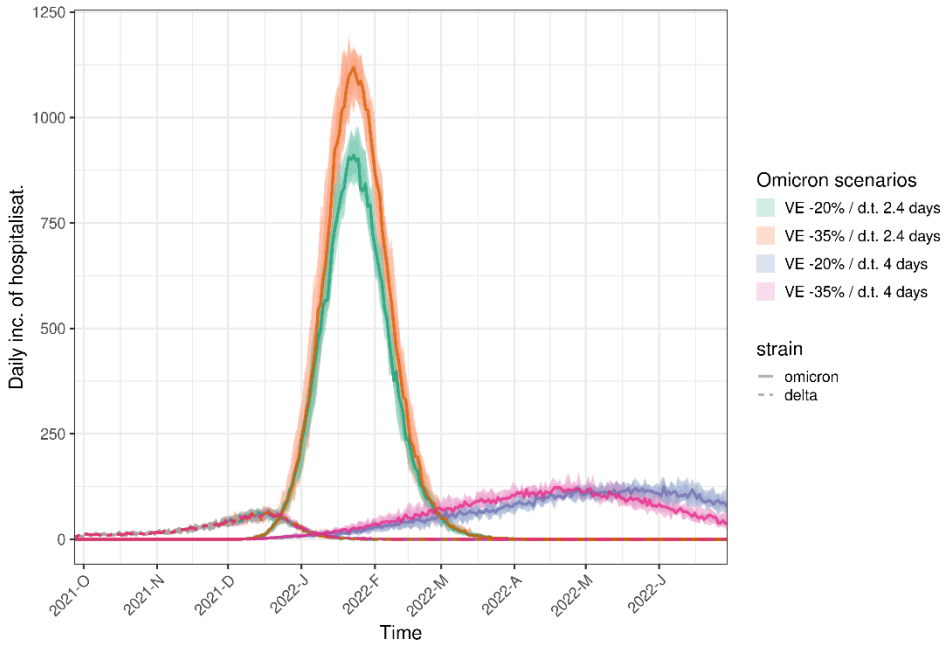
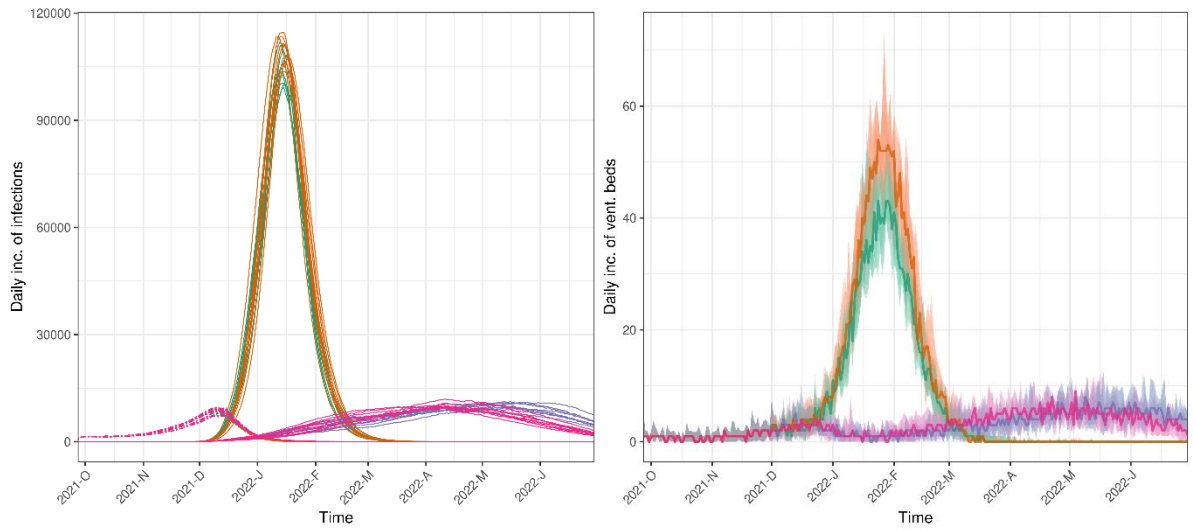


Figure: Daily incidence of hospitalisations in the baseline scenarios. Whole lines indicate hospitalisations with Omicron, dashed lines indicate hospitalisations with Delta.



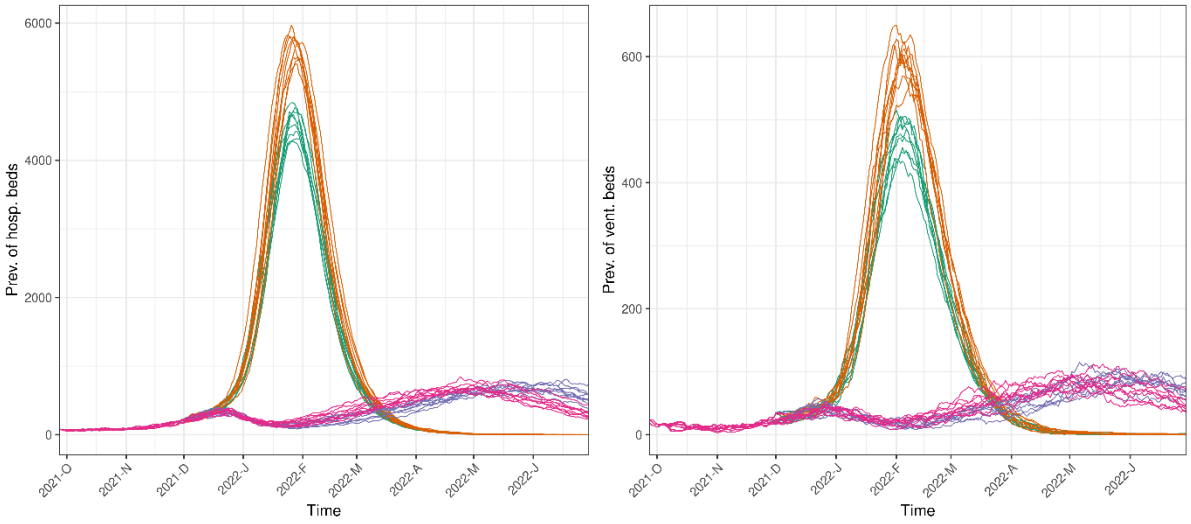


Figure: Daily incidence of infections (top left), ventilator beds (top right), prevalence of hospital beds (bottom left) and prevalence of ventilator beds (bottom right) in the baseline scenarios. Colors as in Fig. 1.

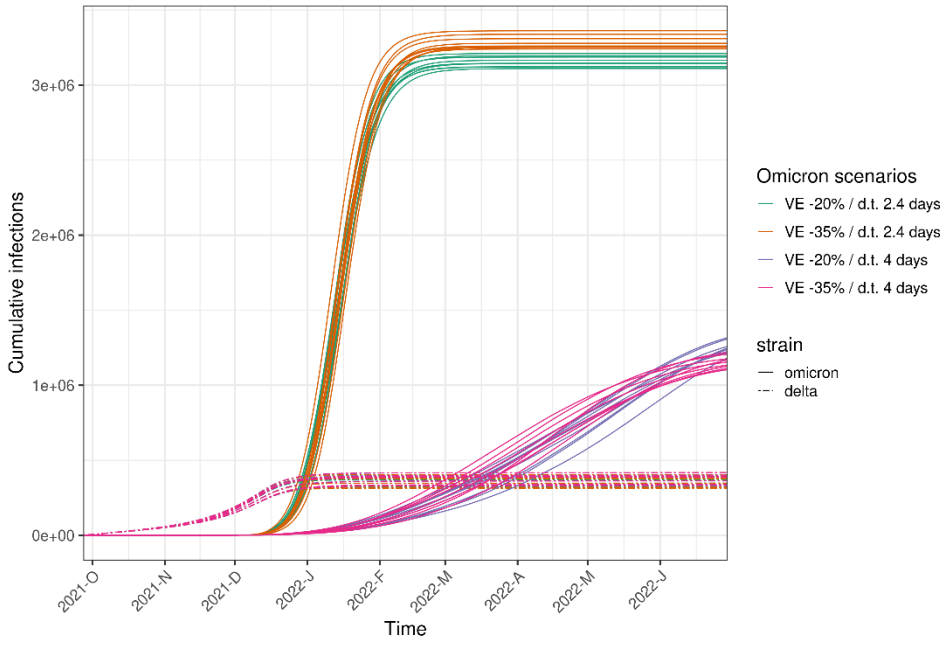


Figure: Cumulative number of infections, in the baseline scenarios.

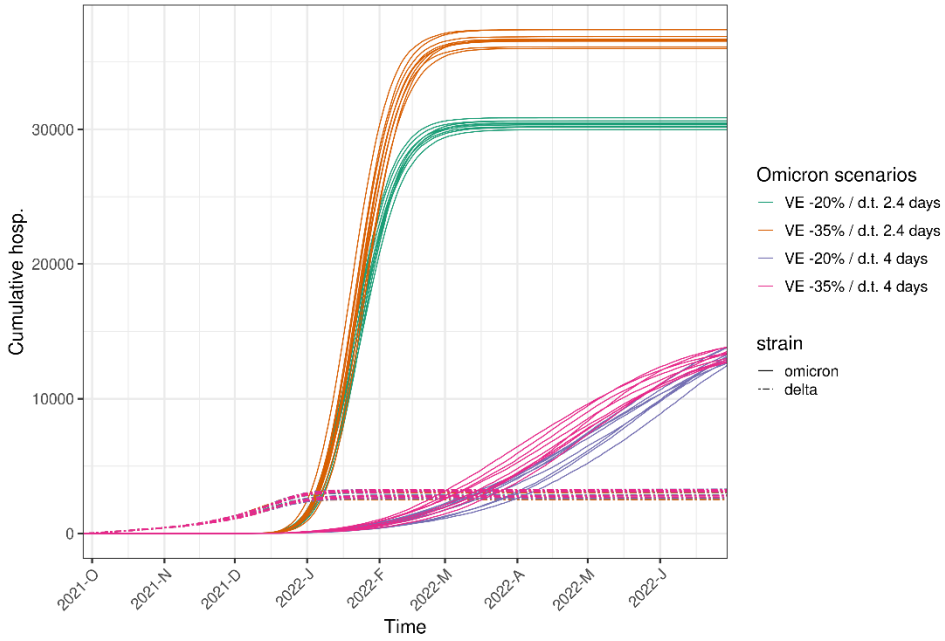


Figure: Cumulative number of hospitalisations, in the baseline scenarios.

2 – Varying effect of interventions

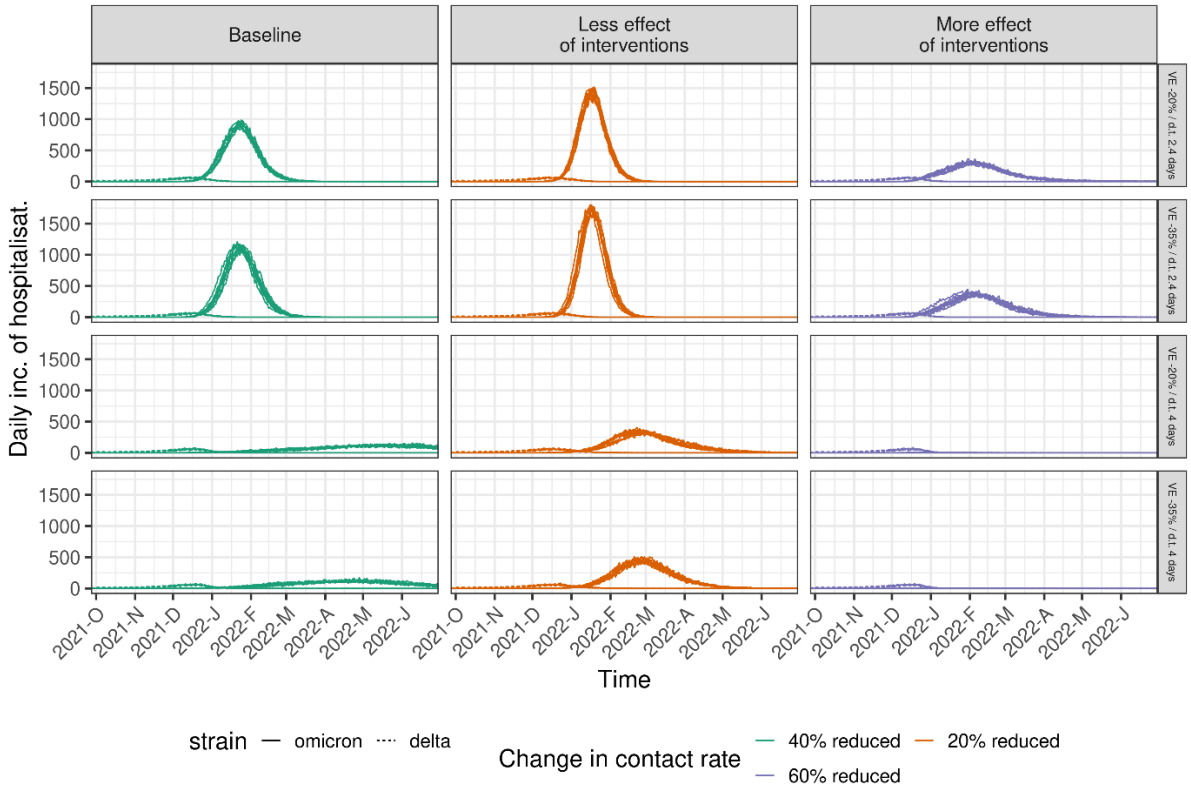


Figure: Daily incidence of hospitalisations for different levels of effect of the interventions. All other parameters are baseline.

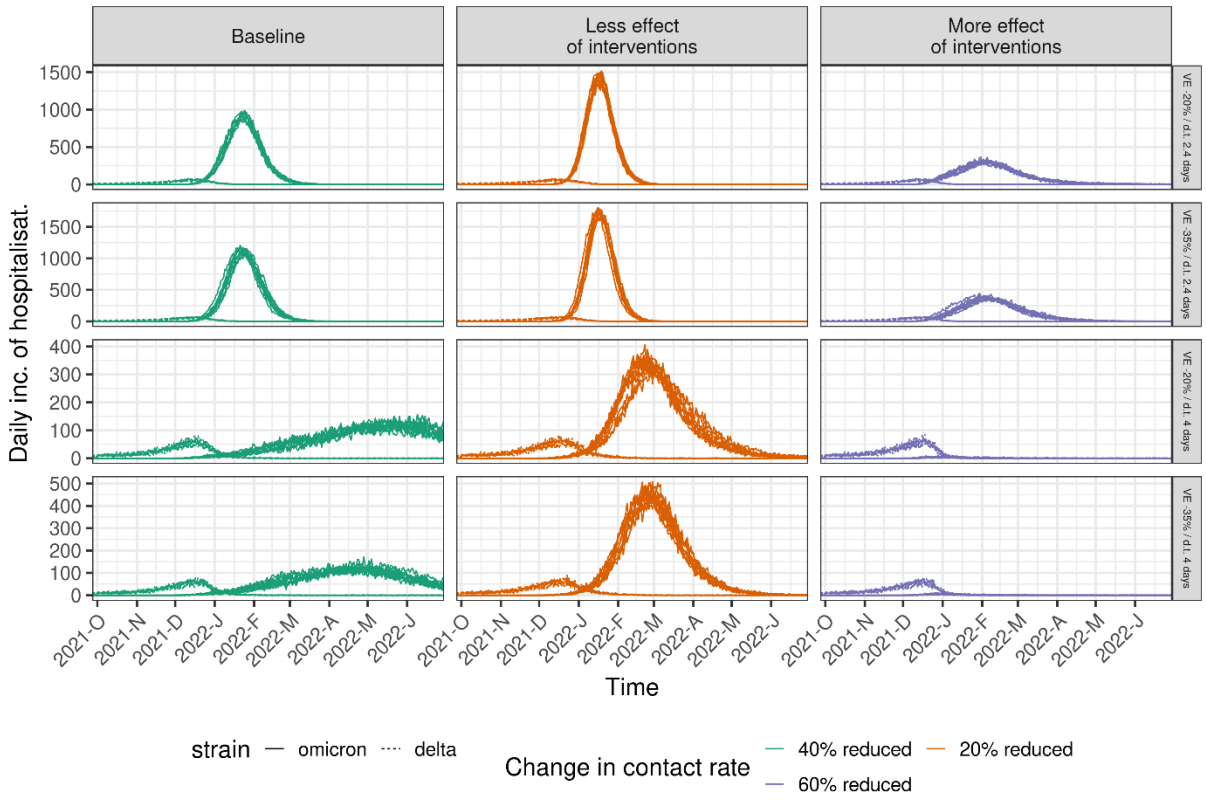


Figure: Daily incidence of hospitalisations. This is the exact same numbers as in Figure 3, except that the y axis scales vary between the rows to make the scenarios with small numbers more interpretable. Baseline parameters except that the effect of interventions is varied.

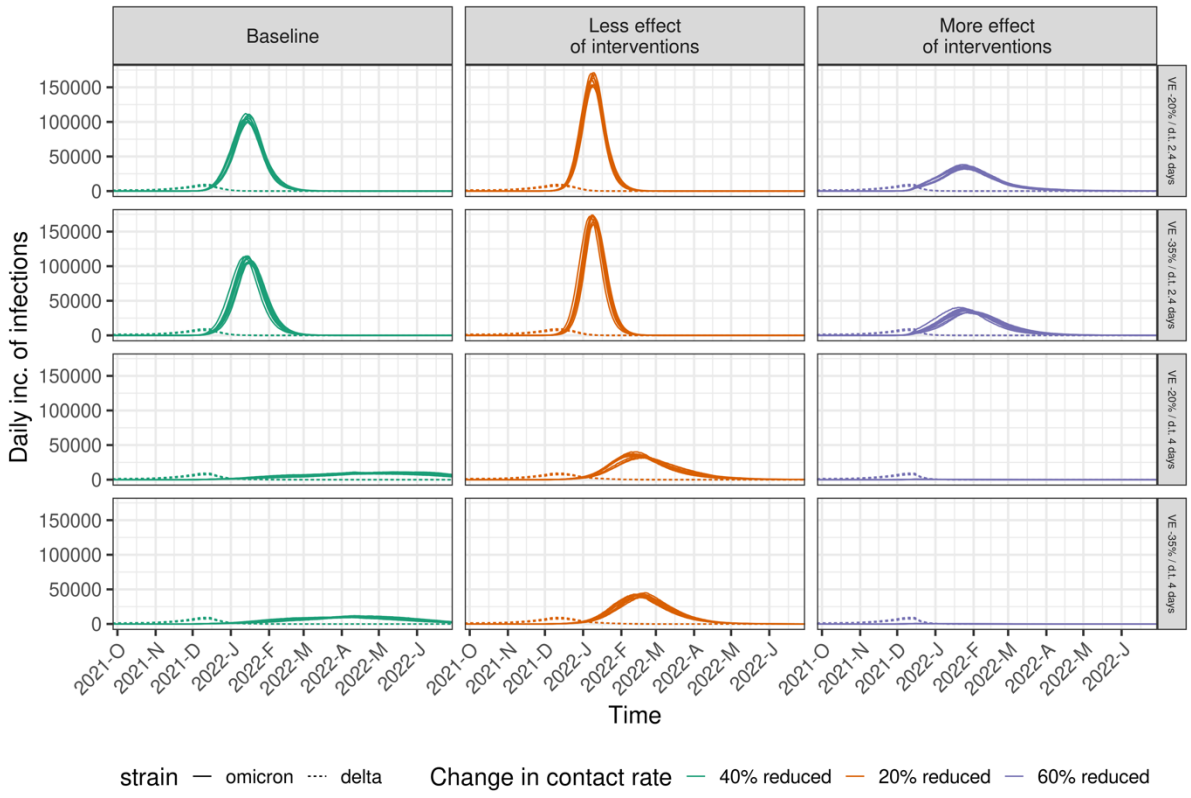


Figure: Daily incidence of infections. Baseline parameters except that the effect of interventions is varied.

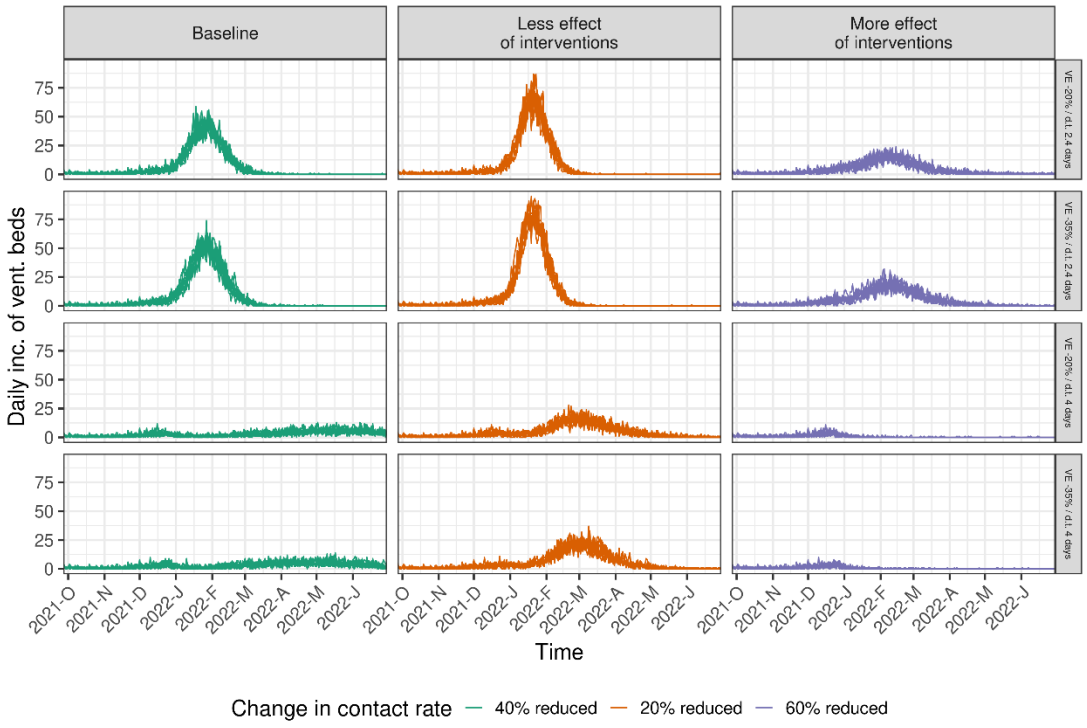


Figure: Daily incidence of ventilator beds. Baseline parameters except that the effect of interventions is varied.

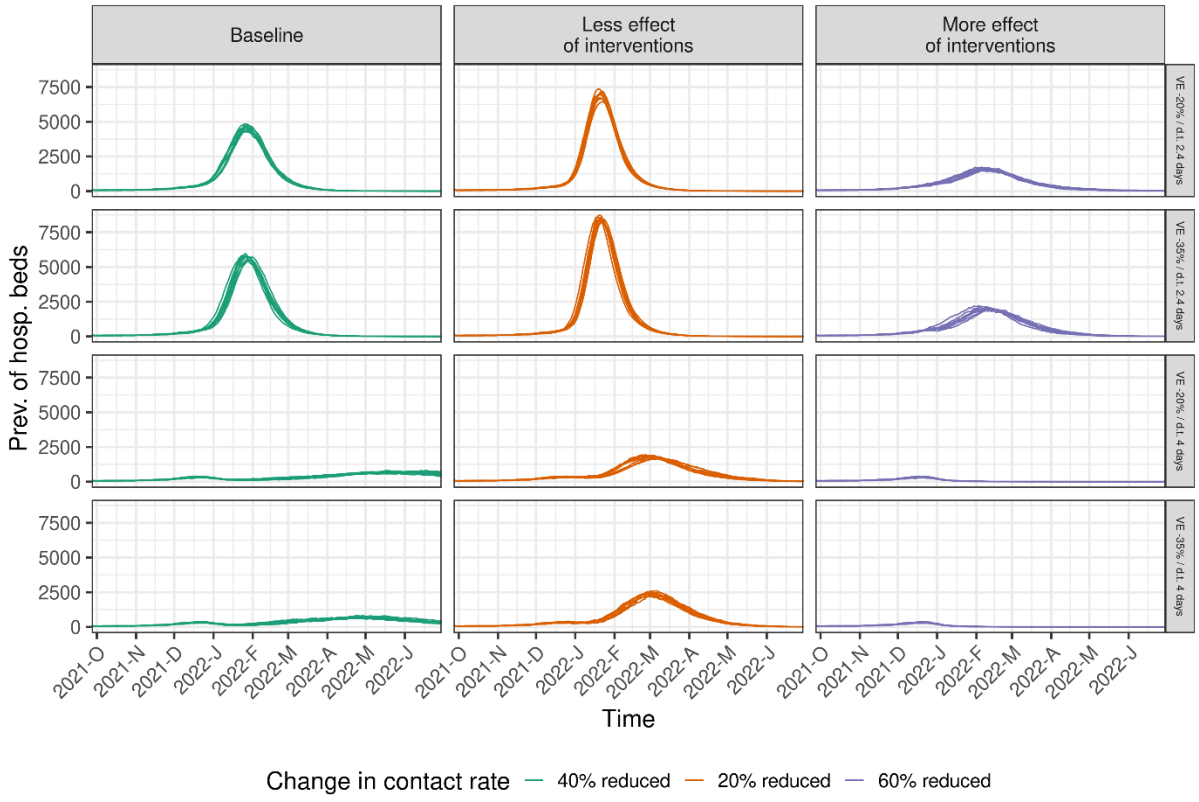


Figure: Prevalence of hospital beds. Baseline parameters except that the effect of interventions is varied.

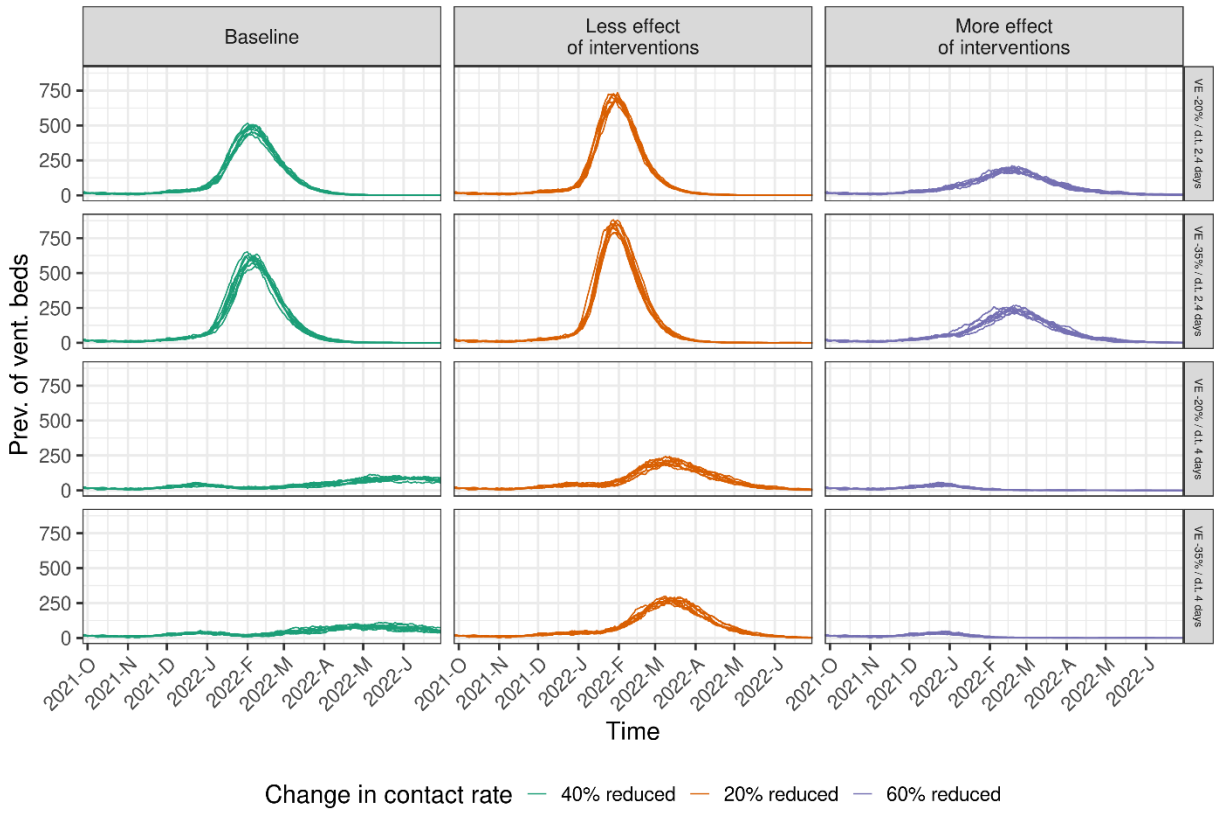


Figure: Prevalence of ventilator beds. Baseline parameters except that the effect of interventions is varied.

3 – Vaccine effectiveness against severe outcomes

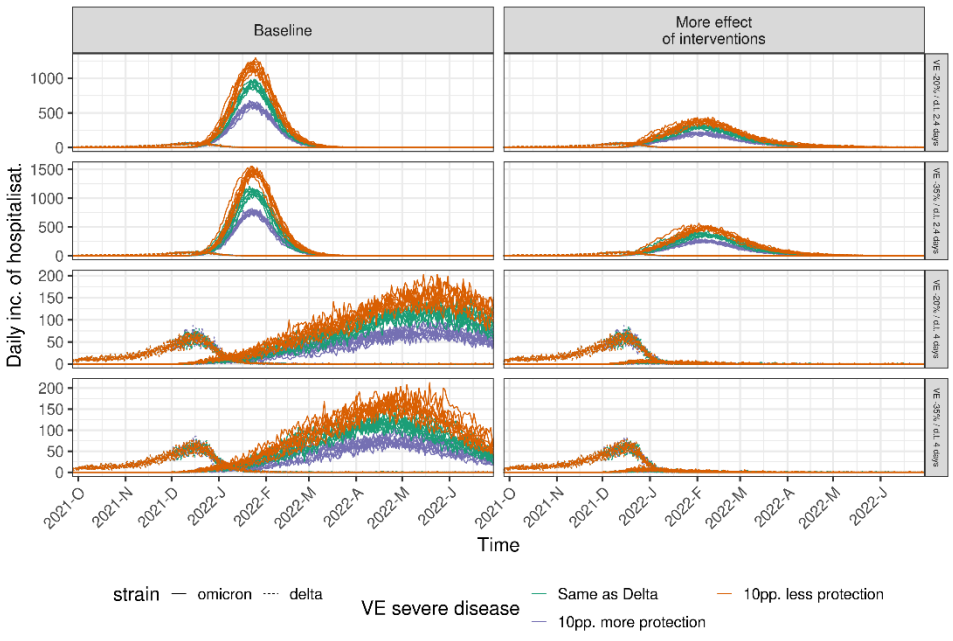


Figure: Daily incidence of hospitalisations for different effectiveness of the vaccines against severe disease. All other parameters are those in the baseline. This is the exact same numbers as in Figure

4, except that the y axis scales vary between the rows to make the scenarios with small numbers more interpretable.

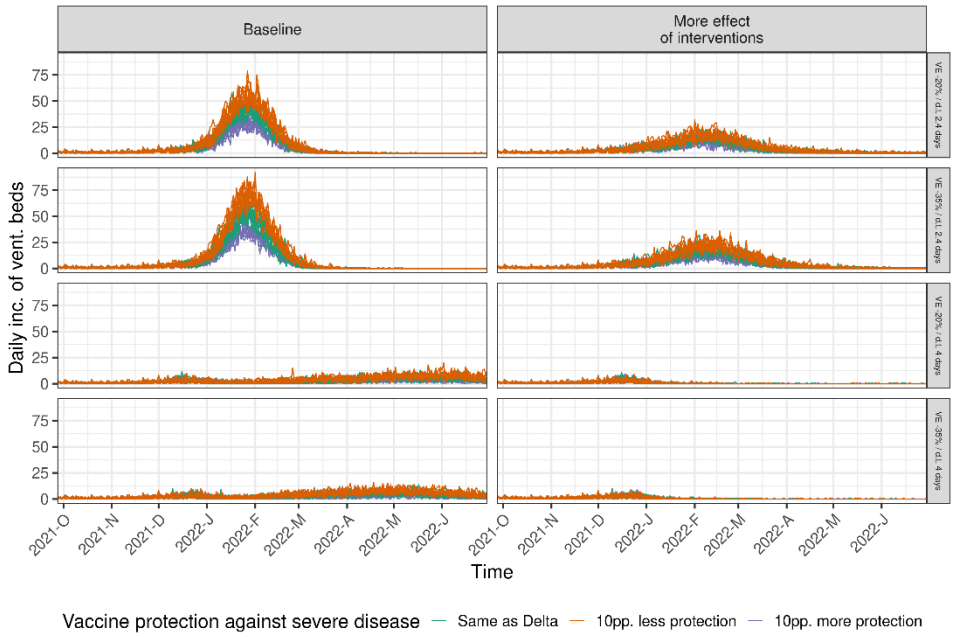


Figure: Daily incidence of ventilator beds for different assumptions about the vaccine effectiveness against severe disease for Omicron. Columns show different assumptions for effect of interventions. All other parameters are those in the baseline.

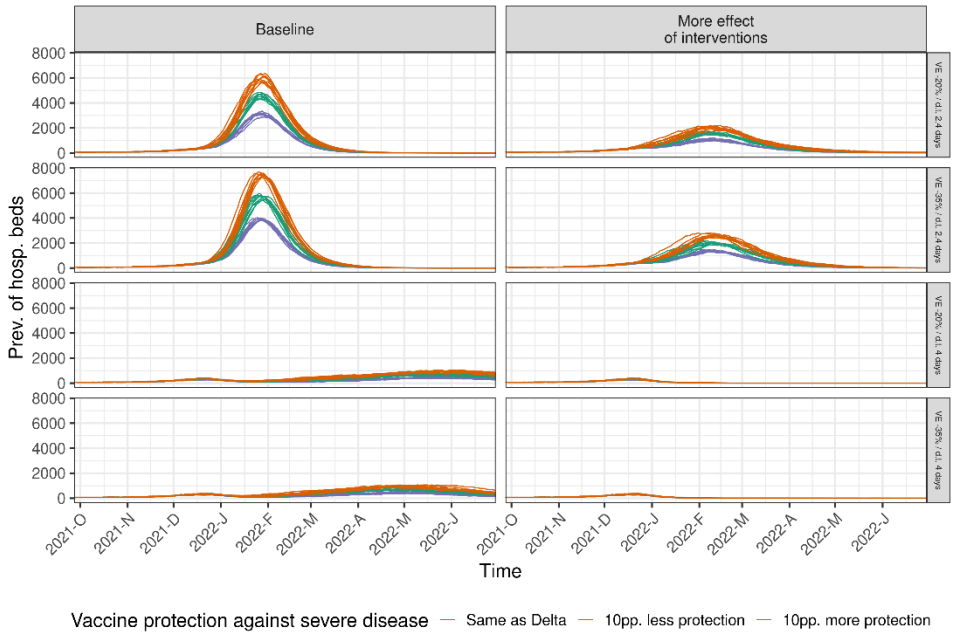


Figure: Prevalence of hospital beds for different assumptions about the vaccine effectiveness against severe disease for Omicron. Columns show different assumptions for effect of interventions. All other parameters are those in the baseline.

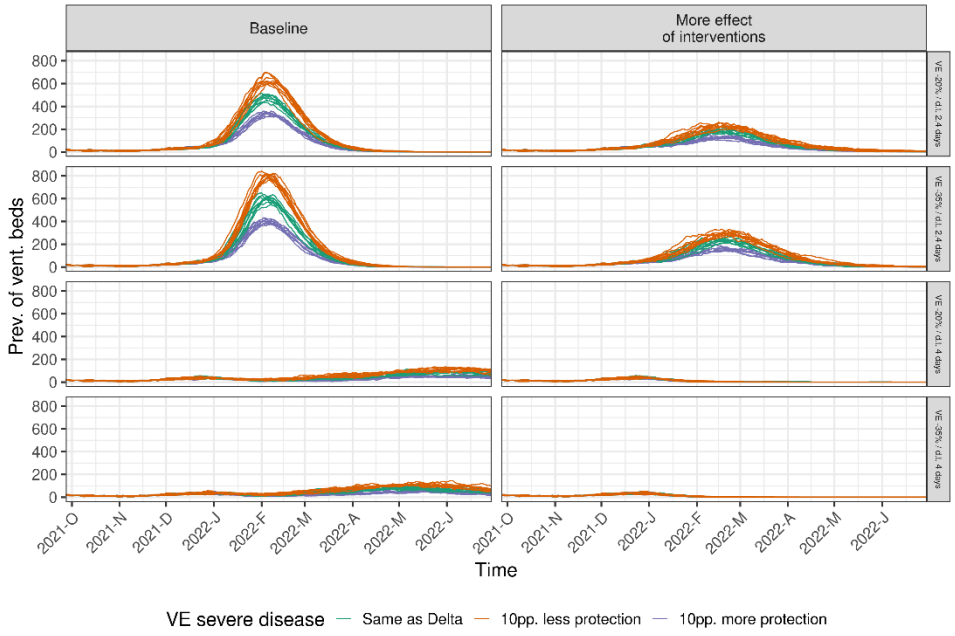


Figure: Prevalence of ventilator beds for different assumptions about the vaccine effectiveness against severe disease for Omicron. Columns show different assumptions for effect of interventions. All other parameters are those in the baseline.

4 – Vaccine uptake

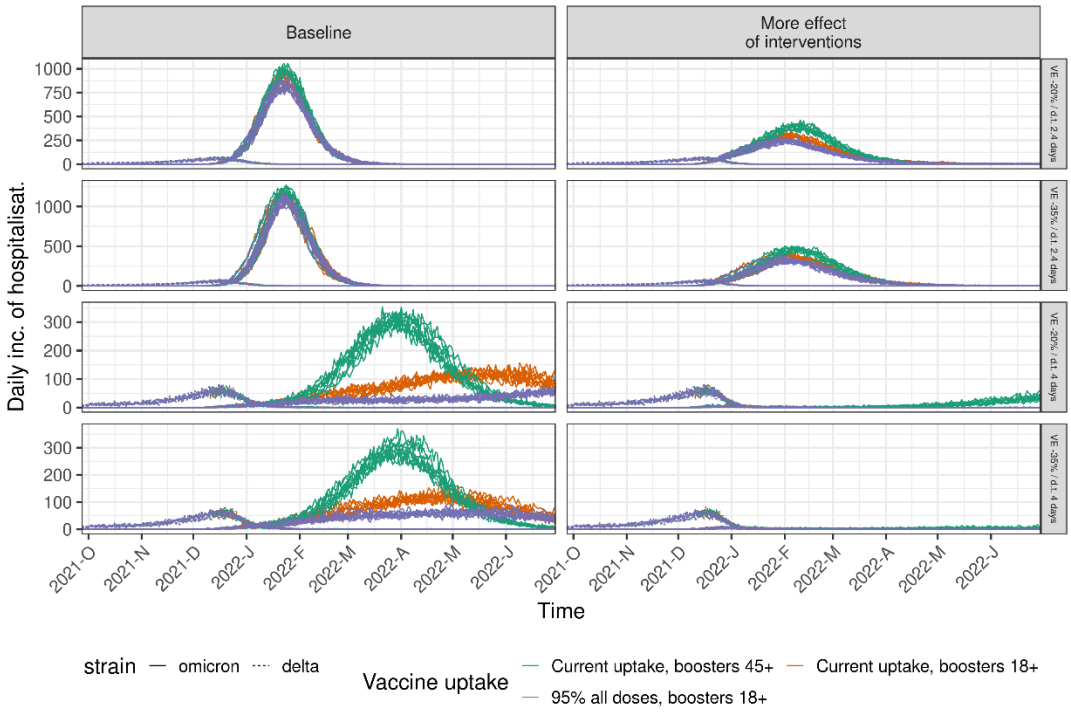


Figure: Daily incidence of hospitalisations for different vaccine uptake scenarios. All other parameters are those in the baseline. This is the exact same numbers as in Figure 5, except that

the y axis scales vary between the rows to make the scenarios with small numbers more interpretable.

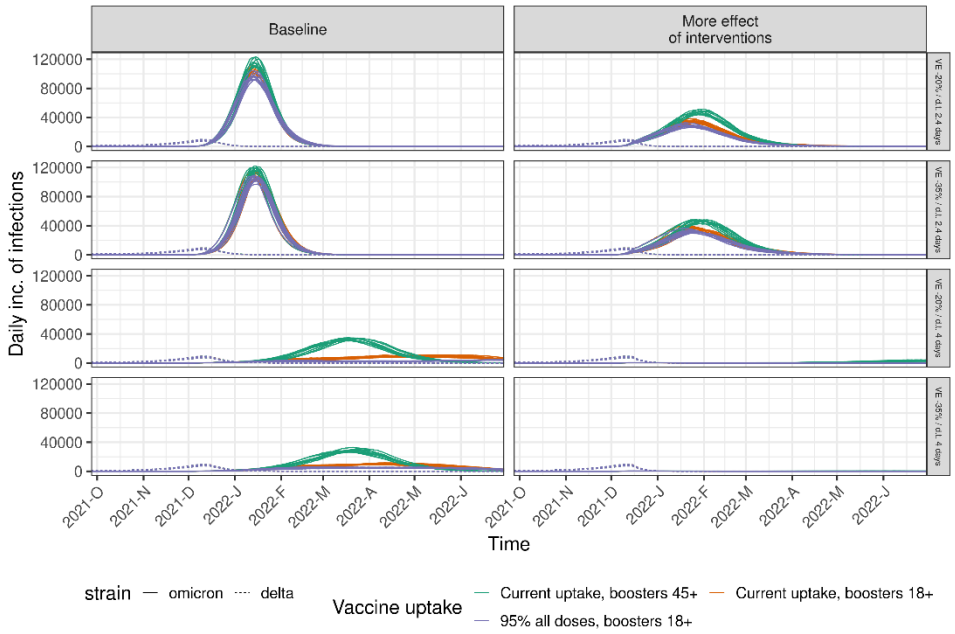


Figure: Daily incidence of infections for different vaccine uptake scenarios. All other parameters are baseline.

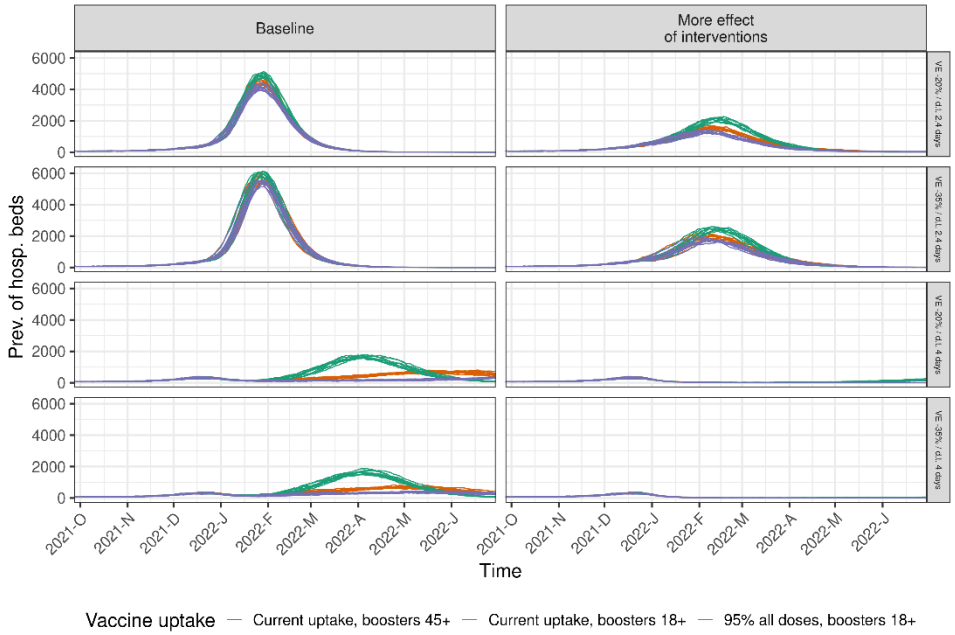


Figure: Prevalence of hospital beds for different vaccine uptake scenarios. All other parameters are baseline.

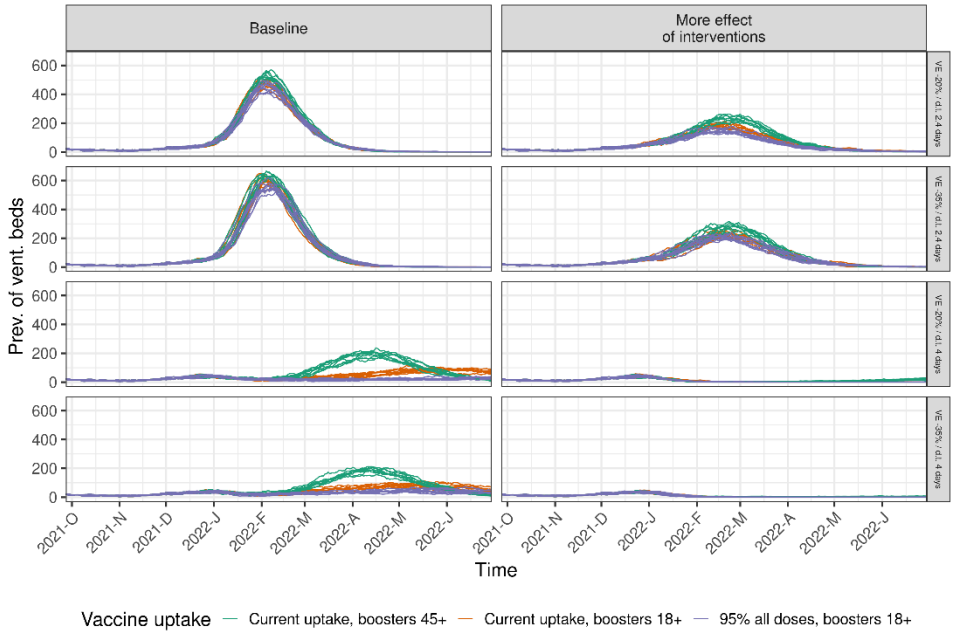


Figure: Prevalence of ventilator beds for different vaccine uptake scenarios. All other parameters are baseline.

5 – Vaccine effectiveness profile

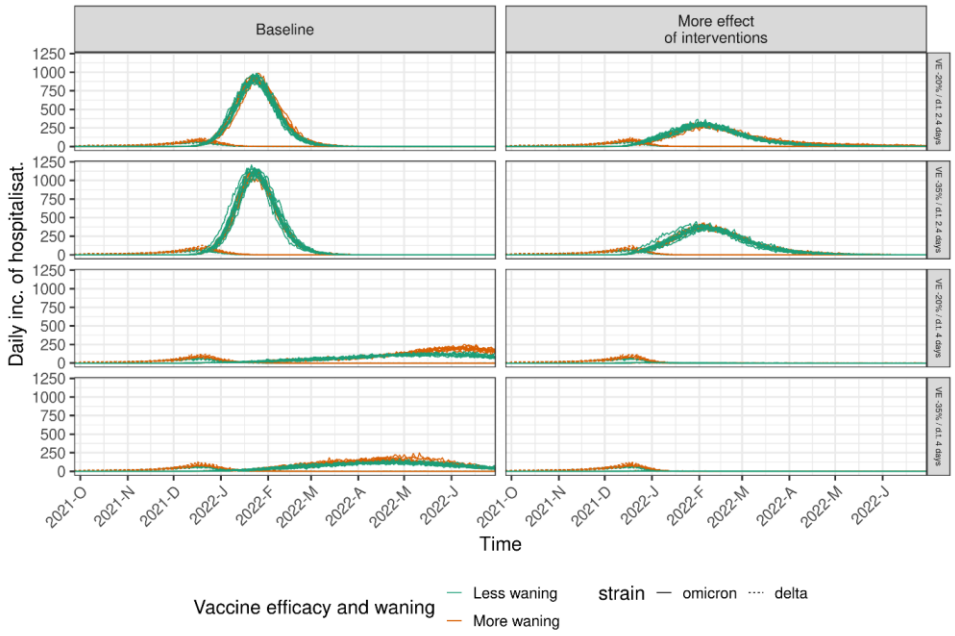


Figure: Daily incidence of hospitalisations for different vaccine profiles. All other parameters are baseline.

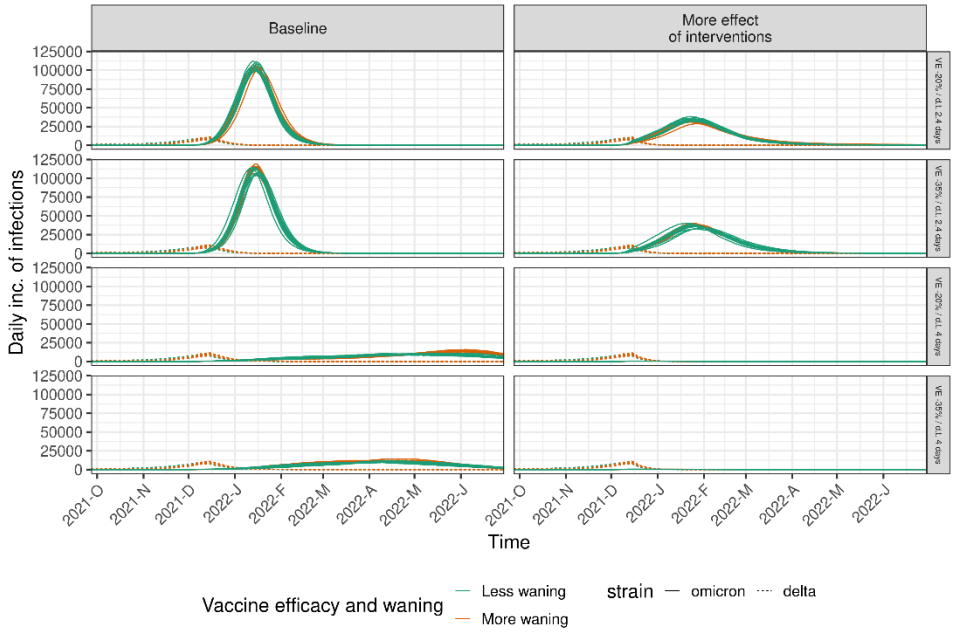


Figure: Daily incidence of infections for different vaccine profiles. All other parameters are baseline.

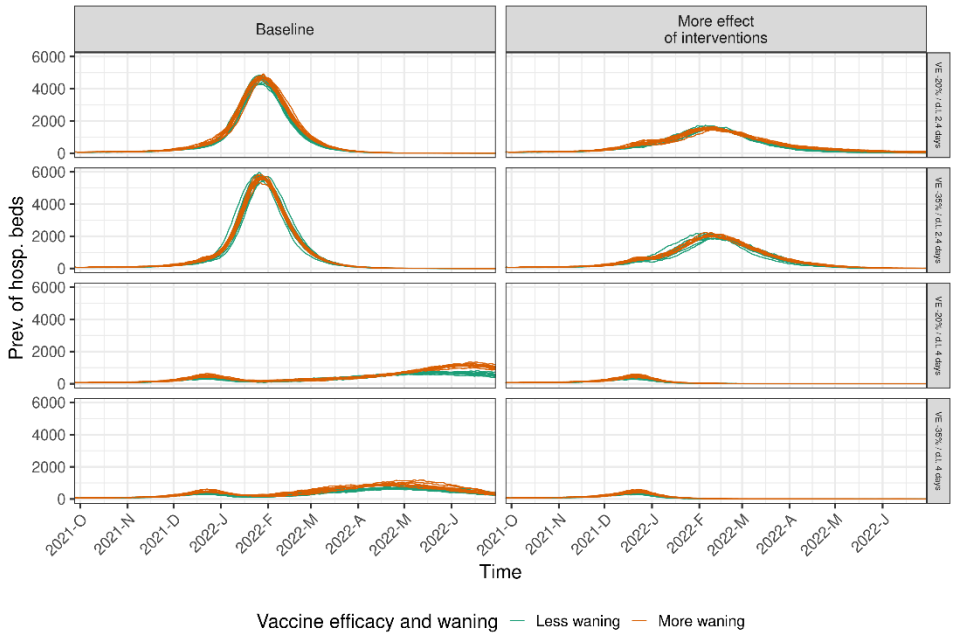


Figure: Prevalence of hospital beds for different vaccine profiles. All other parameters are baseline.

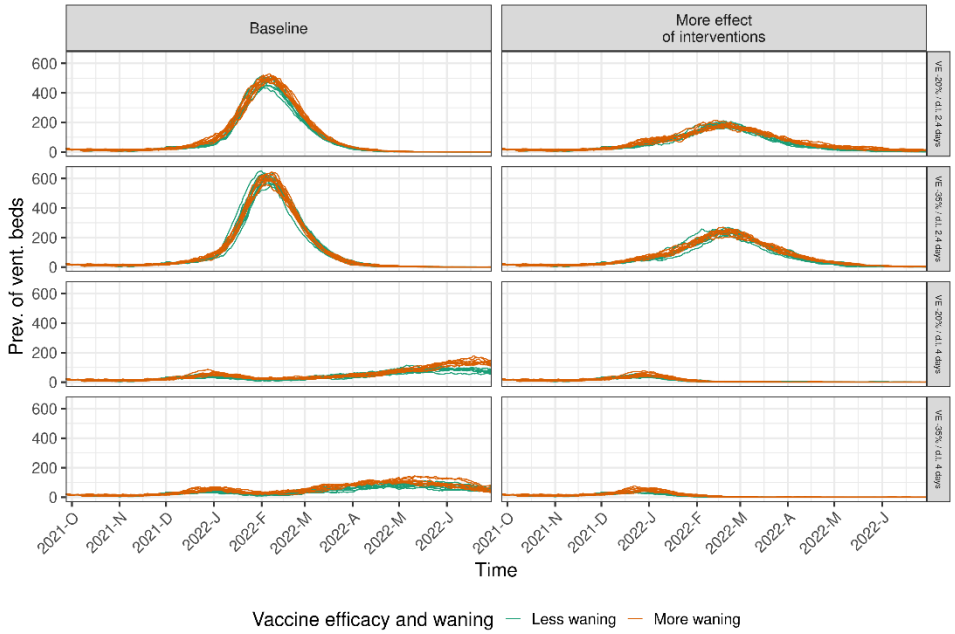
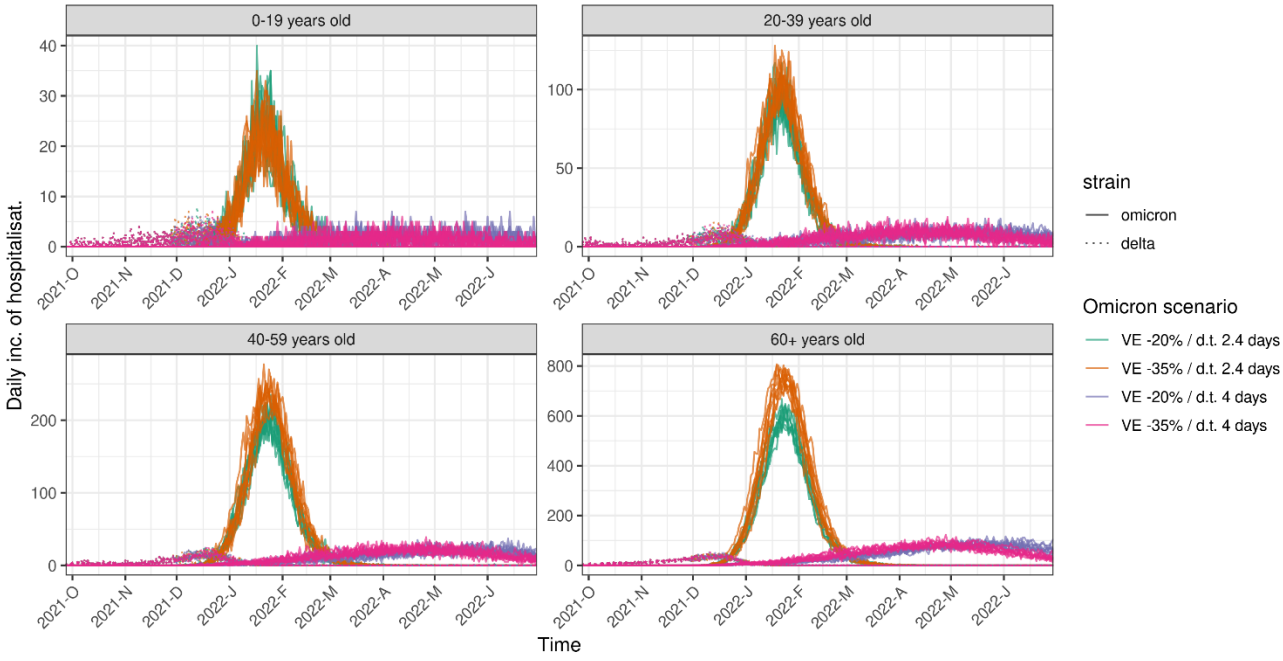


Figure: Prevalence of ventilator beds for different vaccine profiles. All other parameters are baseline.

Age breakdowns of the baseline scenarios



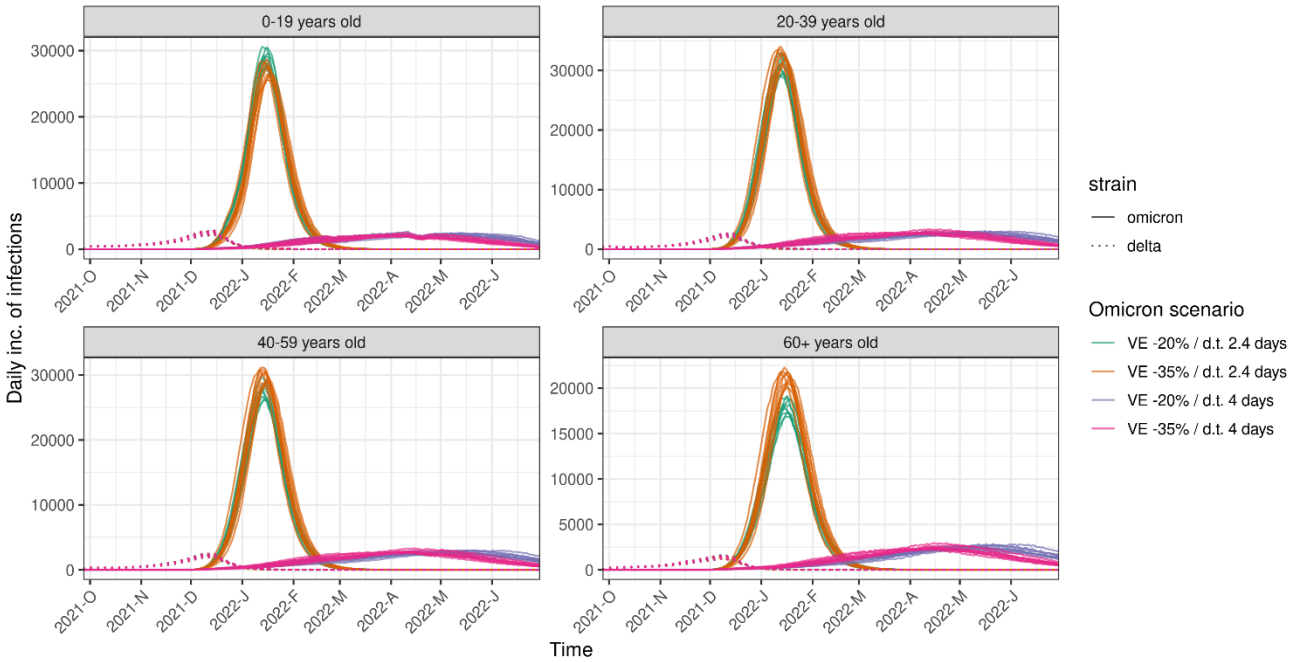


Figure: Daily incidence of hospitalisations (top) and infections (bottom). Panels show different age groups. Baseline parameters with interventions able to reduce the contact rate by 40%.

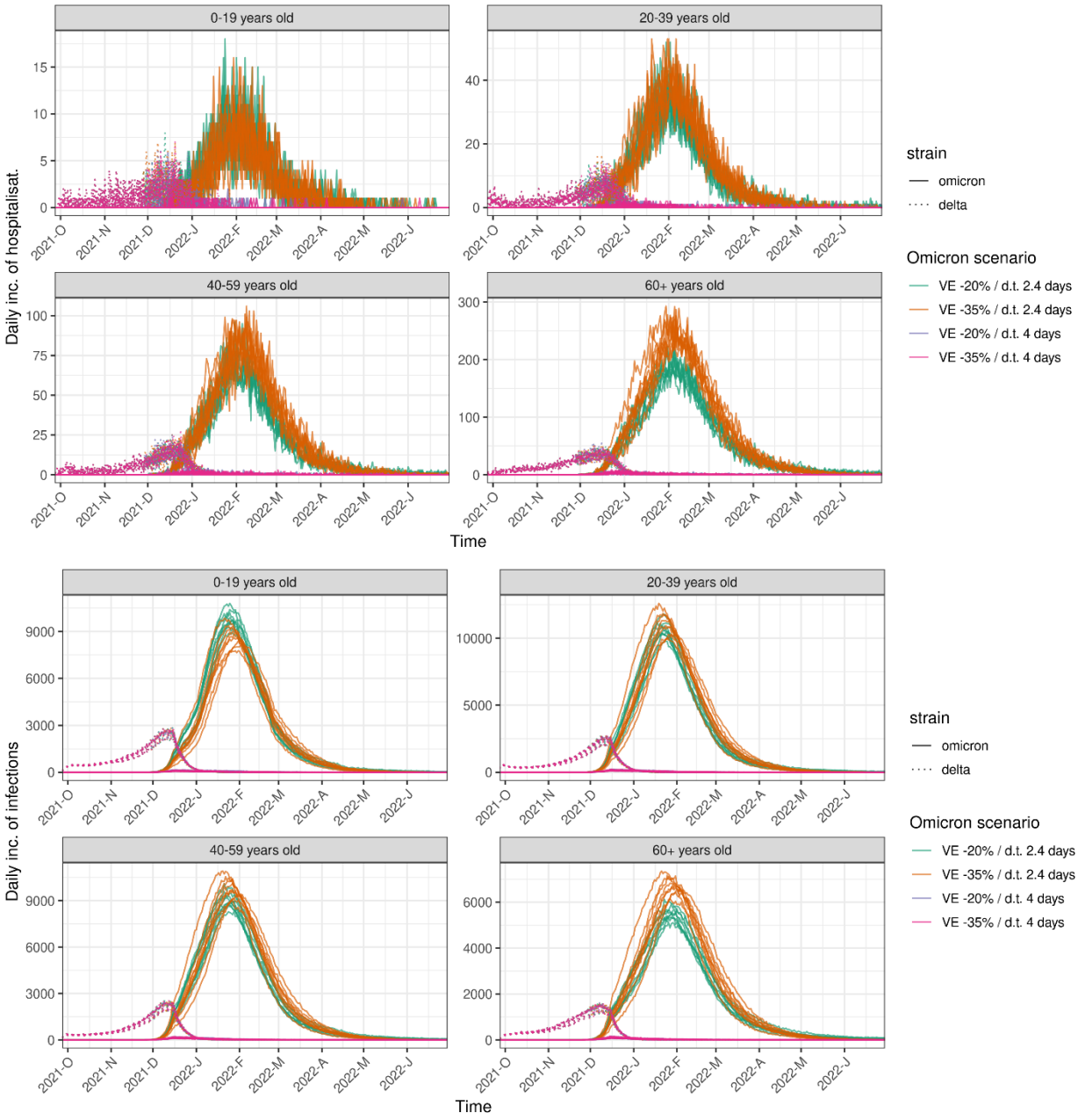


Figure: Daily incidence of hospitalisations (top) and infections (bottom). Panels show different age groups. Baseline parameters, except that interventions are able to reduce the contact rate by 60%.

Effect of the booster program by age group

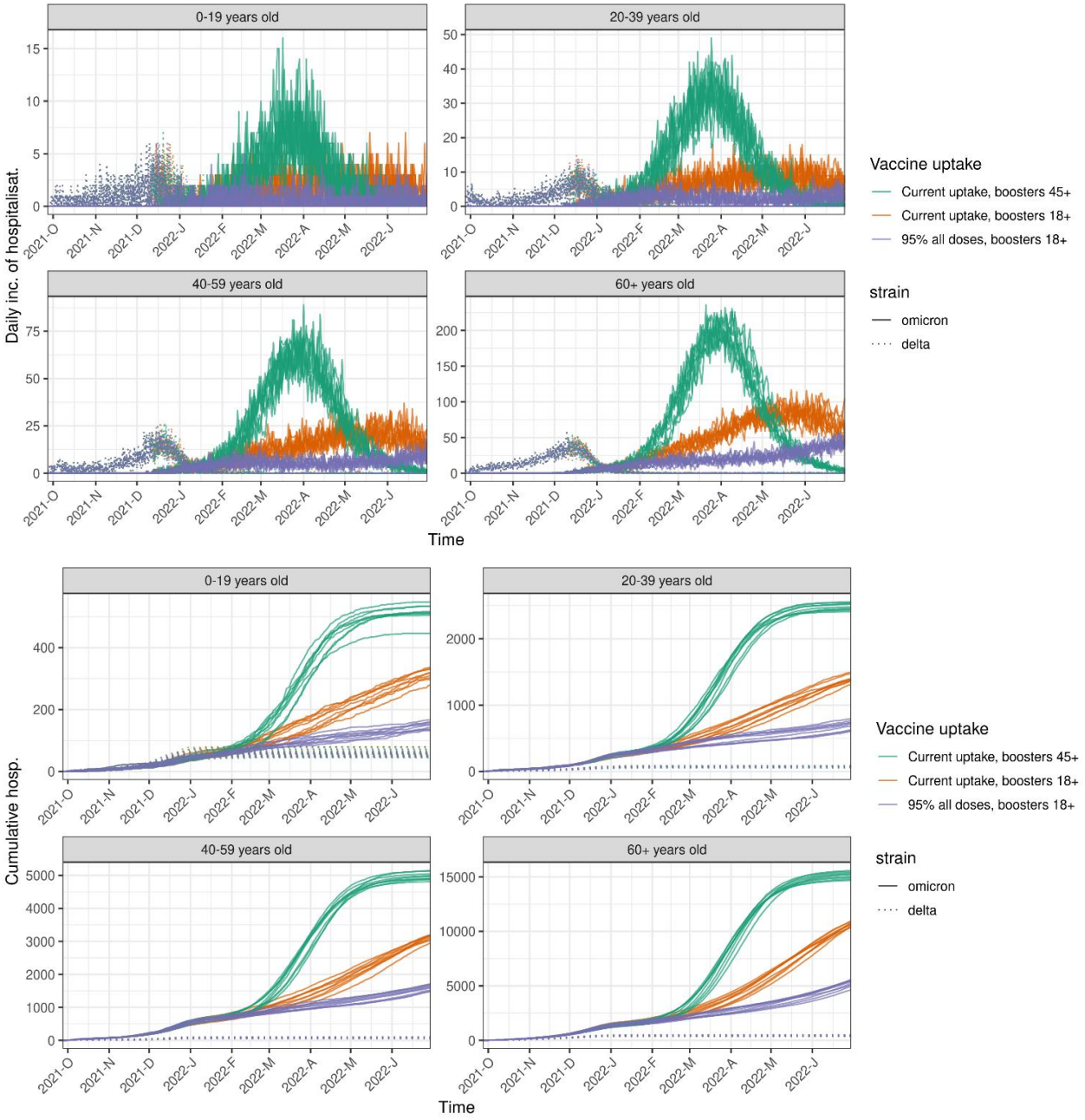


Figure: Daily incidence (top) and cumulative (bottom) hospitalisations. Baseline scenario with the Omicron doubling time set to 4 days and the vaccine effectiveness reduced by 20 percentage points. Incidence and cumulative hospitalisations by age group.

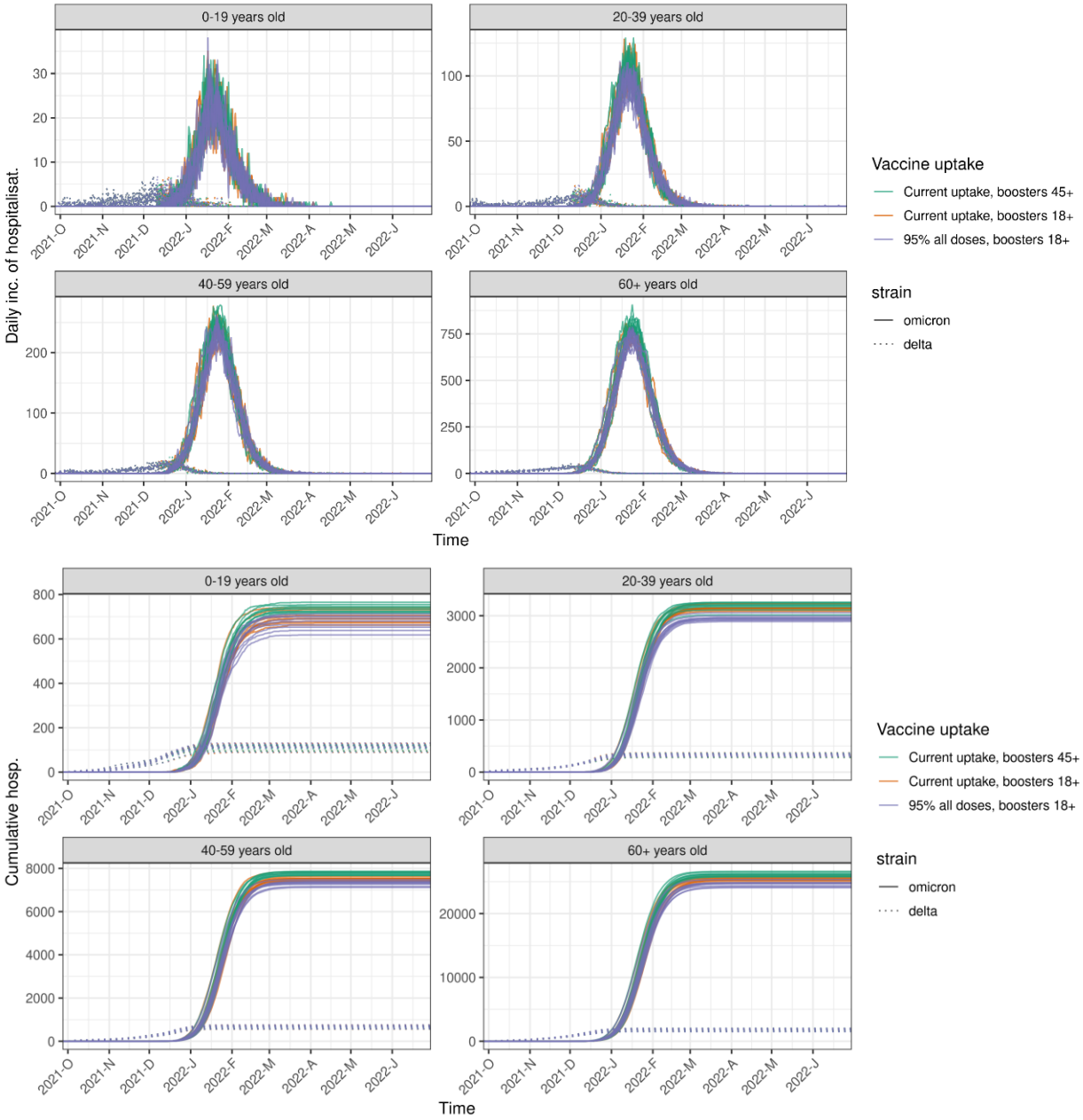


Figure: Daily incidence (top) and cumulative (bottom) hospitalisations. Baseline scenario with the Omicron doubling time set to 2.4 days and the vaccine effectiveness reduced by 35 percentage points. Incidence and cumulative hospitalisations by age group.

[i] FHI COVID-19 modelling group, *Long-term scenarios for Norway for the fall and winter 2021–2022 (*2021). https://www.fhi.no/contentassets/e6b5660fc35740c8bb2a32bfe0cc45d1/vedlegg/nasjonale-og-regionale-rapporter/2021-10-28-long_term_scenarios_report_updated.pdf (Accessed December 19th 2021)

[ii] SARS-CoV-2 variants of concern and variants under investigation in England. Technical briefing 31. 10 December 2021. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1040076/Technical_Briefing_31.pdf (Accessed December 18, 2021)

[iii] Tande, A J et al., *Impact of the Coronavirus Disease 2019 (COVID-19) Vaccine on Asymptomatic Infection Among Patients Undergoing Preprocedural COVID-19 Molecular Screening,* Clinical Infectious Diseases, https://doi.org/10.1093/cid/ciab229 (2021)

Tang, P et al., *BNT162b2 and mRNA-1273 COVID-19 vaccine effectiveness against the SARS-CoV-2 Delta variant in Qatar*, Nature Medicine 27 (2021)

Bruxvoort KJ, Sy LS, Qian L, Ackerson BK, Luo Y, Lee GS, Tian Y, Florea A, Takhar HS, Tubert JE, Talarico CA, Tseng HF. Real-world effectiveness of the mRNA-1273 vaccine against COVID-19: Interim results from a prospective observational cohort study. Lancet Reg Health Am. 2021 Nov 25:100134. doi: 10.1016/j.lana.2021.100134

[iv] Andrews, N. et al. *Effectiveness of BNT162b2 (Comirnaty, Pfizer-BioNTech) COVID-19 booster vaccine against covid-19 related symptoms in England: test negative case-control study* (2021) https://www.medrxiv.org/content/10.1101/2021.11.15.21266341v1 (Accessed December 19th 2021)

Andrews, N. et al, *Vaccine effectiveness and duration of protection of Comirnaty, Vaxzevria and Spikevax against mild and severe COVID-19 in the UK,* https://www.medrxiv.org/content/10.1101/2021.09.15.21263583v2 (accessed December 19th 2021)

[v] 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.