Norwegian Institute of Public Health, Division of Infection Control, Case number 4

Institution: NIPH
Administrative unit: Division of infection control
Title of case study: COVID-19 modelling
Period when the underpinning research was undertaken: 2015-2019
Period when staff involved in the underpinning research were employed by the submitting institution: 2015-2022
Period when the impact occurred: 2020-2022

1. Summary of the impact

Since early 2020, we collaborated with UiO, Norwegian Computing Center and Telenor to develop and implement mathematical and statistical models tailored to manage the COVID-19 pandemic in Norway. These models served multiple purposes, including (i) estimating effective reproduction numbers to assess the current situation, (ii) generating short-term projections to estimate hospital and ICU bed requirements, and (iii) conducting scenario analyses for policy decisions related to vaccine deployment, infection control, risk assessments, and long-term strategies.

Our results were pivotal in providing COVID-19 policy advice and supporting Norwegian national and local health authorities throughout the complex and highly dynamic pandemic with high-profile media coverage.

2. Underpinning research

Contribution 2015-2019

NIPH's aim to build a strong infectious disease modelling group, led to partnership through BigInsight SFI and two PhD projects that became essential for our COVID-19 modelling work:

R1. Development of a spatio-temporal, stochastic model for the spread of influenza informed by mobile phone data, using an Approximate Bayesian Computation (ABC-SMC) calibration technique (PhD Solveig Engebretsen UiO/NIPH; 2019 moved to NR).

R2. Development of a fine-grained individual-based model for MRSA transmission in Norway, closely mimicking the sociodemographic (PhD Francesco Di Ruscio UiO/NIPH; from 2019 NIPH).

Contribution 2020-2022

In February 2020, we quickly mobilised a COVID-19 modelling team with our partners in BigInsight: UiO, NR and Telenor. We provided weekly situational awareness and forecasting reports from March using Norwegian real-time registry data (BEREDT C19). We conducted short-deadline scenario modelling at requests from the government and internally at NIPH. We also received informal requests from hospitals and other stakeholders.

The complexity and breadth of the modelling and data analytics increased over time due to changes in data quality, new knowledge, arrival of novel strains, vaccines, shifts in policy questions, etc., necessitating constant developments. The workload was high and intense throughout. Key methods and deliveries include:

Situational awareness and forecasting (165+ reports March 2020-2022) (C1/C2):

- *National/Regional Changepoint Model:* We adjusted R1 to SARS-CoV-2 and county-level geography of Norway, informed by real-time Norwegian mobility data. The models assumed constant reproduction numbers within specific periods, offset by manually chosen "changepoints", linked to intervention changes. We developed a novel split-ABC-SMC inference technique for high-dimensional calibration(R3).

- *National/Regional Sequential Monte Carlo (SMC) Model:* Using a similar metapopulation structure, we developed a model providing daily-varying reproduction numbers nationally and regionally. The models were fitted adopting an SMC inference technique using resampling of weighted particles for faster calibration (R4).
- *Key outputs: R-numbers, hospital capacity needs, case counts, county mobility trends*

Scenario modelling (40+ reports from May 2020 – 2022):

- *Individual-based model (IBM):* We adapted R2 to model SARS-CoV-2 transmission in Norway using a geolocated grid of 13,521 cells with 5.4 million individuals having multiple attributes, including age, household size, and occupation, based on census data. (R5).
- *Metapopulation model:* In tandem, we developed an age- and risk-structured model for Norway separated into 10-25 regions representing Norway with age-specific mixing based on Norwegian contact matrices and mobile phone data for travel between regions (R5).
- *Key output:*
    - Modelling age- and geographic prioritisation of vaccines (C3)
    - Modelling for health-economic evaluations, Holden Utvalg (II-IV) (C4)
    - Modelling long-term strategies/risk evaluations as a knowledge base into NIPH's advising on policies (C1)
- We produced results on specific aspects of the COVID-19 epidemiology and behaviour relevant to managing COVID-19. For example, analyses of contact tracing data showing increased household transmission and effects of vaccination on Delta and Omicron transmission(R6).

Contribution post COVID-19:

- We continue to document our work through publications, including quantifying the drop in social contacts in Norway in 2020 using Norwegian adult panel data (C6)
- We make methodological developments of IBM calibration (PhD started 2023 in collaboration with Dept. of Physics UiO).
- We extend and use our models through participation in international forecasting hubs ECDC RespiCast and CDC FluSight.

NIPH: Birgitte Freiesleben de Blasio (leader/ 20% OCBE UiO), Francesco Di Ruscio (researcher), Gunnar Rø (reseacher), Alfonso Diz-Lois Palomares (researcher), Jonas Christopher Lindstrøm (researcher), Anja Bråthen Kristoffersen (researcher, started May 2020), Louis Yat Hin Chan (postdoc 2020-2022); Jørgen Midtbø (researcher, started March 2021), Neda Jalali (postdoc 2021-2022), *infrastructure* Richard White (researcher), Gry Grøneng (researcher), Chi Zhiang (researcher/PhD OCBE).
UiO: Oslo Centre for Biostatistics and Epidemiology (OCBE) Arnoldo Frigessi (co-lead), Chi Zhiang (researcher/PhD), David Swanson (researcher May-June 2020); Geir Storvik (senior researcher), Department of Mathematics. Norwegian Computing Centre (NR) Solveig Engebretsen (researcher); Telenor Research Kenth Engø-Monsen

3. References to the research (indicative maximum of six references)

R1: Engebretsen, S., Engø-Monsen, K., Aleem, M.A., Gurley, E.S., Frigessi, A. and De Blasio, B.F., 2020. Time-aggregated mobile phone mobility data are sufficient for modelling influenza spread: the case of Bangladesh. *Journal of the Royal Society Interface*, *17*(167), p.20190809.

R2: Di Ruscio, F., Guzzetta, G., Bjørnholt, J.V., Leegaard, T.M., Merler, S. and De Blasio, B.F., 2019. Quantifying the transmission dynamics of MRSA in the community and healthcare settings in a low-prevalence country. *Proceedings of the National Academy of Sciences*, *116*(29), pp.14599-605.

R3: Engebretsen, S., Diz-Lois Palomares, A., Rø, G., Kristoffersen, A.B., Lindstrøm, J.C., Engø-Monsen, K., Kamineni, M., Hin Chan, L.Y., Dale, Ø., Midtbø, J.E. and Stenerud, K.L., Di Ruscio, F., White, R., Frigessi, A., De Blasio, B.F., 2023. A real-time regional model for COVID-19: Probabilistic situational awareness and forecasting. *PLOS Computational Biology*, *19*(1), p.e1010860.

R4: Storvik, G., Diz-Lois Palomares, A., Engebretsen, S., Rø, G.Ø.I., Engø-Monsen, K., Kristoffersen, A.B., de Blasio, B.F. and Frigessi, A., 2023. A sequential Monte Carlo approach to estimate a time-varying reproduction number in infectious disease models: the Covid-19 case. With discussion. *Journal of the Royal Statistical Society Series A*, *186*(4), pp.616-632.

R5: Chan, L.Y.H., Rø, G., Midtbø, J.E., Di Ruscio, F., Watle, S.S.V., Juvet, L.K., Littmann, J., Aavitsland, P., Nygard, K.M., Berg, A.S. and Bukholm, G., Kristoffersen, A.B., Engø-Monsen, K., Engebretsen, S., Swanson, D., Diz-Lois Palomares, A., Lindstrøm, J.C., Frigessi, A. De Blasio, B.F.,2023. Modeling geographic vaccination strategies for COVID-19 in Norway. Accepted by PLOS *Computational Biology*, available on *medRxiv*

R6: Jalali, N., Brustad, H.K., Frigessi, A., MacDonald, E.A., Meijerink, H., Feruglio, S.L., Nygård, K.M., Rø, G., Madslien, E.H. and De Blasio, B.F., 2022. Increased household transmission and immune escape of the SARS-CoV-2 Omicron compared to Delta variants. *Nature Communications*, *13*(1), p.5706.

3. Details of the impact

Our modelling team provided continuous and timely support to the government and health authorities to inform policy decisions throughout the COVID-19 pandemic in Norway. The instrumental policy impact spanned from early 2020 to the spring of 2022. However, the effect of the research reaches beyond this day, contributing to enhanced preparedness for future pandemics.

Our success was facilitated by collaborations with research institutions in Oslo, leveraging existing modelling partnerships to swiftly scale up activity during the crisis. We also benefited from unique access to real-time Norwegian registry data at NIPH (Beredt C19), and in-house expertise in infection control, surveillance, virology, and vaccination critically supported the development of our models.

The team was responsible for data curation, methodology development, and infrastructure pipeline management, utilising high-performance computing clusters at UiO (Sigma2/USIT) for model execution, visualisations, and report writing. Typically, models for assessment of the SARS-CoV2 transmission were launched on Monday mornings to use the most recent day for the weekly reports that were published at noon on Wednesdays. The latter part of the week was focused on developments and test runs. Reports were written in English for accessibility, featuring results with uncertainty intervals about regional and national developments, county mobility trends, and foreign roamers. Alongside, on requests, scenario modelling involving major model developments and testing had to be planned and executed with short deadlines. We also addressed questions from hospitals regarding staff planning, and from health authorities regarding stockpiling of medical equipment.

Our results were included in presentations to the government, and we presented results in meetings with health authorities, including municipal doctors. The modelling outcomes and the uncertainties were part of the public discourse. Our results commonly made headlines in national newspapers and were commented on by researchers, e.g. on Twitter. Team members were often approached directly by journalists or via the communication department at NIPH.

The Koronakommisjonen evaluating the Norwegian authorities' handling of the COVID-19 pandemic states in their second report, April 2022: "*The country's population and its authorities have handled the pandemic well overall. Norway has had one of Europe's lowest mortality rates, least restrictive infection control regimes and smallest declines in economic activity*". NIPH contributed to this success, including through modelling.

To further corroborate, the final evaluation report by the Koronautvalget, June 2023,(C9) concludes on mathematical modelling: "*Throughout the pandemic period, projections of infections, admissions and sickness absence were an important part of the authorities' decision-making. Projections [..] can take the form of "forecasts" -thought to be most likely future development - and "scenarios", i.e. different more or less realistic outcomes based on various assumptions, such as the virus's contagiousness. The purpose of scenarios is often to show a possible outcome space, not to*

predict the most likely development. The committee believes such projections have clear utility value as a basis for decision-making and therefore should be employed in future crises".

The Koronautvalget report further highlights challenges in effectively communicating modelling uncertainties. We experienced difficulties conveying the meaning of scenarios, often misinterpreted as forecasts (C7). We made our short-term forecasts by keeping the most recent trend in data constant, i.e. assuming a "no-change policy" to support policy decisions, which led to misconceptions. Critiques emerged when our forecasts retrospectively were perceived as too high or too low when policy measures had changed (C7). Furthermore, the lack of critical Norwegian seroprevalence data gave rise to uncertainties and potential biases in our results.

Concerning impact within the research community, we regularly met with modellers at our Nordic sister organisations during the crisis to discuss models and relevant data to inform policies. We also participated in international and national scientific meetings (C8), contributing to discussions, and providing results when possible. However, given the time pressure, contacts with other Norwegian academic modelling teams were limited. In November 2022, we arranged a 2-day network modelling workshop with the Norwegian Science Programme on COVID-19 with participation from UiO, UiB, NTNU and NORCE and NMBU. Norwegian modellers presented their work, and we initiated discussions on collaborating and building modelling capacity for the next pandemic, data sharing problems, etc.

Another impact of our work is an improved understanding of infectious disease epidemiology, like reproduction numbers, and the usefulness of infectious disease modelling in the broader public.

Finally, on long-term impact, we are working on several papers to bolster preparedness for future pandemics, including studies on modelling the Omicron wave in Norway with exit strategies around the start of 2022 and a health-economic evaluation to optimise non-pharmaceutical interventions during pandemics.

4. Sources to corroborate the impact

C1: NIPH COVID-19 modelling webpage with links to reports:
https://www.fhi.no/en/id/corona/coronavirus/coronavirus-modelling-at-the-niph-fhi/

C2: Example of situational awareness report, 24 March 2021
https://www.fhi.no/contentassets/e6b5660fc35740c8bb2a32bfe0cc45d1/vedlegg/nasjonale-og-regionale-rapporter/2021.03.24-national_regional_model.pdf

C3: Example of scenario modelling report for geographic prioritisation March 2021 (In Norwegian)
https://www.fhi.no/contentassets/e6b5660fc35740c8bb2a32bfe0cc45d1/vedlegg/nasjonale-og-regionale-rapporter/oppdrag_8_2303_bfdblasio.pdf

C4: Example of modelling for health economic evaluations (Holden Utvalg III – part 2 -March 2021
https://www.helsedirektoratet.no/rapporter/samfunnsokonomisk-vurdering-av-smitteverntiltak-covid-19/Samfunns%C3%B8konomiske%20vurderinger%20av%20smitteverntiltak%20-Tredje%20rapport%20%20del%202%20(15.%20mars%202021).pdf/_/attachment/inline/d543e9b0-907e-4de887594ca5061fa1d9:f1cb9a46c5015eac6f01693e91b3eefa71a12bd9/Samfunns%C3%B8konomiske%20vurderinger%20av%20smitteverntiltak%20-Tredje%20rapport%20-%20del%202%20(15.%20mars%202021).pdf

Further articles to corroborate our impact:

C5: Use of Norwegian mobile phone data reveals different effects of non-compulsory and mandatory COVID-19 interventions in urban vs rural areas in Norway
https://www.eurosurveillance.org/content/10.2807/1560-7917.ES.2023.28.17.2200382

C6: We participated in the pan-European COMIX study, providing information on behaviour and social mixing during the pandemic for use in models:
https://www.medrxiv.org/content/10.1101/2023.11.18.23298731v1

C7: Selections from the media (In Norwegian):
-Interview with Solveig Engebretsen, "The Corona hunter" Dagens Næringsliv 5 May 2020
www.dn.no/d2/ledestjerner/ledestjerner-2020-koronajegeren/7-1-obyurjfq
-Interview with Gunnar Rø and Alfonso Diz-Lois Palomares in Computer World, 6 January 2021
https://www.cw.no/jakten-pa-en-presis-beskrivelse-av-epidemien/506145
-Aftenposten makes mistakes on forecasts. Again and again. Aftenposten, 18 June 2021,
https://www.aftenposten.no/meninger/kronikk/i/7KbAKo/aftenposten-bommer-om-prognoser-igjen-og-igjen, our answer to the article on Aftenposten of 15 June 2021:
https://www.aftenposten.no/norge/i/0KLBLG/prognosene-bommet-fullstendig-paa-antallet-pasienter-igjen-og-igjen
-No a single calculation did not keep Norway closed. Aftenposten, 4 February, 2022.
https://www.aftenposten.no/meninger/kronikk/i/8QLwbW/nei-eit-reknestykke-held-ikkje-noreg-stengt, our answer to the article on Aftenposten of 1 February 2022
https://www.aftenposten.no/norge/i/ALWwEj/her-er-regnestykkene-som-holdt-norge-stengt-enda-lenger
In English: COVID-19: The Norwegian model, The UNESCO Courier, 15 December 2022,
https://courier.unesco.org/en/articles/covid-19-norwegian-model

C8: Selection of talks at virtual conferences/events:
Talk 17 March 2022 at The Turing Institute by Birgitte F de Blasio and Arnoldo Frigessi:
https://www.turing.ac.uk/events/probabilistic-approach-situation-awareness-and-forecasting-covid-19-pandemics-norway
Talk 8 June 2022 on the Norwegian experience with use of mobile phone data in modelling at the National Academies of Sciences USA Workshop by Birgitte F de Blasio
https://nap.nationalacademies.org/catalog/26645/location-data-in-the-context-of-public-health-research-and-law-enforcement-an-exploration-of-governance-frameworks
and later contributions:
Talk 15 March 2023 by Alfonso Diz-Lois Palomares at Bayes Comp on use of Bayesian computation to track the COVID-19 pandemic
https://bayescomp2023.com/programme
Talks at the Nordita workshop 23-27 May 2023 on the COVID-19 modelling work by Francesco Di Ruscio and Jørgen Midtbø
Unifying the Epidemiological and Evolutionary Dynamics of Pathogens (29 May 2023 - 23 June 2023): Main Page · Agenda (Indico) (su.se)

C9: The Koronautvalget report on the evaluation of the management of the pandemic in Norway
https://www.regjeringen.no/no/dokumenter/nou-2023-16/id2982388/

C10: Camilla Stoltenberg, former head of Norwegian Institute of Public Health, thanks BigInsight for the collaborative modelling work during the pandemic (video with English translation):
https://www.biginsight.no/news/2023/11/21/biginsight-celebration-day-was-fun