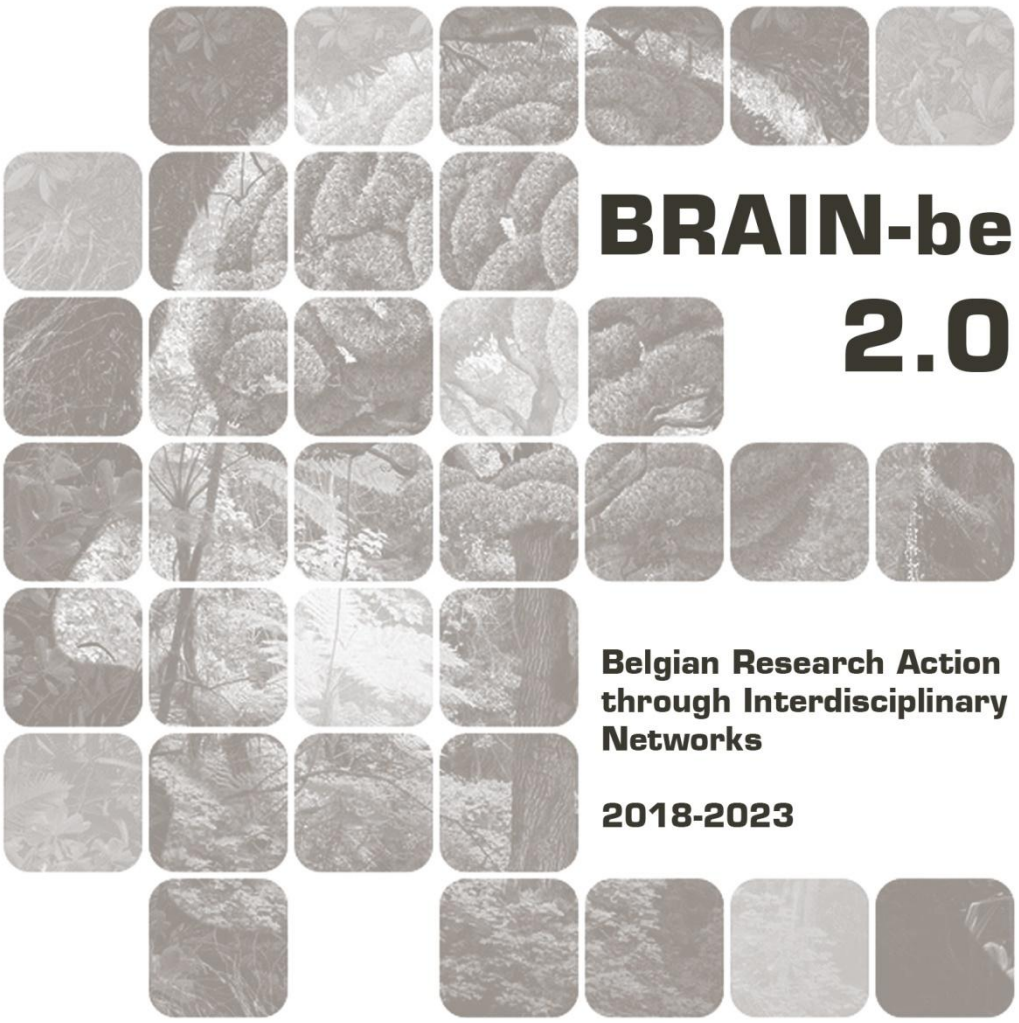


# HELICON

## Unravelling the long-term and indirect health impact of the COVID-19 crisis in Belgium

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Pillar 3: Federal societal challenges

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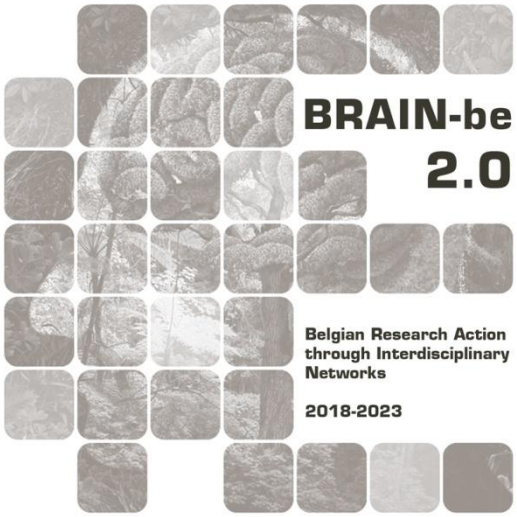


NETWORK PROJECT

# HELICON

## Unravelling the long-term and indirect health impact of the COVID-19 crisis in Belgium

**Contract - B2/202/P3/HELICON**

## FINAL REPORT

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**ABSTRACT**

**Objectives**

HELICON aimed to address three research objectives:

A. Identify sociodemographic and socio-economic factors of risk and resilience through the assessment of the social patterning of COVID-19 vaccination, infection, hospitalizations and mortality.
B. Describe the medium- and long-term direct health impact of COVID-19 infections with regard to healthcare use after COVID hospitalization.
   Assess the indirect health impact of the COVID-19 crisis in terms of non-COVID morbidity and mortality and the health economic impact of delayed health care use.

**Conclusions**

HELICON demonstrated that COVID-19 disproportionately affected socially and economically vulnerable groups in Belgium.

A. Municipalities with greater socioeconomic deprivation experienced higher COVID-19 incidence compared to the less deprived areas, although these inequalities varied over time. COVID-19 hospitalization and mortality were higher among older adults, men, residents of collective households and individuals with a migration background. Important educational and income disparities were also observed for COVID-19 hospitalization and mortality. COVID-19 vaccination uptake was lower among younger individuals, men, persons with a migrant background, and persons with lower educational attainment or lower income levels.
B. Patients hospitalized with COVID-19 experienced substantial post-acute health consequences in the aftermath. COVID-19 hospitalization was associated with increased risks of cardiovascular and pulmonary complications, especially after severe illness. Lower income was a risk factor for post-acute pulmonary complications. In-hospital mortality was higher among patients with lower education or income, without employment, living in collective households, men, older adults, and residents of the Walloon or Brussels-Capital Region. Although healthcare costs in the year following COVID-19 hospitalization were generally lower than after non-COVID hospitalization, considerable social disparities were found among COVID-19 hospitalized patients with higher costs among persons with lower education, lower income, older age, or living in collective households.
C. HELICON also revealed that the indirect toll of the COVID-19 pandemic on non-communicable diseases in Belgium was multifaceted—showing sharp but temporary declines in acute cardiovascular care and delayed yet measurable health and economic impacts in cancer. Although the overall effects were modest due to the rapid recovery of healthcare services, the findings highlight persistent vulnerabilities in the continuity of care and emphasise the need for resilient, equitable, and data-driven preparedness strategies to mitigate future health crises.

**Keywords**

COVID-19; Social inequalities; Hospitalization; Mortality; Vaccination; Health care use; Health care costs; Pandemic preparedness

## 1. INTRODUCTION

The COVID-19 crisis has posed unprecedented societal and public health challenges for Belgium. Considerable uncertainties existed regarding its multidimensional impact on population health. As depicted in Figure 1, the public health burden unfolds across different time scales and affects diverse population groups.

HELICON aimed to address these challenges through three research objectives:

C. Identify sociodemographic and socio-economic factors of risk and resilience through the assessment of the social patterning of COVID-19 vaccination, infection, hospitalizations and mortality (Dimension 1).
D. Describe the medium- and long-term direct health impact of COVID-19 infections with regard to healthcare use after COVID hospitalization (Dimension 1).
E. Assess the indirect health impact of the COVID-19 crisis in terms of non-COVID morbidity and mortality and the health economic impact of delayed health care use (Dimension 2, 3 and 4).

These objectives were guided by four guiding principles: valorisation of administrative health data sources, evaluation of social differentials, evaluation of differentials across the epidemic waves, and knowledge translation and policy transfer.

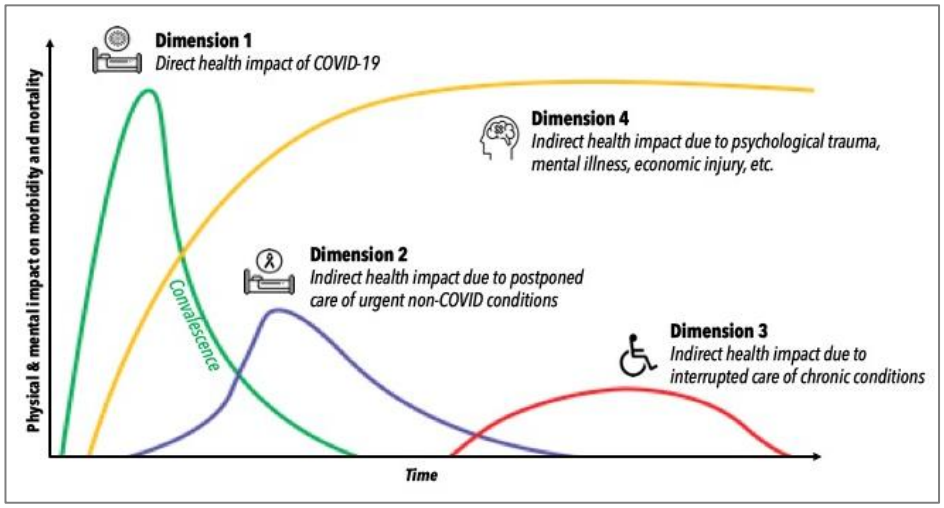


*Figure 1 The COVID-19 crisis has a multidimensional impact on population health.*

## 2. STATE OF THE ART AND OBJECTIVES

The COVID-19 pandemic marked one of the most profound public health crises in recent history, disrupting societies, economies, and healthcare systems worldwide. Belgium was no exception. From early 2020 onwards, authorities at all levels, supported by scientific experts, took far-reaching measures to contain the virus and protect the population. The federal phase of the crisis officially ended on 14 March 2022, closing an intense and transformative period.

The pandemic caused significant human loss and long-term health consequences for many. Beyond the direct effects of infection, it also deeply affected daily life, social relations, and mental well-being.

Looking back, we wish to acknowledge the extraordinary efforts of all those who contributed to the response — policymakers, healthcare professionals, researchers, and many others who worked with commitment and resilience throughout this unprecedented period.

The HELICON consortium extends its condolences to all who lost loved ones and its solidarity to those affected by health issues. We express our gratitude to everyone who helped safeguard public health and support those in need.

The COVID-19 pandemic has also fuelled research collaborations and scientific productivity, resulting in a torrent of COVID-related research. In the following sections, we synthesize the current literature relevant for the project objectives and methodology.

At the onset of the crisis, Belgium rapidly installed active surveillance systems to monitor the number of COVID-19 cases, hospitalizations and deaths in real-time. These data provide valuable insights in the direct health impact of COVID-19 in Belgium (Sciensano, 2021). Early research efforts suggested a heavy direct impact of COVID-19 on population health in Belgium. A European comparison of excess mortality – a well-established proxy for the total COVID-19 associated mortality- showed that Belgium experienced substantial excess mortality during the first and second wave of the epidemic in 2020 (Nørgaard et al., 2021; Vestergaard et al., 2020). Despite the wealth of information, the HELICON consortium identified **three important knowledge gaps – i.e., (1) the social patterning of COVID-19; (2) the long-term direct health impact of COVID-19 infections; and (3) the indirect health impacts of the COVID-19 crisis.**

The available databases offered only fragmentary perspectives on the clinical health situation, socio-demographic and socio-economic context, and healthcare expenditures. Integrating and reusing these different clinical and administrative data sources posed substantial and multifaceted obstacles spanning technology, governance, and data protection. Experience from other countries demonstrated that linked data systems can be a powerful tool for managing the epidemic and its aftermath (Hamer et al., 2020; Lo et al., 2021; Lyons et al., 2020; Schønning et al., 2021; Simpson et al., 2021).

⇨ HELICON sets out to integrate relevant data from multiple sources (e.g., Sciensano, Statistics Belgium, the InterMutualistic Agency, the Belgian Cancer Registry). This integrated data approach is intended to provide a comprehensive basis for research, covering in- and post-pandemic health information, socio-demographic and socio-economic characteristics, healthcare use, and associated costs.

### Social health inequalities

The COVID-19 crisis has been described as a syndemic pandemic, meaning that it interacts with and is exacerbated by social, economic and health inequalities (Bambra et al., 2021). Risk factors and comorbidities (e.g., obesity) are expected to be intertwined, interactive and cumulative.

Early evidence identified a clear association between COVID-19 severity and two sociodemographic factors: advanced age and male sex (Booth et al., 2021; Van Beckhoven et al., 2020). International studies also highlighted the socially patterned distribution of COVID-19 outcomes, with higher risks of exposure, infection, symptom severity, hospitalization, and death among disadvantaged groups (e.g., low-income populations, people with a migrant background) and certain occupations (e.g., healthcare workers) (Bambra et al., 2021; Calderón-Larrañaga et al., 2020; Upshaw et al., 2021; Vist et al., 2021).

Early Belgian research largely supported international findings of social inequalities in COVID-19 outcomes. Excess mortality was associated with old age and male sex (Natalia et al., 2024). Negative education and income gradients were observed in younger and middle-aged groups, while among adults ≥65, gradients appeared mainly in non-nursing-home residents (Decoster et al., 2021; Gadeyne et al., 2021). Nursing home residents were highly vulnerable, with some subgroups experiencing particularly high mortality (Hardy et al., 2021; Willaert, 2020). Certain vulnerable communities such as persons with a migration background and homeless persons also faced elevated health risks, most likely due to barriers to healthcare access during the early stages of the pandemic (Politi & Roblain, 2021; Roland et al., 2021; Vanthomme et al., 2021). Occupational and economic factors influenced SARS-CoV-2 infection risk, shaped by protective measures, testing, and vaccination, with healthcare, cleaning, security, and transport sectors among the most affected (Molenberghs et al., 2021; Verbeeck et al., 2021).

These findings underscore the importance of examining how sociodemographic and socioeconomic disparities in COVID-19 outcomes evolve over time. International evidence indicates that relationships between socioeconomic indicators and COVID-19 incidence and mortality can change dynamically, highlighting the need for detailed, time-sensitive analyses (Clouston et al., 2021; Bambra et al., 2021).

⇨ HELICON plans to investigate sociodemographic (e.g., sex, age, migration background, household status) and socioeconomic (e.g., educational attainment, employment status, income level) differences in COVID-19 infections, hospitalization and death at population level for Belgium. The analyses will account for intersectionality and the dynamic nature of the epidemic.

### Long-term health and social impact

COVID-19 has the potential of causing long-lasting health effects (Castanares-Zapatero, Chalon, et al., 2021; Castanares-Zapatero, Hanquet, et al., 2021). Early evidence had indicated that health impairments can occur even after mild or asymptomatic infections, with a range of neurological, cardiovascular, respiratory, gastrointestinal, and dermatological symptoms. Fatigue and shortness of breath are the most prevalent (Fernández-de-las-Peñas et al., 2021; The Writing Committee for the COMEBAC Study Group et al., 2021). Symptoms may persist for weeks or months or appear after apparent recovery. Despite extensive research, defining, characterizing, and treating Post-COVID conditions remains challenging (National Institute for Health Research, 2021).

Although studying the full spectrum of post-COVID syndrome in the general population is beyond the scope of this project, HELICON focuses on post-acute health impacts following hospitalization for COVID-19**,** which are highly relevant for healthcare planning and understanding the consequences of severe infections. Hospitalized patients tend to report more frequent and severe symptoms, with higher rates of multiorgan dysfunction, readmission, and mortality (Ayoubkhani et al., 2021; Fernández-de-las-Peñas et al., 2021). They are generally older, more often male, more ethnically diverse, and have more pre-existing comorbidities, which complicates the interpretation of causal relationships. Belgian evidence on long-term outcomes remains limited (Taccone et al., 2021; Vaes et al., 2021; Van Beckhoven et al., 2020), emphasizing the need to identify vulnerable populations and quantify the public health and healthcare burden associated with post-acute COVID-19. For more information on post-COVID-19 syndrome in Belgium, we refer to the research from the COVIMPACT study (Smith et al., 2022) and the Belgian Health Care Knowledge Centre (Castanares-Zapatero, Chalon, et al., 2021; Castanares-Zapatero, Hanquet, et al., 2021).

⇨ HELICON aims to assess health complications and premature mortality during and after a severe COVID-19 infection and evaluate related healthcare expenditures.

### Indirect health impact

In order to prevent the healthcare system from being overwhelmed by COVID-19 patients, non-urgent and elective care in Belgium was suspended between 14 March and 4 May 2020. Primary and hospital care were limited to urgent cases to preserve capacity for triage and treatment of COVID-19 patients. The suspension affected access to care, diagnosis, and treatment, but the full scope and magnitude of these consequences remain unclear. Even after regular care resumed, delays in diagnosis and treatment may have caused knock-on effects with long-term implications for health services. In addition, early evidence suggested that patients were less inclined to seek professional help during the pandemic (Nab et al., 2021). International research confirms reductions in healthcare use for acute, chronic, and mental health conditions (Dinmohamed et al., 2020; Mansfield et al., 2021), although it remains unclear to what extent this reflects missed care opportunities or genuine changes in disease incidence.

HELICON originally aimed to focus on three priority disease groups: acute life-threatening cardiovascular diseases, cancers, and mental disorders.

For **acute cardiovascular diseases,** early Belgian evidence showed that during the first wave, hospital admissions for ST-elevation myocardial infarction declined by 26% compared to pre-pandemic levels (Claeys et al., 2020). Moreover, the time between admission and treatment increased during lockdown. Such delays were associated with worse prognosis and increased mortality (Ruzzenenti et al., 2021). Similarly, stroke admissions decreased by 15-16% during the first wave of the COVID-19 pandemic accompanied by delays in treatment initiation which raising concerns about long-term outcomes (Raymaekers et al., 2021).

**Cancer** care was also heavily affected. During the first wave, cancer diagnoses fell by 44% compared to pre-pandemic levels. Diagnosis rates returned to baseline by June 2020 and remained stable until the second wave, which had a smaller impact (–2%) (Peacock et al., 2021). Preliminary evidence showed a 33% increase in mortality among Belgian cancer patients diagnosed in 2013–2018 during the first wave (Silversmit et al., 2021), similar to that observed in the general population. While this suggested limited immediate impact of delayed treatment, longer-term consequences on healthy life years and healthcare costs remain uncertain.

Although HELICON initially aimed to examine the indirect health impact for **mental health disorders**, published, periodic literature indicated limited evidence of long-term effects and thus modelling was deemed unfeasible within the project scope. Although HELICON originally aimed to include **mental health**, data linkage and quality limitations made this infeasible within the project scope. For example, Robinson et al. performed a meta-analysis of 65 longitudinal cohort studies comparing mental health before vs. during the COVID-19 pandemic (Robinson et al., 2022). Studies were only eligible for inclusion if they had sampled the same cohort of patients prior to 11/03/2020 (date the WHO declared the pandemic) and at least once after this date. The results suggested a significant increase in symptoms of anxiety ($p= 0.21$) and depression ($p<.001$). Yet, change in symptoms from pre-pandemic levels became smaller over each month during the COVID-19 pandemic. Subgroup analysis considering only samples with pre-existing mental health conditions

suggested non-significant changes in mental health before and during the COVID-19 crisis. The latter results may be explained by the fact that negative life events such as the COVID-19 pandemic are typically followed by resilience (minimal effect on symptoms of anxiety and depression) or by recovery (initial short-term increase in symptoms, followed by recovery) (Chen & Bonanno, 2020). Pan et al. used longitudinal data from three existing Dutch psychiatry case-control cohorts to assess the mental health impact of the COVID-19 pandemic on people with and without depressive, anxiety or obsessive-compulsive disorders. The results suggested that people with more severe or a chronic mental disorder experienced a higher impact on their mental health, more fear of COVID-19 and less positive coping. On the other hand, no evidence was identified that there was a strong increase in symptoms during the COVID-19 crisis in people with the most severe and chronic mental disorders. In fact, changes of symptom levels were minimal or even negative in those individuals (Pan et al., 2021). Relevant findings on mental health during the COVID-19 crisis are available from other initiatives:

- Superior Health Council. Belgian Mental Health Data Repository. Living Document I: Belgian mental health (care), Version 8, 2022. https://doi.org/10.5281/zenodo.4415442
- Jonker, H., Duveau, C., Charafeddine, R., Gisle, L., & Demarest, S. Summary of BELHEALTH results – Waves 1 to 6: Mental health data on Belgian adults in the wake of COVID-19 (Sept 2022 – June 2024), 2024. https://doi.org/10.25608/8rx4-me28
- Fabri, V., Hervy, A., Hoellinger, T., Vrancken, J., & Vanoverloop, J. Admission à l'hôptial pour tentative de suicide. Analyse des profils, des facteurs de risque et évolution de la prise en charge (2013-2024). Solidaris, 2025 https://www.institut-solidaris.be/wp-content/uploads/2025/11/Etude-sante-mentale-2025.pdf

⇨ HELICON sets out to investigate the indirect health impacts of the COVID-19 disruptions on morbidity and mortality related to cardiovascular diseases and cancer, focusing on changes in healthcare use and expenditure, as well as on losses in quality and quantity of life.

## 3. METHODOLOGY

Understanding the full impact of the COVID-19 pandemic requires examining its effects across multiple dimensions and time scales. The HELICON project investigates both the direct health consequences of COVID-19 -such as hospitalizations, mortality and long-term complications- and the indirect consequences, including delayed care for non-COVID conditions and disruptions in chronic disease management. HELICON integrates detailed individual-level health, social, and administrative data with robust analytical methods and modelling techniques to estimate medium- and long-term impacts.

This section outlines the key data sources, the methods used for analyses, and the limitations encountered.

Key data sources include:

**LINK-VACC Database** – Integrates the Belgian COVID-19 vaccination register (Vaccinnet+), COVID-19 laboratory test results, sociodemographic and socioeconomic variables from the DEMOBEL database from Statistics Belgium, and information about the healthcare diploma from CoBRHA. This dataset enabled individual-level analyses of vaccination uptake, hospitalizations, and outcomes across Belgium.

**HELICON Database** – Combines Sciensano's COVID-19 Clinical Hospital survey results with sociodemographic and socioeconomic data from the DEMOBEL database from Statistics Belgium, and health care expenditure data from InterMutualistic Agency (IMA-AIM). The database includes a 10% random sample of Belgian adults alongside all individuals hospitalized with confirmed COVID-19, providing data on sociodemographics, socioeconomic indicators, healthcare utilization, costs, infections, hospitalizations, and mortality.

**Statistics Belgium** – Provides exhaustive individual-level information from various sources including DEMOBEL, Belgian Census 2011, IPCAL tax information and death certificates. The resulting dataset allows us to investigate sociodemographic (e.g., household situation, migration background) and socioeconomic indicators (e.g., education, income), as well as all-cause and cause-specific mortality. These datasets were used to calculate excess mortality, relative and absolute inequalities, and cause-specific mortality patterns.

**Belgian Cancer Registry** – Provides aggregated stage-specific cancer data (breast, colorectal, lung, and head and neck cancer) by sex and age group for modelling the indirect health (Quality-Adjusted Life Year losses) and economic (direct healthcare cost) impacts of delayed cancer diagnosis due to the COVID-19 pandemic. Observed counts as well as predicted values, for 2020, based on data available at BCR for incidence period 2017-2019 (making use of a Poisson model) were calculated. Corrected projection for each sub-categories were compared to observed counts in 2020.

Various **analytical methods** were tailored to the type of data and research questions. Associations between sociodemographic, socioeconomic and regional factors, and COVID-19 outcomes (vaccination uptake, hospitalization, mortality) were examined using **logistic, negative binomial, and Poisson regression** models, adjusting for relevant covariates. **Hierarchical and mediation models** disentangled individual and area effects and assessed pathways linking social determinants to health outcomes. **Markov decision-analytic models** simulated the progression and outcomes of delayed cancer and cardiovascular care, projecting health impacts, costs, and Quality-Adjusted Life Years under different scenarios. Scenario and sensitivity analyses explored uncertainty and identified key drivers of health and economic outcomes. **Survival analyses and competing risk models** evaluated mortality and recovery among hospitalized COVID-19 patients. **Conditional inference trees** were used to identify key sociodemographic predictors of COVID-19 mortality and hospitalization outcomes. **Population attributable fractions and standardization techniques** were used to quantify the burden of living in deprived areas and enabled assessment of social inequalities across multiple dimensions. **Systematic reviews** adopting the PECO framework (Population, Exposure, Comparator, Outcomes) and the the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) have been used to synthesise the

knowledge on the role of socioeconomic factors, multimorbidity, and frailty in the acquisition and evolution of COVID-19 related health outcomes.

HELICON explicitly examines the role of **socioeconomic position (SEP) and sociodemographic factors** in shaping COVID-19 health outcomes. Indicators include educational attainment, occupational status, household income per capita, personal income and household composition. **Intersectionality** is used to account for cumulative social disadvantage, with age and sex always included as core sociodemographic variables. Migrant background and care home residency were included in our models when data was available.

The project incorporates the dynamic nature of the epidemic and changes in containment policies by comparing waves of the pandemic, allowing us to evaluate how the different dimensions of health impact evolved over time, while considering policy changes, testing capacity, and healthcare resources.

Despite the richness of available **data**, access was often restricted by **legal and administrative barriers.** For example, detailed population-level testing data could not be fully accessed, limiting analyses of inequalities in test reimbursement. Some high-quality data for Belgium are lacking, such as for undocumented residents or granular disease diagnoses (e.g., multimorbidity), which constrains certain analyses. Missing variables and delayed updates in approved datasets may introduce selection bias or reduce representativeness. Due to modifications in the HELICON database design, we were unable to establish a sub-cohort that could serve as a reliable control group for hospitalized COVID-19 patients, which limits our ability to avoid potential selection bias.

## 4. SCIENTIFIC RESULTS AND RECOMMENDATIONS

### 4.1 WORK PACKAGE 1 ON SOCIAL PATTERNING

#### Task 1.0 Social inequalities in COVID-19 vaccination

##### A. Sociodemographic and socioeconomic disparities in COVID-19 vaccine uptake

📖 Cavillot, Lisa, Joris A. F. van Loenhout, Brecht Devleesschauwer, Chloé Wyndham-Thomas, Herman Van Oyen, Jinane Ghattas, Koen Blot, Laura Van den Borre, Matthieu Billuart, Niko Speybroeck, Robby De Pauw, Veerle Stouten, Lucy Catteau, and Pierre Hubin. 2023. "Sociodemographic and Socioeconomic Disparities in COVID-19 Vaccine Uptake in Belgium: A Nationwide Record Linkage Study." Journal of Epidemiology and Community Health 78(3):176–83. https://doi.org/10.1136/jech-2023-220751

This study aimed to investigate the sociodemographic and socioeconomic characteristics associated with the uptake of COVID-19 vaccine in Belgium.

We conducted a cross-sectional analysis of the uptake of a first COVID-19 vaccine dose among 5,342,110 adults (≥18 years) in Belgium on 31 August 2021. A research collaboration was set up

with Sciensano's LINK-VACC project. The **LINK-VACC database** contains, within a pseudonymised environment, selected variables from multiple existing national health and social sector registers linked at an individual level using the Belgian social security number. For this study, four databases were used: (1) the Belgian **vaccine register** (Vaccinnet+), containing data on COVID-19 vaccine doses administered to Belgian residents as well as demographical data on the vaccinated person, (2) the **COVID-19 Healthdata test database**, containing data from COVID-19 laboratory tests performed in Belgium as well as demographical data on the tested person, (3) **DEMODEL database** provided by Statistics Belgium (Statbel) containing variables related to sociodemographic and socioeconomic characteristics as well as information on the status in the national register, (4) the **Common Base Register for HealthCare Actors (CoBRHA)** allowing the identification of individuals licensed to practice a healthcare profession in Belgium. Multivariable logistic regression analysis was used for identifying characteristics associated with not having obtained a first COVID-19 vaccine dose in Belgium and for each of its three regions (Flanders, Brussels Capital Region and Wallonia).

By 31 August 2021, 10% of Belgian adults (536,716 out of 5.3 million) had not received a first COVID-19 vaccine dose. **Vaccine uptake was significantly lower among younger individuals, men, people with a migration background, single parents, single-person households, and socioeconomically disadvantaged groups (lower income, lower education, unemployed).** These disparities were consistent across Flanders, Brussels, and Wallonia.

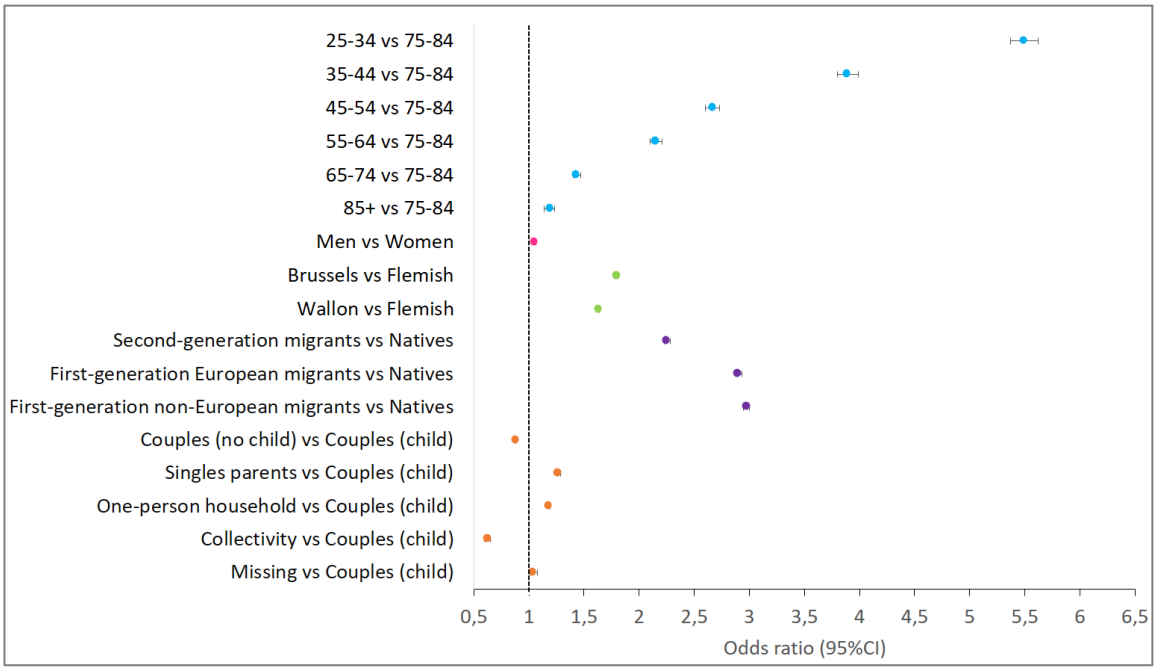


*Figure 2 Adjusted OR and 95%CI for the association between SD determinants and the odds of not having received a first COVID-19 vaccine dose – Belgium – 31 August 2021*

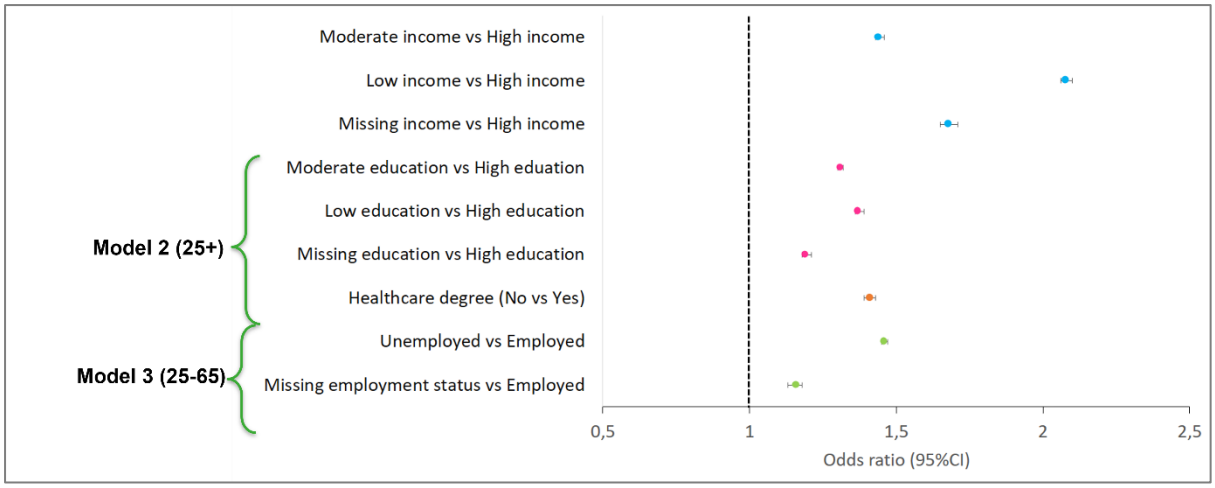


*Figure 3 Adjusted OR and 95%CI for the association between SE determinants and the odds of not having received a first COVID-19 vaccine dose – Belgium – 31 August 2021*

➲ The study demonstrates clear sociodemographic and socioeconomic inequalities in COVID-19 vaccination coverage. Addressing these disparities is essential to ensure equitable vaccine uptake in Belgium. The findings call for targeted vaccination strategies focusing on disadvantaged groups, both for the ongoing pandemic and for future public health crises. Further research into reasons for vaccine refusal will be important to design effective interventions.

**Key takeaway:** Social inequalities strongly shaped COVID-19 vaccination coverage in Belgium. Tailored strategies are needed to reach disadvantaged groups and ensure equitable protection in future health crises.

### B. Area and individual level analyses of demographic and socio-economic disparities in COVID-19 vaccination uptake in Belgium

🕮 Hubin, Pierre, Laura Van den Borre, Toon Braeye, Lisa Cavillot, Matthieu Billuart, Veerle Stouten, Léonore Nasiadka, Elias Vermeiren, Izaak Van Evercooren, Brecht Devleesschauwer, Lucy Catteau, and Joris A. F. van Loenhout. 2024. "Area and Individual Level Analyses of Demographic and Socio-Economic Disparities in COVID-19 Vaccination Uptake in Belgium." *Vaccine: X* 18:100496. https://doi.org/10.1016/j.jvacx.2024.100496

This study aimed at investigating to which extent COVID-19 vaccination status is associated with area level and/or individual level demographic and socio-economic factors.

The data linkage was developed in the context of the LINK-VACC project, integrating the Belgian vaccine register for the COVID-19 vaccination campaign at individual level with other registers, notably the COVID-19 laboratory test results and demographic and socio-economic variables from the DEMOBEL database.

From the **LINK-VACC data** with individuals tested for SARS-CoV-2, demographic and socio-economic indicators are derived and their impact on vaccination coverage at an aggregated geographical level (municipality) is quantified. The same indicators are calculated for the full

Belgian population, allowing to assess the representativeness of the LINK-VACC sample with respect to the impact of demographic and socioeconomic disparities on vaccination uptake. In a second step, hierarchical models are fitted to the individual level LINK-VACC data to disentangle the individual and municipality effects allowing to evaluate the added value of the availability of individual level data in this context.

The results show that **disparities in COVID-19 vaccination coverage were observed at both the individual and municipality level. Individual-level factors (age, sex, migration background, and low household income) explained most of the COVID-19 vaccination disparities.** Municipality-level factors added complementary information and including them in analyses improved the accuracy of effect estimates. Aggregated municipality data largely reflected the patterns seen in individual-level data, but individual data allowed for more detail, stronger statistical power, and finer categorisations. Regional differences in vaccination coverage were only partly explained by the available demographic and socioeconomic indicators on individual and aggregate level.

➲The LINK-VACC database (based on individuals tested for SARS-CoV-2) provided a reliable representation of sociodemographic and socioeconomic disparities in vaccination uptake for the entire Belgian population. The study revealed that both individual and municipal characteristics of demographic and socio-economic background are relevant factors in COVID-19 vaccination research. Overall, similar conclusions are drawn from both levels, however individual-level data allow for a more granular approach as well as for more statistical power. The individual demographic and socio-economic situation appears to be the main driver for vaccine uptake, especially migration background, income, and age.

**Key takeaway:** To reduce inequalities in vaccination, analyses and policies should primarily focus on individual-level sociodemographic and socioeconomic factors, while also considering local context to refine interventions.

### Task 1.1 Social inequalities in COVID-19 test reimbursements

We were unable to complete Task 1.1 due to both the lack and the limited quality of population-level COVID-19 testing data. The original plan -to link data on all tests and positive results- was not approved by the Information Security Committee. The approved dataset only includes hospitalized patients, which does not provide the information needed to study social inequalities in test reimbursements. Although we have explored alternative sources, these do not allow a full assessment due to several potential biases inherent to the data collection (e.g., selection bias due to differences in testing availability and recommendations over time).

## Task 1.2 Social inequalities in COVID-19 infections

### A. The association between area deprivation and COVID-19 incidence

🕮 Meurisse, Marjan, Adrien Lajot, Brecht Devleesschauwer, Dieter Van Cauteren, Herman Van Oyen, Laura Van den Borre, and Ruben Brondeel. 2022. "The Association between Area Deprivation and COVID-19 Incidence: A Municipality-Level Spatio-Temporal Study in Belgium, 2020–2021." Archives of Public Health 80(1):1–10. https://doi.org/10.1186/s13690-022-00856-9

This study provides a temporal perspective to COVID-19 incidence in Belgium by examining the association between COVID-19 incidence and area-level deprivation during the first five wave and interwave periods.

This was an observational, retrospective study on **Belgian COVID-19 confirmed cases**, during the period 1 March 2020 to 1 June 2021, using aggregated data at the municipality level for the 581 Belgian municipalities. Data on COVID-19 incidence were collected through the national COVID-19 surveillance system, which was set up by Sciensano to monitor daily trends of virus circulation in the Belgian population. Five periods of interest or "waves" were distinguished based on differences in the epidemiological situation, confinement measures and testing strategy. Each municipality was assigned an **area deprivation score based on** three socioeconomic indicators derived from 'Vlaamse Arbeidsrekening' and Statistics Belgium: **the share of unemployed persons, the share of households without a car, and the share of low-educated persons**. Spatio-temporal associations were examined using multivariable negative binomial regression, with population size as an offset and controlling for median age and urbanization. Population attributable fractions (PAFs) were computed to quantify the relative burden of living in deprived areas.

The results show that **municipality-level socioeconomic inequalities in COVID-19 incidence were observed** across Belgium. For the entire study period, **the most deprived municipalities were predicted to experience 24% higher incidence than the least deprived areas**. We observed differences over time with the largest disparities in COVID-19 incidence by area deprivation in wave 2 (31 August 2020 – 1 December 2020) and wave 3 (15 February 2021 – 1 June 2021), with deprived municipalities most affected. Wave 1 (1 March 2020 – 22 June 2020) and Interwave 1 (23 June 2020 – 30 August 2020) showed smaller or negligible differences, likely due to restricted testing and selective reporting. The **patterns of inequality were most likely influenced by testing strategies, viral circulation, and lockdown measures over time**. These findings highlight that area deprivation is an important driver of COVID-19 incidence, though results at the municipal level cannot be directly extrapolated to individual-level risk.

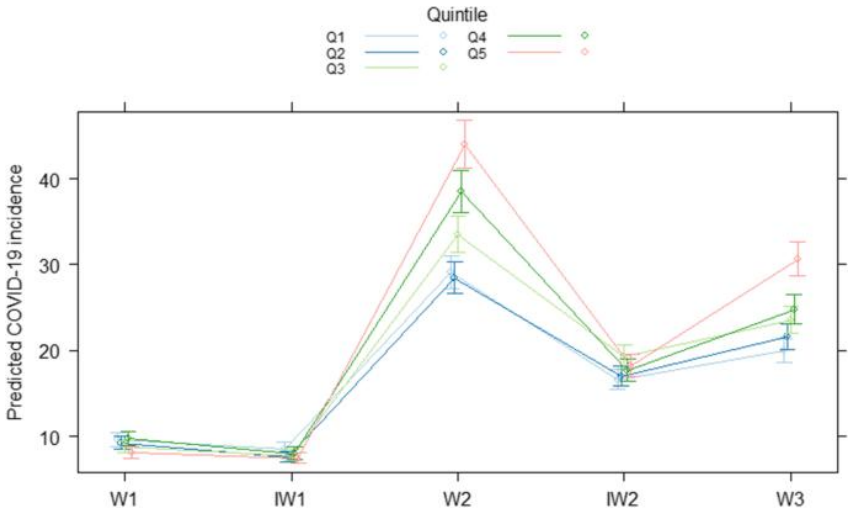


*Figure 4 Predicted COVID-19 incidence from the negative binomial regression with the area deprivation index (Q1-Q5) as explanatory variable, by area deprivation, by period of interest in the Belgian COVID-19 crisis.*

*Note: W1: wave 1, 1 March 2020 – 22 June 2020; IW1: interwave 1, 23 June 2020 – 30 August 2020; W2: wave 2, 31 August 2020 – 1 December 2020; IW2: interwave 2, 2 December 2020 – 14 February 2021; W3: wave 3, 15 February 2021 – 1 June 2021. Municipality-specific population size was used as an offset variable and we controlled for the median age per municipality and degree of urbanization in the regression model. Q1 represents the least deprived quintile, Q5 the most deprived quintile.*

➲The study provides new insights into the spatio-temporal dynamics of socioeconomic inequalities in COVID-19 incidence in Belgium and demonstrates that PAFs can be a useful tool for monitoring the relative burden of deprivation. Further research on the drivers of these inequalities and cause-specific analyses is warranted.

**Key takeaway:** Socioeconomic inequalities in COVID-19 incidence exist at the municipality level and shift over time. Monitoring area-level disparities can inform targeted public health interventions and guide future epidemic preparedness.

## B. Multimorbidity and frailty are associated with poorer SARS-CoV-2-related outcomes

🕮 Makovski, T. T., Jinane Ghattas, Sylvie Monnier-Besnard, Lisa Cavillot, Michaela Ambrožová, Barbora Vašinová, Rita Feteira-Santos, Pavel Bezzegh, Florian P. Bollmann, James Cottam, Raza Haneef, Brecht Devleesschauwer, Niko Speybroeck, Pedro J. Nogueira, Maria J. Forjaz, Jean Coste, and Laurence Carcaillon-Bentata. 2024. "Multimorbidity and Frailty Are Associated with Poorer SARS-CoV-2-Related Outcomes: Systematic Review of Population-Based Studies." Aging Clinical and Experimental Research 36(1):40. https://doi.org/10.1007/s40520-023-02685-4

This **systematic review** aimed to evaluate the etiological and prognostic roles of multimorbidity and frailty in SARS-CoV-2 infection and COVID-19-related short-term outcomes in population-representative studies during the early years of the pandemic.

Overall, 9,701 records were screened by title/abstract and 267 with full text. The review included 14 studies on multimorbidity between January 2020 and 7 April 2021, and 5 studies on frailty until 1 February 2022, covering short-term outcomes such as mortality. Studies were selected from PubMed, Embase, WHO COVID-19 Global literature, and PsycINFO, focusing on population-representative samples with validated measures of multimorbidity and frailty.

The results showed an association between poorer COVID-19 outcomes and an increased number of chronic diseases, higher Charlson Comorbidity Index scores, specific disease combinations, and elevated frailty levels. Evidence was limited to short-term outcomes, primarily mortality; no studies on long-term impacts were identified. The associations were observed consistently across the included studies, highlighting that vulnerable health groups faced mainly higher mortality risks, among other risks such as higher infection, hospitalisation risks, or ICU admission during the early pandemic waves. Socioeconomic factors, age, and sex were noted as important potential confounders**,** but stratified analyses were limited in the included studies.

➲ The review underscores the importance of considering multimorbidity and frailty at the population level when planning public health measures. Biological mechanisms, such as impaired physiological reserves, may explain the increased susceptibility and worse outcomes in these groups.

**Key takeaway:** Multimorbidity and frailty were clearly associated with poorer short-term COVID-19 outcomes in population-representative studies. Future research should include standardized measures, stratification by age and sex, and consider long-term impacts to better guide public health policies and healthcare resource allocation, particularly in ageing societies.

### C. Socio-Economic Determinants in SARS-CoV-2 Health Outcomes

🕮 Ghattas, Jinane, Tatjana T. Makovski, Stéphanie Monnier-Besnard, Lisa Cavillot, Monika Ambrožová, Barbora Vašinová, Rodrigo Feteira-Santos, Peter Bezzegh, Felipe Ponce Bollmann, James Cottam, Romana Haneef, Niko Speybroeck, Paulo Jorge Nogueira, Maria João Forjaz, Joël Coste, Laure Carcaillon-Bentata, and Brecht Devleesschauwer. 2024. "The Role of Socio-Economic Determinants in SARS-CoV-2 Health Outcomes: Systematic Review of Population-Based Studies." *medRxiv*, June 18, 2024.https://doi.org/10.1101/2024.06.18.24309062. *(Preprint; not peer-reviewed)*

This **systematic review** aimed to investigate the etiological and prognostic roles of socio-economic factors on COVID-19 outcomes during the early phase of the pandemic, using population-based studies across multiple countries.

The review included studies from PubMed, Embase, WHO COVID-19 Global literature, and PsycINFO (January 2020–April 2021), focusing on peer-reviewed articles with population-representative samples. Outcomes considered included SARS-CoV-2 infection, hospitalization, intensive care unit (ICU) admission, mechanical ventilation, mortality, quality of life, and mental health.

Results showed that out of 9,701 screened records, 100 studies met the inclusion criteria: 67 on the etiological role, 25 on the prognostic role, and 8 on both. **Disadvantaged socio-economic groups (lower income, crowded households, higher deprivation) and certain ethnic populations (Black, Asian, Hispanic) experienced higher infection rates and more severe COVID-19 outcomes. Educational status showed variable associations depending on the wave and region.** Most evidence came from the USA and UK, with limited early studies from Asia, Africa, Latin America, and continental Europe.

➲ The review demonstrates that social inequalities significantly influenced COVID-19 incidence and severity during the initial pandemic phase. Population-based studies are essential for identifying vulnerable groups and guiding targeted interventions.

**Key takeaway:** Populations with disadvantaged socio-economic positions and certain ethnic backgrounds face higher risks of SARS-CoV-2 infection and poorer outcomes. Public health surveillance and pandemic response strategies should incorporate social determinants of health to reduce disparities and guide interventions.

## Task 1.3 Social inequalities in COVID-19 hospitalizations

### A. Socioeconomic Disparities in COVID-19 Hospitalization: Mediation by Vaccination, Health, and Healthcare Work

📖 Cavillot, Lisa, Beatrijs Moerkerke, Brecht Devleesschauwer, Jinane Ghattas, Joris A.F. van Loenhout, Laura Van den Borre, Niko Speybroeck, Tom Loeys, and Robby De Pauw. 2024. "The Role of Vaccination, Underlying Health Conditions, and Working in Healthcare in the Socioeconomic Disparities in COVID-19 Hospitalization: A Mediation Analysis Using Interventional Effect Models." Submitted to BMC Infectious Diseases (September 2024).

This study investigates whether COVID-19 vaccination, underlying health conditions, and working in healthcare mediate the relationship between education and COVID-19 hospitalization.

We used the **LINK-VACC database**, an individual-level linkage of national health and social registers containing information on COVID-19 hospitalizations, educational attainment, vaccination status, comorbidities, and healthcare diplomas. The analysis included 148,590 adults with confirmed SARS-CoV-2 infection during the Delta-predominant period (September–December 2021) and 430,693 during the Omicron-predominant period (January–September 2022) in Belgium. Mediation was assessed using interventional effect models.

During Delta and Omicron periods, 1,059 (0.71%) and 1,828 (0.43%) individuals were hospitalized for COVID-19, respectively. Patients with low education were substantially overrepresented (56.4% during Delta and 66.3% during Omicron), compared to 32% of the general Belgian adult population with low education. Our models revealed that individuals with **low versus moderate/high education had a 0.653% (Delta) and 0.517% (Omicron) higher probability of COVID-19**

**hospitalization**. **Vaccination mediated 9.5% of this association during Delta** and 1.2% during Omicron, while **underlying health conditions mediated 5.8%** and 4.1%, respectively. Having a healthcare degree did not significantly mediate the relationship once interactions were accounted for.

➲ Educational disparities in COVID-19 hospitalization are only partly mediated by vaccination and underlying health conditions. The stronger mediation effect of vaccination during the Delta period likely reflects increased vaccine effectiveness against Delta and variant severity, while reduced mediation during Omicron may be due to waning immunity and increasing natural immunity.

**Key takeaway:** Low education was associated with a slightly higher likelihood of COVID-19 hospitalization, only partly explained by vaccination and underlying health conditions. Public health strategies to reduce COVID-19 hospitalization disparities should focus on promoting vaccination and preventing chronic conditions, especially among lower-educated groups. Strengthening health education and vaccine confidence in disadvantaged populations could help mitigate social inequalities in pandemic outcomes. However, further studies are needed to deepen social inequalities in severe COVID-19 outcomes and their other potential mediating factors (e.g., working conditions, living conditions, …).

### B. The effect of socioeconomic risk factors in the association between COVID-19 hospitalization and severe outcomes in hospitalized Belgian adults with cancer and a confirmed SARS-CoV-2 infection

🕮 Ghattas Jinane, Lisa Cavillot, Brecht Devleesschauwer, Laura Van den Borre, and Robby De Pauw. (2025) The effect of socioeconomic risk factors in the association between COVID-19 hospitalization and severe outcomes in hospitalized Belgian adults with cancer and a confirmed SARS-CoV-2 infection (In preparation).

Cancer patients face a significantly increased risk of SARS-CoV-2 infection, with studies indicating a two-fold higher likelihood of testing positive compared to the general population. Moreover, cancer is associated with more severe COVID-19 outcomes, including ICU admission, invasive ventilation, and mortality. Cancer patients are more susceptible to COVID-19 and its complications due to tumoral activity, immunological suppression, antineoplastic treatment, and increased exposure to multiple diagnostic and treatment procedures. Additionally, large ethnic disparities in cancer survival have been documented, particularly among socioeconomically disadvantaged groups. Focusing on COVID-19 patients with a cancer diagnosis, a notably vulnerable population, this study assesses the mediating role of socio-economic determinants in the association between cancer and severe COVID-19 outcomes.

This study aims to identify the role of socioeconomic determinants in the association between COVID-19 severe outcomes and cancer in the hospitalized Belgian adults with confirmed SARS-CoV-2 between July 2020 and December 2021.

In this retrospective cohort, all patients hospitalized for COVID-19, at least once, in Belgium between July 2020 and December 2021 will be included in our analysis. The primary outcome is COVID-19 severity, defined as ICU admission and/or acute respiratory distress syndrome (ARDS) and/or mortality due to COVID-19. Mediation analysis for cancer and multimorbidity will be conducted to assess the role of cancer in the association between socioeconomic factors and COVID-19 severity. This study focuses on the following socioeconomic factors: income quintile and education. Study results are expected by the Spring of 2026.

## Task 1.4 Social inequalities in COVID-19 mortality

### A. Excess mortality among native Belgians and migrant groups

📖 Vanthomme, Katrien, Sylvie Gadeyne, Brecht Devleesschauwer, and Laura Van den Borre. 2023. "Excess Mortality among Native Belgians and Migrant Groups in Belgium during the First Three COVID-19 Waves: The Evolving Dynamics of Social Inequalities." Journal of Public Health. https://doi.org/10.1007/s10389-023-02180-0

This study assessed patterns in excess mortality by migrant group during the first three COVID-19 waves in Belgium, while taking sociodemographic and socioeconomic indicators into account.

Exhaustive individual-level data from **Statistics Belgium** were used, building on a linkage between the Belgian National Register, the 2011 Belgian census and the tax register. The study population consisted of the legal Belgian population aged 40 years and older (N = 6,004,695). Age-standardized all-cause mortality rates were calculated for the first three COVID waves, and for the same weeks in 2019. Relative mortality differences were studied using Poisson regression. Analyses were stratified by age group, gender and wave.

The results showed that the **heaviest mortality burden fell on the elderly male population**, whose mortality patterns also diverged considerably from pre-pandemic times. The largest mortality differences with the Belgian population were observed for **elderly Turkish men** (> 26% in waves 1–3) and women (~40% in wave 2–3), after controlling for sociodemographic and socioeconomic indicators. In 2019, **some migrant groups** experienced a mortality advantage compared to their Belgian peers, however this **advantage diminished or even turned into a disadvantage during the COVID-crisis.**

➲ Significant mortality inequalities were found by migrant group, even after controlling for sociodemographic and socioeconomic background. Mortality patterns varied considerably throughout the three waves under investigation, possibly because of the dynamic nature of the epidemic and the uptake of preventative measures.

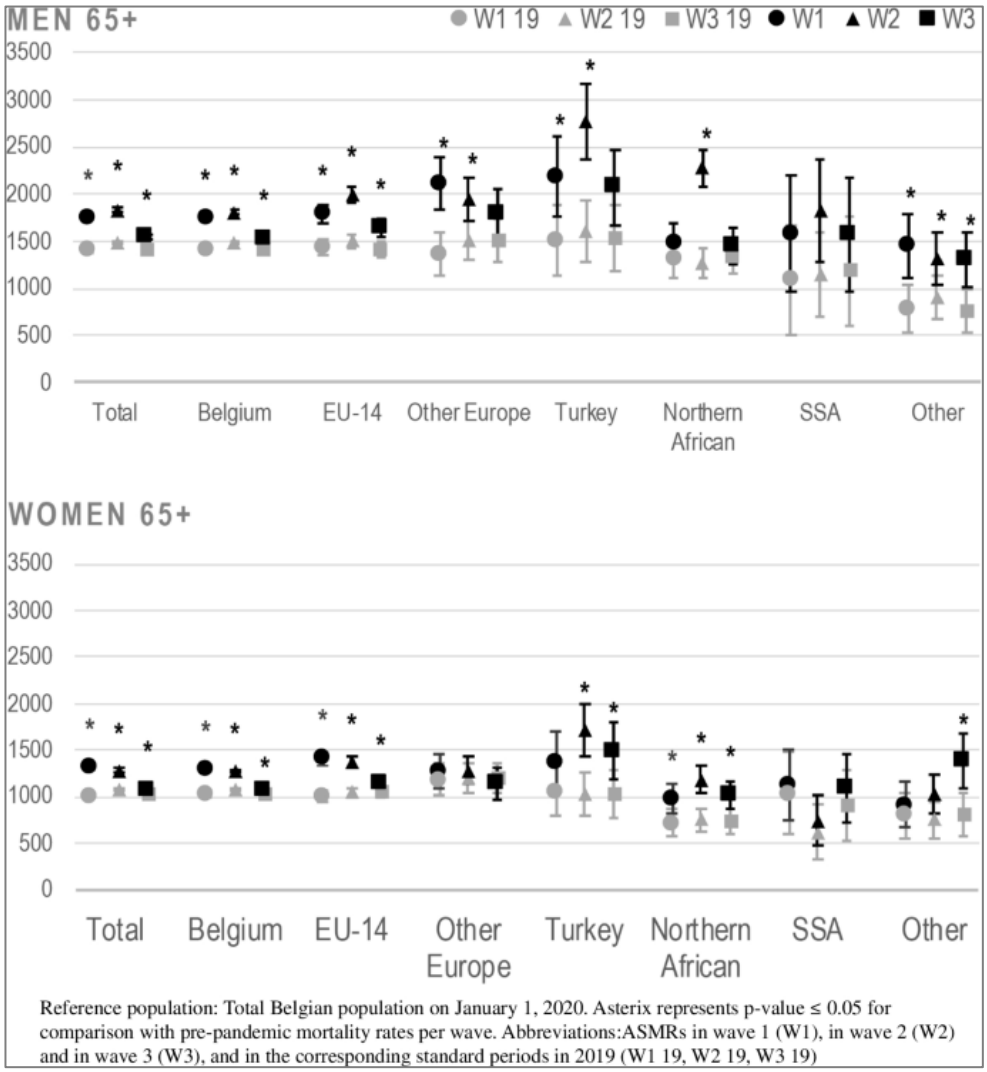


*Figure 5 Directly standardized mortality rates (per 100,000) and 95% confidence intervals for the elderly population during the pandemic and the corresponding standard periods in 2019, by migrant group and wave*

**Key takeaway:** The findings point to significant inequalities in excess mortality by migrant background, varying across the three waves. The study highlights the need for tailored public health measures, including culturally sensitive communication, targeted vaccination campaigns, workplace protections, and improved health literacy. Future research should integrate cause-of-death data, comorbidities, and migrants' lived experiences to better explain these inequalities and strengthen preparedness for future pandemics.

## B. Excess mortality and social patterns in Belgium

🕮 Van den Borre, Laura, Sylvie Gadeyne, Brecht Devleesschauwer, and Katrien Vanthomme. 2024. "Uncovering the Toll of the First Three COVID-19 Waves: Excess Mortality and Social Patterns in Belgium." Archives of Public Health 82:217. https://doi.org/10.1186/s13690-024-01444-9

This study aims to assess which population groups experienced the heaviest mortality burden during the first three COVID-19 waves in Belgium; and investigate potential changes in social differences in all-cause mortality during the epidemic and compared to the pre-COVID period.

**Statistics Belgium** provided individual-level linked data covering the population legally residing in Belgium. Data sources included the Belgian National Register (sociodemographic information and yearly all-cause mortality 2015-2021), the 2011 administrative census (educational attainment) and official tax information (yearly personal income 2014–2017). Annual cohorts consisting of 6.5 million to 6.8 million persons were created selecting persons aged 35 and older. Excess mortality was investigated comparing the 137,354 deaths observed during the first three COVID-19 waves with mortality in the reference period 2015–2019. Absolute mortality inequalities were investigated using direct standardization. Relative mortality inequalities were analysed using Poisson regression models.

The results showed that **elderly men** experienced the highest absolute mortality burden during all three COVID-waves, followed by **elderly women**, **middle-aged men**, and **middle-aged women**. **Care home residents** consistently experienced **higher mortality rates** during the first and second wave compared to peers living in other living arrangements. In wave 3, **care home residents** showed **significant absolute mortality deficits** compared to the reference period. When adjusting for all demographic and socioeconomic factors, the traditional pattern of **educational and income mortality inequalities** was found among the elderly population during the COVID-waves, suggesting effective COVID-19 support and preventative measures in Belgium. In contrast, the **educational mortality gap among middle-aged persons** deepened during COVID-waves 2 and 3 with **excess mortality between 19 and 30%** observed among mainly **lower-educated persons**. **Income mortality inequalities** among middle-aged women and men remained stable or even diminished for some specific groups in some waves.

➲ The widening educational mortality gap among middle-aged persons in successive waves suggest an important role of knowledge and associated educational resources during the COVID-19 epidemic. Belgium's broad implementation of public health control and prevention measures may have successfully averted a further widening of social mortality inequality between income groups and among the elderly population.

**Key takeaway:** The findings highlight the importance of education-related resources in shaping health outcomes during the pandemic. Belgium's public health measures may have prevented further widening of income-based and elderly inequalities but rising educational disparities among middle-aged adults underscore the need for targeted knowledge-driven interventions in future health crises.

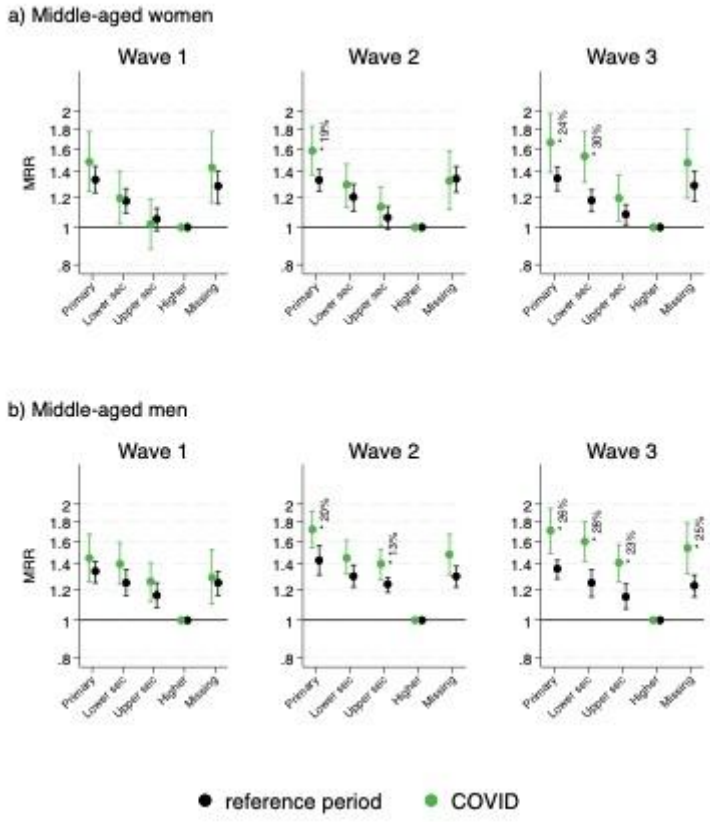


*Figure 1 Mortality Rate Ratios (MRRs) for the middle-aged population by educational attainment and wave.*

*Note: MRRs are adjusted for age (years), personal income, migrant background, household living arrangement, region of residence, and having received a high share of health benefits; (*) marks significant excess mortality between the COVID-wave and the reference period (p<0.05); (%) indicates the proportional change in MRR compared to the reference period.*

## C. Excess mortality: the influence of pre-existing health status and social factors

📖 Van den Borre, Laura, Brecht Devleesschauwer, Sylvie Gadeyne, Katrien Vanthomme, and Didier Willaert. 2025. "Understanding Excess Mortality during COVID in Belgium: The Influence of Pre-Existing Health Status and Social Factors." *Archives of Public Health* 83:18. https://doi.org/10.1186/s13690-025-01499-2

This study investigated how pre-existing health status and social background contributed to excess mortality during the first two years of the COVID-19 crisis in Belgium.

Data came from nearly 1.4 million adult members of **Solidaris, the second largest health insurance fund** in the country. Pre-existing health was assessed through reimbursement data (including medication use), while social indicators included socioeconomic status, nationality of origin, and living arrangement. Excess mortality was measured as the difference between all-cause mortality in 2020–2021 and the average yearly mortality in 2015–2019. Directly Standardised Mortality Rates

(DSMRs) captured absolute inequalities, and Poisson regression analyses were used to estimate Mortality Rate Ratios (MRRs).

Results showed that individuals without pre-existing disease experienced significant excess mortality in 2020, alongside men with one to three chronic conditions and women with varying disease burdens. By contrast, some disease groups showed mortality deficits. Notably, cancer patients experienced a 17% mortality deficit in 2020 and 9% in 2021, while persons with cancer combined with asthma or COPD also displayed lower mortality than in the pre-pandemic period. **Patterns varied substantially by disease group, pointing to complex dynamics of excess and deficit mortality during the crisis.**

Pre-existing health, age and sex are key to understanding patterns of excess and deficit mortality. Nonetheless, our study **underlines the importance of including sociodemographic and socioeconomic information to effectively explain mortality differences**. The comparison between the model with only adjustment for age and sex and the fully adjusted model revealed the potential for underestimation (in the case of cancer and chronic kidney disease) and overestimation (in the case of anxiety of depression) of MRRs by disease group when not taking sociodemographic and socioeconomic factors into account.

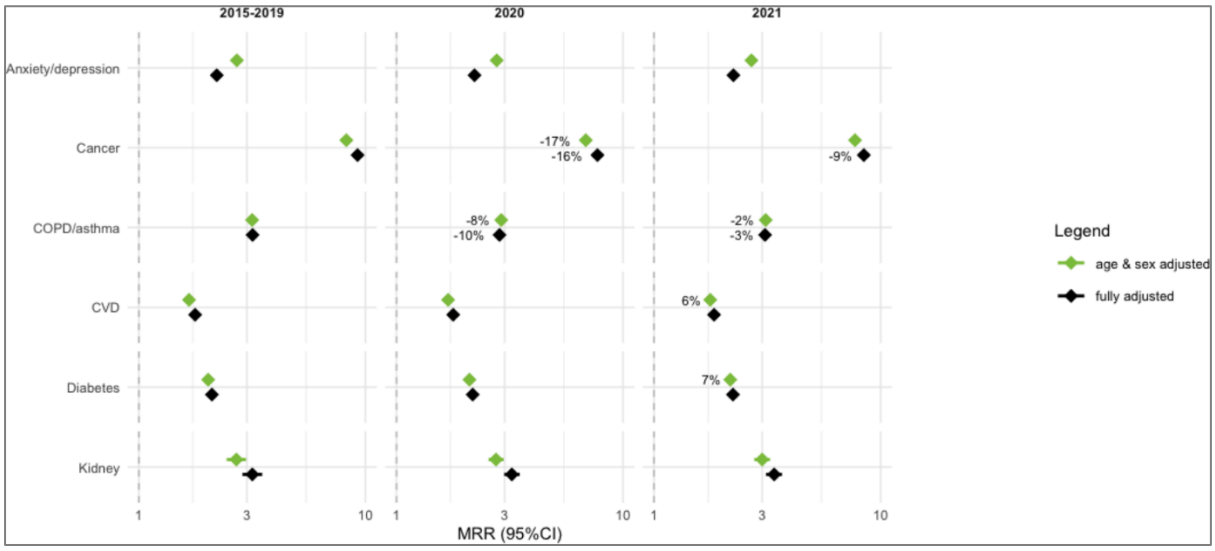


*Figure 6 Mortality Rate Ratios (MRR) for six specific diseases, compared to persons with no identified disease.*

*Note: Percentages mark significant excess or deficit mortality compared to the corresponding model for reference period 2015–2019. Green diamond represents the age-and sex-adjusted MRRs. Black diamonds represent the fully-adjusted MRRs.*

➲The study underscores the importance of jointly considering pre-existing health conditions and sociodemographic and socioeconomic characteristics when analysing pandemic-related mortality. Results suggest that ignoring social background may lead to over- or underestimation of mortality risks in specific groups. Evidence of mortality displacement among persons with anxiety or depression further highlights the complex interplay between health inequalities and the pandemic.

**Key takeaway:** Pre-existing health conditions, age, and sex are central to understanding patterns of excess mortality, but the sociodemographic and socioeconomic context is crucial to correctly explain mortality differences. A more integrated approach combining health and social data is needed to uncover the mechanisms linking multimorbidity, social inequalities, and mortality, thereby strengthening crisis preparedness and informing equitable public health strategies.

### D. COVID-19 and Other Mortality: demographic and socioeconomic patterns

🕮 Cavillot, Lisa, Laura Van den Borre, Katrien Vanthomme, Aline Scohy, Patrick Deboosere, Brecht Devleesschauwer, Niko Speybroeck, and Sylvie Gadeyne. 2024. "Unravelling Demographic and Socioeconomic Patterns of COVID-19 Death and Other Causes of Death: Results of an Individual-Level Analysis of Exhaustive Cause of Death Data in Belgium, 2020." *Archives of Public Health* 82(1):209. https://doi.org/10.1186/s13690-024-01437-8

This study investigated sociodemographic and socioeconomic disparities in cause-specific mortality during the first year of the COVID-19 pandemic in Belgium, using exhaustive individual-level data on all adult deaths in 2020 from **Statistics Belgium**. Logistic regression models and conditional inference trees (CIT) were applied to compare three outcomes: (1) COVID-19 deaths versus survival, (2) other-cause deaths versus survival, and (3) COVID-19 deaths versus other-cause deaths.

**Older individuals, males, those living in collective households, first-generation migrants, and people from deprived socioeconomic groups experienced higher odds of dying from COVID-19 compared to survival.** Living in collective households was identified by the conditional inference tree (CIT) as the strongest predictor, followed by age and sex. Among individuals not living in collective households ties, education emerged as one of the strongest predictors. The CIT algorithm allowed for hierarchical ranking of risk factors and accounted for multicollinearity and interactions among predictors, strengthening the robustness of the findings.

Similar patterns were observed for all other causes of death (OCOD), with age being the strongest predictor. However, first- and second-generation migrants showed lower odds of dying from OCOD compared to survival, reflecting the well-documented **"migrant mortality advantage"**, often explained by selective migration of healthier individuals and healthier lifestyle habits. In contrast, first-generation migrants had 24% higher COVID-19 mortality compared to survival even after controlling for socioeconomic factors. When comparing COVID-19 deaths to all OCOD, this excess rose to 50%, suggesting that **the protective effect seen in general mortality does not apply to highly transmissible infectious diseases like SARS-CoV-2**. The higher COVID-19 mortality among migrants can be explained to multiple factors, including poorer living conditions favouring virus transmission, higher representation in essential or public-facing jobs, and barriers to accessing healthcare, such as language, cultural differences, or lack of digital literacy.

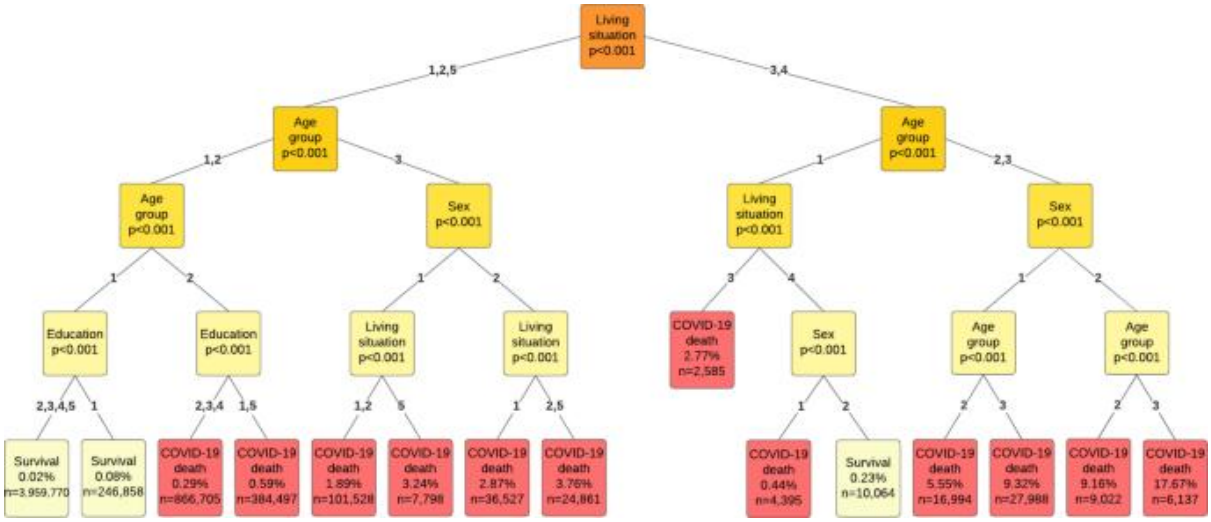


*Figure 2 Conditional recursive partitioning tree algorithm considering COVID-19 specific death as cases and survivors as controls. The variable 'Living situation' was categorized as follows: 1='With partner', 2='Without partner', 3='Care homes', 4='Other collectivities (no care home)', 5='Other'. The variable 'Age group' (in years) was categorized as follow: 1='25–64', 2='65–84', 3='85+'. The variable 'Sex' was categorized as follow: 1='Females', 2='Males'. The variable 'Education' was categorized as follows: 1='Primary or less', 2='Lower secondary', 3= 'Upper secondary', 4='Higher education', 5='Missing'. The percentages in the terminal nodes indicate the percentage of COVID-19 deaths relative to the sample size of each terminal node, denoted 'n'. When the proportion of COVID-19 deaths in the terminal nodes exceeded its prevalence in the study population (i.e. 0.27%), they were categorized as 'COVID-19 death' and colored in red*

**Education and income were also important predictors of COVID-19 deaths, particularly among individuals not residing in collective households**, highlighting the role of knowledge-related resources and socioeconomic circumstances in shaping infection risk and outcomes. Overall, the results underscore the intersection of demographic, social, and economic factors in predicting COVID-19 mortality, revealing that both individual and structural characteristics jointly drive disparities observed during the early phases of the pandemic.

➲ The study identified major sociodemographic and socioeconomic disparities in COVID-19 mortality, particularly linked to living in collective households, migration background, education, and income. Preventive measures in collective settings and targeted communication strategies for disadvantaged groups are essential for reducing inequalities during pandemics. By using CIT algorithms, the study provided a hierarchical ranking of predictors, enabling the identification of high-risk groups for tailored interventions. Future research should assess how vaccination campaigns influenced these disparities.

**Key Takeaway:** COVID-19 mortality in Belgium was strongly influenced by living situation, age, sex, migration background, and socioeconomic factors. Living in collective households was the strongest predictor across all ages. First-generation migrants faced higher COVID-19 mortality despite a usual migrant mortality advantage for other causes. Among those not living in collective households, low education and income increased the mortality risk, highlighting the importance of knowledge-related resources. These findings underscore the need for targeted preventive measures and tailored public health messaging that account for both living conditions and socioeconomic characteristics to reduce disparities in future pandemics.

## 4.2 WORK PACKAGE 2 ON DIRECT LONG-TERM HEALTH IMPACT

### Task 2.1 Setting up the HELICON database

#### A. Studying Social Inequalities and the Long-Term Health Impact of COVID-19 in Belgium: the HELICON Population Data Linkage

🕮 De Pauw, Robby, Laura Van den Borre, Youri Baeyens, Lisa Cavillot, Sylvie Gadeyne, Jinane Ghattas, Delphine De Smedt, David Jaminé, Yasmine Khan, Patrick Lusyne, Niko Speybroeck, Judith Racape, Andrea Rea, Dieter Van Cauteren, Sophie Vandepitte, Katrien Vanthomme, and Brecht Devleesschauwer. 2023. "Social Inequalities and Long-Term Health Impact of COVID-19 in Belgium: Protocol of the HELICON Population Data Linkage." BMJ Open 13(5): e069355. https://doi.org/10.1136/bmjopen-2022-069355

While data linkage systems have proven to be powerful tools for managing and studying the COVID-19 pandemic, the interoperability and reuse of multiple sensitive data sources posed substantial challenges. **Our protocol for the HELICON database aimed to provide a case study for linking highly sensitive individual-level information; however, establishing the intended dataset proved far more difficult than anticipated.**

The project aimed to create a comprehensive, national case-cohort dataset linking highly sensitive individual-level information from multiple sources, including health surveillance records and administrative data from Sciensano Statistics Belgium, and the InterMutualistic Agency. The goal was to investigate social health inequalities and the medium- to long-term health impact of COVID-19 in Belgium.

The dataset was designed to include 1.2 million randomly selected Belgians as a population cohort, alongside 4.5 million individuals with a confirmed COVID-19 diagnosis (PCR or antigen test), of which 108,211 were hospitalized patients. Data coverage was planned from July 2020 to January 2026, with yearly updates, and included both during-pandemic and post-pandemic health information. Available variables would cover sociodemographic characteristics, socioeconomic indicators, healthcare utilization, related costs, and COVID-19 testing, infections, hospitalizations, and mortality.

This study aimed to address two main questions: (1) identifying socioeconomic and sociodemographic risk factors in COVID-19 testing, infection, hospitalizations, and mortality, and (2) assessing the medium- and long-term health impact of COVID-19 infections and hospitalizations. Specific objectives included comparing healthcare expenditure during and after COVID-19 infection or hospitalization, investigating long-term complications or premature mortality, and validating the administrative COVID-19 reimbursement nomenclature. Analyses were planned using absolute and relative risk calculations through survival analysis methods.

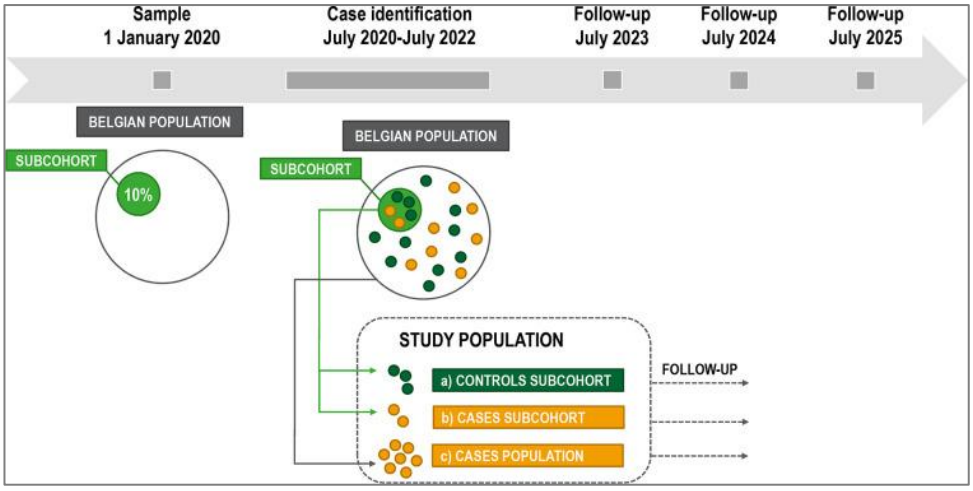


*Figure 7 Schematic overview of the case-cohort study design.*

**Technical challenges were expected, but additional delays arose from time-consuming administrative procedures, complex communication between stakeholders, and strict data security requirements.** The data application process of the Information Security Committee (ISC) was particularly burdensome. Despite extensive meetings with other research teams, legal experts, data specialists, and cryptographers to address ISC concerns, several proposed solutions were repeatedly rejected.

As a result, the original scope of the dataset -covering all COVID-19 tests, positive cases, hospitalizations, and control persons- was reduced. **The approved dataset now includes only hospitalized COVID-19 patients and control persons, allowing completion of certain research tasks (work package 2 and parts of work package 3), but preventing population-level analyses such as Task 1.1 on social inequalities in COVID-19 test reimbursements.**

Even the approved dataset has presented unforeseen issues, including missing variables, missing transfer keys, variables differing from what was requested, delayed data updates, issues with the analysis environment, unforeseen costs related to data delivery, etcetera.

Despite these compromises and challenges, the resulting database remains a unique and rich source of information on COVID-19 hospitalizations, infections, and related health outcomes. However, it lacks key information on vaccination, granular sociodemographic determinants (e.g., specific migrant groups, family composition), and other variables relevant for understanding social health inequalities. Moreover, selection bias cannot be ruled out because the mechanism underlying missing data cannot be fully investigated, which may affect the validity of control groups.

➲ In summary, while a partial dataset has been successfully created and enables several research objectives, administrative, technical, and data security hurdles, along with remaining data limitations, have prevented full realization of the original plan, particularly for population-level analyses of testing and social inequalities.

## Task 2.2 Healthcare expenditures

### A. Post-acute healthcare expenditure following COVID-19 hospitalization and associated social inequalities in Belgium

> 🕮 Boiy, Elin, Lisa Cavillot, Brecht Devleesschauwer, Robby De Pauw, Delphine De Smedt, Sylvie Gadeyne, Vanessa Gorasso, Masja Schmidt, Katrien Vanthomme, Nick Verhaege, & Laura Van den Borre. Post-acute healthcare expenditure following COVID-19 hospitalization and associated social inequalities in Belgium: a matched cohort study. Submitted to BMC Health Services Research, August 2025 (under review).

This study aimed to investigate post-acute healthcare expenditure among patients hospitalized with and without COVID-19 and to identify socioeconomic and sociodemographic factors associated with increased post-acute health costs.

The study used the **HELICON database**, a population-level data linkage combining individual-level information from the Clinical Hospital Surveillance (COVID-19 hospitalizations), Statistics Belgium (sociodemographic and socioeconomic factors, mortality, and emigration), and the InterMutualistic Agency (healthcare utilization and costs) via pseudonymized Belgian social security numbers. A matched cohort of 10380 patients with COVID-19 and 26270 patients without COVID-19 hospitalized in Belgium between 14 September and 31 December 2020 was created. A health systems approach was adopted and the direct individual post-acute healthcare expenditure in the calendar year 2021 in the context of the Belgian compulsory health insurance was available from the InterMutualistic Agency. The association of socioeconomic and sociodemographic variables with post-acute healthcare costs was investigated using multivariable generalized linear models with a negative binomial distribution and a log-link function.

The results indicate that **COVID-19 hospitalization** was associated with 18.5% (95% confidence interval: 16.9% to 20.1%) **lower healthcare costs in the calendar year following hospitalization** compared to non-COVID hospitalization. Potential explanations include that, during the pandemic, patients without COVID-19 may have been admitted to the hospital for more severe health conditions. **Lower education level, lower income, living in a collective household, and older age** were associated with **higher post-acute healthcare costs among COVID-19 patients**, whereas COVID-19 patients having a migration background experienced lower healthcare costs.

➲This study identified different socioeconomic and sociodemographic characteristics associated with increased post-acute healthcare expenditure among COVID-19 patients in the year following hospitalization, emphasizing the vulnerability of hospitalized COVID-19 patients with lower social status.

**Key takeaway:** Socioeconomic and sociodemographic factors shape post-acute healthcare costs among hospitalized COVID-19 patients, with lower-educated, lower-income, older, and collectively living patients incurring higher costs. However, uncertainty remains regarding how these disparities

evolve over longer periods and the underlying mechanisms driving these inequalities. Public health monitoring and interventions should consider these social disparities to ensure equitable access to post-acute care and to mitigate the long-term impact of COVID-19 on vulnerable populations.

## Task 2.3 Long-term complications

### A. Post-Acute Organ Complications following COVID-19 Hospitalization and Related Socioeconomic Inequalities

📖 Cavillot, Lisa, Niko Speybroeck, Laura Van den Borre, Jinane Ghattas, Elin Boiy, Joris A. F. van Loenhout, Pierre Hubin, Pierre Smith, Delphine De Smedt, Katrien Vanthomme, Sylvie Gadeyne, Robby De Pauw, and Brecht Devleesschauwer. 2025. "Post-Acute Organ Complications following COVID-19 Hospitalization and Related Socioeconomic Inequalities." Submitted for review at *Nature Communications*, May 2025.

This study investigated the risk of one-year post-acute organ complications following COVID-19 hospitalization and the role of socioeconomic inequalities among Belgian adults without pre-existing conditions at baseline.

The study used **data from the HELICON** project, a population-level data linkage initiative by Sciensano, the Belgian National Institute for Health, which combines selected variables from the Sciensano COVID- 19 test database, Statistics Belgium and the InterMutualistic Agency at the individual level via pseudonymized social security numbers. The HELICON cohort included a 10% random sample of adults legally residing in Belgium as of January 1, 2020, augmented with patients hospitalized with confirmed COVID-19 in Belgian hospitals and linked to reimbursement and hospitalization data from the InterMutualistic Agency (IMA).

The cohort consisted of 7,261 individuals hospitalized with a confirmed COVID-19 diagnosis as of July 1, 2020 and 52,090 controls, i.e. individuals hospitalized during the same time period without a confirmed COVID-19 diagnosis as registered in the CHS database. Subcohorts were created for each organ system under study (i.e. cardiovascular, pulmonary, renal and liver) by excluding individuals with pre-existing conditions in that systems. Finally, COVID-19 patients were stratified by disease severity: critical (ICU admission and/or ARDS) versus severe (non-ICU, no ARDS)**.** Analyses used overlap propensity score-weighted odds ratios and adjusted odds ratios to estimate the risk of one-year post-acute organ complications following COVID-19 hospitalization and related social inequalities.

Results showed that **severe COVID-19 patients** had 1.19 times **higher odds of post-acute cardiovascular complications**, with an excess burden of 20.16 per 1,000 persons, compared to non-COVID hospitalized controls without baseline cardiovascular disease; this odds further increased among critical patients. Compared to non-COVID-19 hospitalized controls, severe COVID-19 patients had a 2.05 higher odds and a 38.7 higher excess burden per 1,000 persons of developing post-acute pulmonary complication; these odds and excess burden further increased with disease

severity. However, compared to controls, COVID-19 hospitalized patients were not significantly at higher risk of developing renal and liver post-acute organ complications.

Among COVID-19 hospitalized patients, **socioeconomic disparities were observed for post-acute pulmonary complications**, with lower-income severe patients at higher risk, while no significant socioeconomic patterns were detected for cardiovascular outcomes. Pre-existing health conditions at baseline remained the strongest predictor of post-acute organ complications among COVID-19 hospitalized patients.

➲ The findings show that COVID-19 hospitalization is associated with a higher risk of post-acute cardiovascular and pulmonary complications, especially following severe illness. Among COVID-19 hospitalized patients, having lower income increases the likelihood of post-acute pulmonary complications. These results underscore the need for long-term monitoring and follow-up care, particularly for critically ill patients and socioeconomically disadvantaged groups.

**Key Takeaway:** COVID-19 hospitalization can lead to significant post-acute cardiovascular and pulmonary complications, particularly among critically ill patients. Pulmonary outcomes are also shaped by low income, highlighting the need for targeted long-term follow-up and care strategies for vulnerable populations.

## Task 2.4 In-hospital mortality

### A. Social inequalities in in-hospital mortality following COVID-19 hospitalization

🕮 Boiy, Elin, Lisa Cavillot, Brecht Devleesschauwer, Delphine De Smedt, Sylvie Gadeyne, Niko Speybroeck, Laura Van den Borre, Katrien Vanthomme, Nick Verhaege, and Robby De Pauw. 2025. *Social inequalities in in-hospital mortality following COVID-19 hospitalization in Belgium: a competing risk survival analysis.* Submitted to BMJ Public Health, October 2025.

This study assessed socioeconomic and sociodemographic disparities in in-hospital mortality among COVID-19 patients in Belgium using competing risk survival analysis.

Using individual-level data from the **HELICON database**, a cohort of 44,518 COVID-19 hospitalized patients (31 August 2020 – 27 June 2023) was constructed. In-hospital mortality was analyzed using cumulative incidence curves and multivariable proportional subdistribution hazard models, considering death and recovery as competing events. Disparities by education, income, employment status, migration background, household type, sex, age, and region were investigated.

Among COVID-19 hospitalized patients, 6,585 (14.8%) died, 36,603 (82.2%) recovered, and 1,330 (3.0%) were censored. **Mortality hazards were higher among patients with lower education, lower income, without employment, living in collective households, males, older age, and residents of the Walloon or Brussels-Capital Region**.

➲ This study demonstrates substantial socioeconomic and sociodemographic disparities in in-hospital COVID-19 mortality in Belgium. Patients with lower education, lower income, unemployment, and those living in collective households experienced higher mortality, alongside male sex, older age, and residence in the Walloon or Brussels-Capital Region. These patterns likely reflect differences in baseline health, healthcare access, vaccination, and exposure risk.

**Key takeaway:** Socioeconomic and sociodemographic factors strongly influence in-hospital mortality following COVID-19 hospitalization in Belgium. Patients with lower education, lower income, unemployment, or living in collective households face higher risks of death, emphasizing the need for targeted public health interventions to reduce health inequalities in vulnerable populations. Future research should investigate long-term survival after COVID-19 hospitalization and explore the mechanisms driving these social disparities.

### Task 2.5 IMA-AIM nomenclature code

Due to the considerable challenges in setting up the HELICON data linkage, we concluded that the validation could not be performed after consulting with IMA-AIM.

## 4.3 WORK PACKAGE 3 ON INDIRECT HEALTH (ECONOMIC) IMPACT

### Task 3.1 – 3.4 Change in non-COVID disease and indirect impact

#### A. Modelling Cancer Care Delays in Belgium

🕮 Khan, Yasmine, Nick Verhaeghe, Robby De Pauw, Brecht Devleesschauwer, Sylvie Gadeyne, Vanessa Gorasso, Yolande Lievens, Niko Speybroeck, Nancy Van Damme, Miet Vandemaele, Laura Van den Borre, Sophie Vandepitte, Katrien Vanthomme, Freija Verdoodt, & Delphine De Smedt. 2023. Evaluating the health and health economic impact of the COVID-19 pandemic on delayed cancer care in Belgium: A Markov model study protocol. PLOS ONE, October 30, 2023. https://doi.org/10.1371/journal.pone.0288777

This study protocol presents a **flexible decision-analytic Markov model** designed to assess the health and economic impact of delayed cancer care resulting from the COVID-19 pandemic in Belgium. Focusing on **four cancer types—breast, colorectal, lung, and head and neck cancer**—the model compares costs and quality-adjusted life year (QALY) losses before and during the pandemic. It integrates data from published studies and administrative databases, capturing both medical and societal costs.

This methodological framework directly informs the project tasks:

**Task 3.1 – Change in non-COVID disease diagnoses:** By simulating delays in cancer diagnosis, the model quantifies potential reductions in non-COVID disease detection.

**Task 3.2 – Change in non-COVID causes of death:** The model estimates excess mortality resulting from delayed care and suboptimal treatment.

**Task 3.3 – Indirect impact on health-related quality of life:** By incorporating health-related quality of Life (HRQoL) values, the model projects the impact of care disruptions on patients' health-related quality of life.

**Task 3.4 – Indirect impact on healthcare resource use, direct medical costs, and productivity losses (indirect costs):** The framework integrates resource utilization, costs, and productivity losses associated with delayed care.

One-way and probabilistic sensitivity and scenario analyses are incorporated to account for parameter uncertainty and to test the robustness of results. The framework is intended as a methodological tool for researchers and policymakers to evaluate the consequences of delays in cancer care and guide resource allocation aimed at improving patient outcomes and reducing healthcare costs.

In sum, the study introduces a reusable modelling approach that can be applied beyond COVID-19 to assess the impact of future healthcare delays on cancer outcomes and expenditures, supporting evidence-based decision-making in public health and health economics.

### B. Subtype-specific health and economic impact of delayed breast cancer diagnosis: A Markov model analysis

📖 Khan, Yasmine, Nick Verhaeghe, Chris Monten, Katrien Vanthomme, Sylvie Gadeyne, Brecht Devleesschauwer, Freija Verdoodt, Hanna Peacock, and Delphine De Smedt. 2025. Subtype-specific health and economic impact of delayed breast cancer diagnosis during the early COVID-19 pandemic in Belgium: A Markov model analysis. In review at Breast Cancer Research.

Next, the generic method outlined above was adapted to the breast cancer case. This study aimed to estimate the **five-year health and economic impact of delayed breast cancer diagnosis during Belgium's first COVID-19 wave**, stratified by molecular subtype. Breast cancer was selected given its high incidence in Belgium, its reliance on early detection for favourable prognosis, and evidence of diagnostic delays during the COVID-19 pandemic. Its molecular subtypes also differ markedly in aggressiveness and prognosis, making it well suited to subtype-specific modelling of delayed diagnosis impacts. The disruption period (March–June 2020) halted the national screening programme, leaving 135 invasive breast cancers undiagnosed. A Markov cohort model compared two cohorts of 10,147 Belgian women: a "delayed-care" cohort including the 2020 undiagnosed cases and a "non-disrupted" cohort based on 2017–2019 trends. Outcomes over five years were evaluated from the healthcare payer perspective, including direct medical costs, quality-adjusted life years (QALYs), and mortality. Data sources included the **Belgian Cancer Registry, NomenSoft—the online searchable database maintained by the National Institute for Health and Disability Insurance (NIHDI), Belgian Centre for Pharmacotherapeutic Information (BCPI), and the**

**international literature.** One-way and probabilistic sensitivity and scenario analyses were used to account for parameter uncertainty. The methodology followed the general Markov framework (Khan et al., 2023) but was adapted to the specific clinical and epidemiological features of breast cancer. Because disease progression, staging, treatment, and prognosis differ across cancers, applying this model elsewhere would require cancer-specific tailoring of health states, transition probabilities, and cost and utility parameters, as shown in the tornado diagrams.

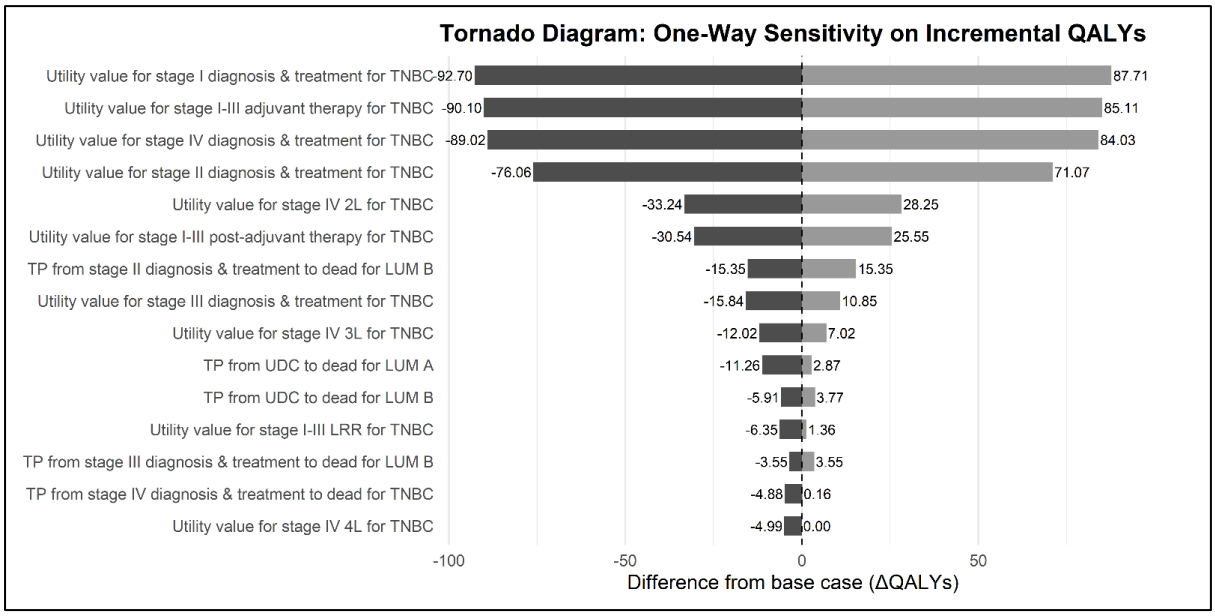


*Figure 8 Tornado diagram showing the impact of varying transition probabilities and utilities on incremental QALYs across breast cancer molecular subtypes*

*Note: L: Lines of systemic therapy (2L: second therapy line; 3L: third therapy line; 4L: fourth therapy line) LRR: Locoregional recurrence LUM A: Luminal A; LUMA B: Luminal B QALY: Quality-Adjusted Life Year TNBC: Triple-negative breast cancer TP: Transition probabilities UDC: Undiagnosed cancer *The vertical dashed line represents the base case incremental QALY result. Dark grey bars indicate the change when the parameter is set to its lower bound, and light grey bars indicate the change when set to its upper bound.*

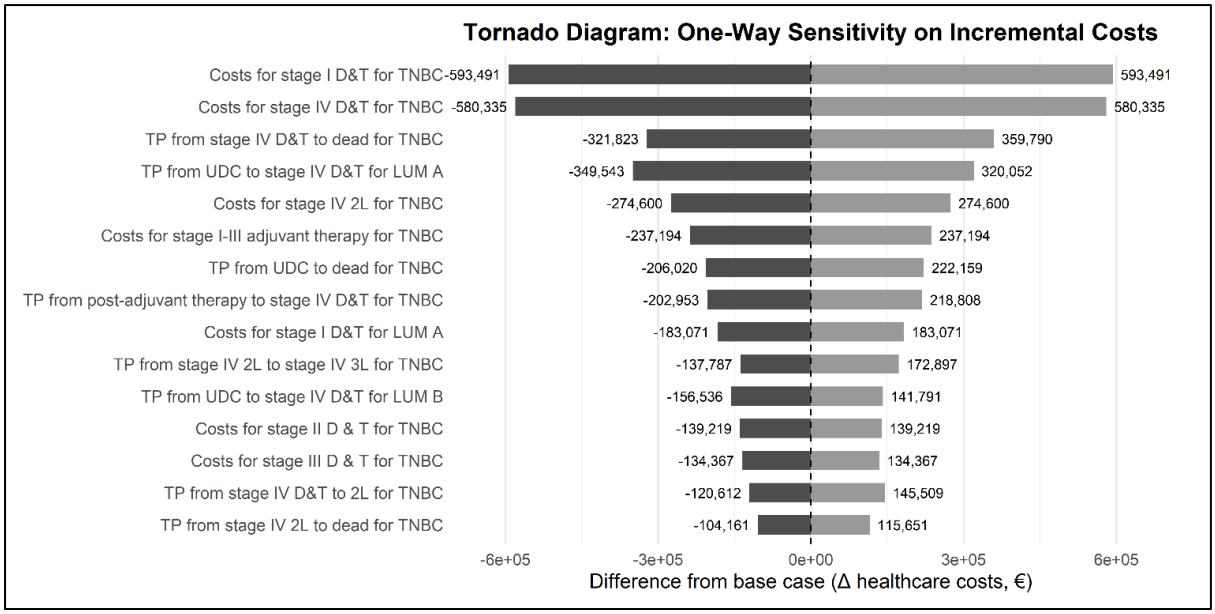


*Figure 9 Tornado diagram showing the impact of varying transition probabilities and treatment costs on incremental healthcare costs across breast cancer molecular subtypes*

*Note: D&T: Diagnosis and treatment L: Lines of systemic therapy (2L: second therapy line; 3L: third therapy line; 4L: fourth therapy line) LRR: Locoregional recurrence LUM A: Luminal A; LUMA B: Luminal B TNBC: Triple-negative breast cancer TP: Transition probabilities UDC: Undiagnosed cancer *The vertical dashed line represents the base case incremental healthcare cost result. Dark grey bars indicate the change when the parameter is set to its lower bound, and light grey bars indicate the change when set to its upper bound.*

Results indicate **a modest overall impact: 21 QALYs lost, six additional deaths, and €3.2 million in extra healthcare costs across all subtypes**, corresponding to an average of 0.002 QALYs and €315 per patient. Given the heterogeneous nature of breast cancer and the inability of screening to distinguish between aggressive, fast-growing tumours and less aggressive, slow-progressing ones, assumptions were incorporated into the model to account for subtype-specific differences in progression. These refinements revealed that the impact of diagnostic delays could vary by molecular subtype, underscoring the importance of considering breast cancer molecular subtypes when assessing the indirect health and economic effects of care disruptions. Under these assumptions, the model revealed that **the burden was mainly carried by aggressive subtypes**; triple-negative breast cancer accounted for the largest health loss (−9.5 QALYs) and highest costs (€1.6 million), followed by HER2+ cancer (−2.5 QALYs; €0.5 million). Rapid recovery measures likely prevented sustained stage shifts, limiting the overall impact, though uncertainty remains, particularly for fast-progressing subtypes.

➲ The study highlights that early pandemic disruptions had a limited short-term impact on breast cancer outcomes at the population level but could disproportionately affect aggressive subtypes. Maintaining diagnostic continuity, prioritizing high-risk cancers, and improving subtype-specific data collection are crucial for mitigating future healthcare system shocks.

**Key takeaway:** While the first COVID-19 wave resulted in only modest overall losses (compared to pre-COVID) in health outcomes and healthcare costs, reflecting the resilience of diagnostic pathways, aggressive breast cancer subtypes were found to be more vulnerable to diagnostic delays. The higher incidence of less aggressive luminal-like subtypes could have masked the adverse effects in triple-negative and HER2-positive cancers. Policy and health system strategies should therefore ensure uninterrupted diagnostic services, rapid recovery of screening programmes, and targeted follow-up of high-risk groups, while emphasising the need to include subtype-specific variables in routine data collection.(i.e. aggressive form of disease)

## Task 3.1 – 3.2 Change in non-COVID disease diagnoses and causes of death

### A. Delayed care of cardiovascular diseases

📖 Khan, Yasmine, Nick Verhaeghe, Brecht Devleesschauwer, Lisa Cavillot, Sylvie Gadeyne, Nele Pauwels, Laura Van den Borre, and Delphine De Smedt. 2023. *The impact of the COVID-19 pandemic on delayed care of cardiovascular diseases in Europe: a systematic review. European Heart Journal – Quality of Care and Clinical Outcomes* 9(7): 647–661. https://doi.org/10.1093/ehjqcco/qcad051

This study aimed to **systematically review the impact of the COVID-19 pandemic on delayed cardiovascular disease care in Europe**, evaluating changes in hospital admissions, treatment delays, cardiac procedures, and mortality across acute and chronic cardiovascular conditions. A systematic search of the electronic bibliographic peer-reviewed databases PubMed, Embase, and Web of Science from 1 November 2019 up to September 2022 identified 132 observational retrospective studies. Outcomes included changes in hospital admissions, mortality rates, delays in seeking care, treatment initiation, and changes in urgent and elective cardiac procedures, stratified by disease group (ischemic heart disease, stroke, cardiac arrest, heart failure, and other cardiovascular conditions). Note that most studies analysed the pandemic's impact during or after the first wave, leaving a gap in our understanding of its long-term effects.

The available evidence confirmed **substantial decreases in acute cardiovascular admissions** (e.g., acute coronary syndrome reduced by 40–50%, stroke emergencies by 12–40%) **and increases in cardiac arrests and mortality during the first wave. Later waves showed partial recovery** in hospital admissions and treatment times, reflecting adaptation of healthcare systems and public health measures. Delays in care were attributed to government restrictions, fear of infection, healthcare system strain, and changes in lifestyle or social behaviours. Higher cardiovascular mortality was linked to treatment delays, more severe presentations, and indirect pandemic effects such as stress and reduced secondary prevention opportunities. Hospital admissions for ischemic heart disease, stroke, and heart failure, as well as urgent and elective cardiac procedures, decreased markedly, while hospital admissions cardiac arrest cases increased. Mortality rates were higher for ischemic heart disease and stroke compared to pre-COVID times.

➲ The COVID-19 pandemic significantly disrupted cardiovascular care, reducing acute hospital admissions, delaying treatments, and increasing mortality, particularly for ischemic heart disease, stroke, and heart failure.

**Key takeaway**: These findings highlight the need for robust healthcare preparedness, clear clinical guidance and public communication, resource allocation, and strategies such as telemedicine to maintain timely care during health crises. Long-term monitoring and decision-analytic modelling are crucial to assess the enduring health and economic impacts of delayed cardiovascular care.

## Task 3.2 Change in non-COVID causes of death

### A. Social inequalities in cancer mortality

🕮 Khan, Yasmine, Laura Van den Borre, Delphine De Smedt, Nick Verhaeghe, Brecht Devleesschauwer, Patrick Deboosere, Katrien Vanthomme, and Sylvie Gadeyne. 2025. A nationwide exploration of social inequalities in cancer mortality amidst the COVID-19 pandemic in Belgium. Cancer Medicine 14(1). https://doi.org/10.1002/cam4.70487

This study assessed changes in overall and site-specific cancer mortality in Belgium between March and December 2020 compared with the same period in 2019 and examined whether social inequalities in cancer mortality shifted during the first year of the COVID-19 pandemic.

Nationwide individually-linked data from **Statistics Belgium** was used, combining information from the Belgian National Register, death certificates, the 2011 Census, and the tax register. Analyses were stratified by sex, age group (45–59, 60–74, 75+), and education level across all cancers (C00-C97). The following specific cancer types were investigated: breast (ICD-10 code C50, for women only), colorectal (ICD-10 codes C18–C20), lung (ICD-10 codes C33–C34), pancreatic (ICD-10 code C25), and prostate (ICD-10 code C61, for men only) cancer. Direct age-standardized mortality rates and Poisson regression models were applied to estimate absolute and relative changes, as well as relative inequalities across social groups.

The results showed **overall decreases in cancer mortality during 2020, especially among persons aged 75 and older**, without major shifts in existing educational disparities. Declines in reported cancer deaths likely reflect the prioritization of COVID-19 as the underlying cause of death and its role as a competing risk, rather than real improvements in cancer outcomes. **Overall, the COVID-19 pandemic did not considerably change the educational patterns of cancer mortality**. This shows the tenacity of social differences in cancer mortality, which are unlikely to change in less than a year. When examining the five selected cancer types, we found that for more preventable cancers, such as colorectal and lung cancers, individuals with lower education continued to face higher mortality risks than their higher educated counterparts. This was particularly evident among men aged 45–59 and women aged 60–74 showing increased relative mortality in 2020 compared to those in 2019. These disparities were less pronounced among the oldest individuals, while no significant educational differences were observed for less preventable cancers, such as prostate

cancer in men or breast cancer in women. It is unclear whether this reflects a persistent pattern of educational inequality in health determinants during the early pandemic, or whether the short timeframe simply did not capture the effects of these changes.

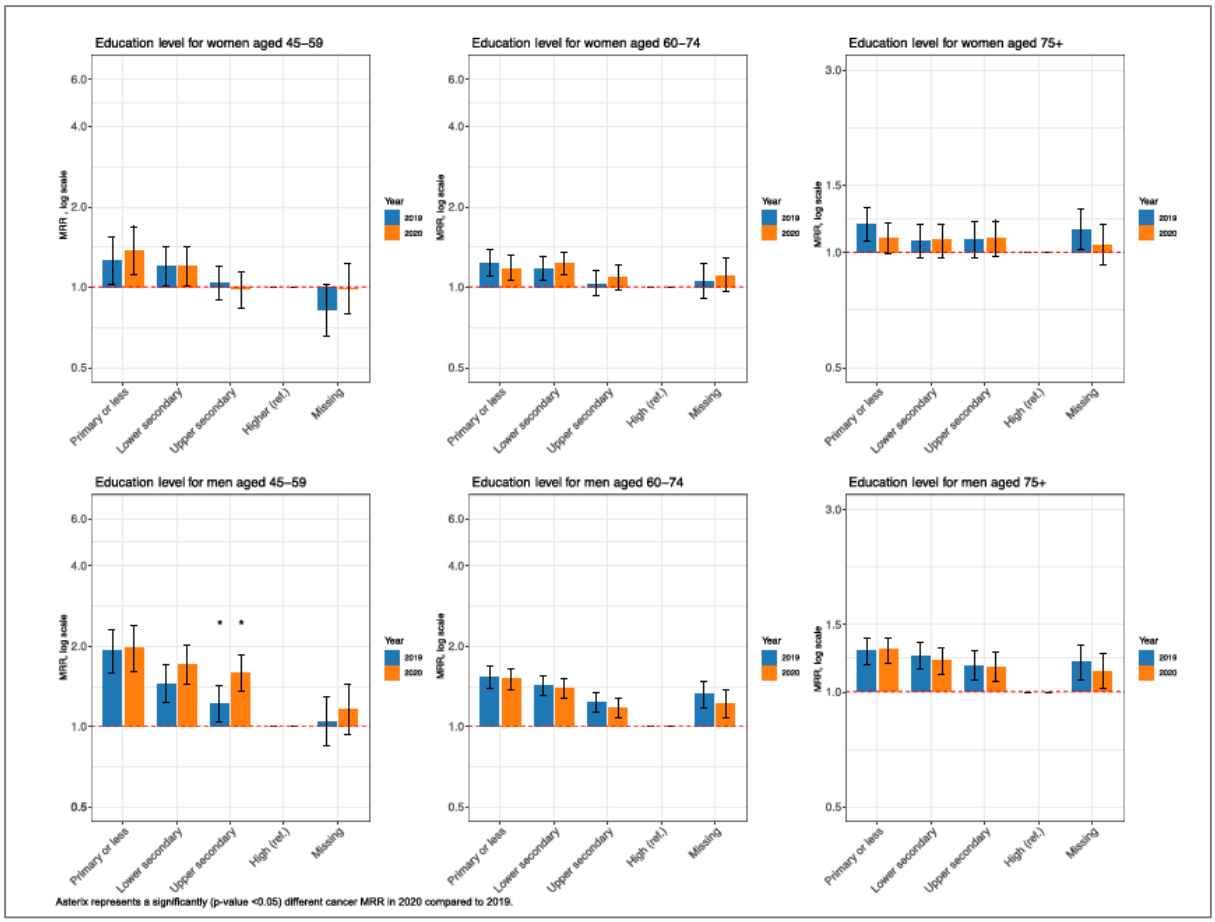


*Figure 10 Education- related cancer mortality rate ratios (MRRs) and 95% CI for all cancers (C00–C97) in 2020 and 2019, among the 45–59, 60–74, and 75+ age groups, by sex.*

➲ This study provides a nationwide overview of cancer mortality patterns during the early COVID-19 pandemic and demonstrates that, despite overall declines in reported cancer deaths, pre-existing educational inequalities persisted.

**Key takeaway:** The decreases in reported cancer mortality in 2020 should be interpreted with caution, as they may partly reflect changes in cause-of-death coding practices and the competing impact of COVID-19, rather than true reductions in cancer-related deaths. Despite the challenges posed by COVID-19, pre-existing educational inequalities in cancer mortality largely persisted. While pandemic response efforts helped prevent worsening of these inequalities, achieving greater equity will require continued and targeted actions—improving access to care, strengthening preventive programs, and enhancing health literacy among disadvantaged groups. Long-term, strategic policies are essential to reduce these entrenched social disparities beyond the immediate crisis. For insights into existing policies and actions to reduce social inequalities in cancer, we kindly refer to the 2024 OECD report 'Beating cancer inequalities in the EU'.

## 4.4 POLICY RECOMMENDATIONS

### 1) Strengthen foundations: health promotion, prevention, and protection

HELICON's findings underline that pandemic resilience starts long before a crisis occurs. Strengthening health promotion, disease prevention, and health protection reduces vulnerability and health inequalities. **Equity-oriented strategies** should be integrated across chronic and infectious disease programs, complemented by investments in community-based health literacy and behavioural interventions to build public trust and responsiveness. **Reinforcing occupational** (e.g., Occupational Health Services) **and environmental** (e.g., indoor air quality programs in schools and workplaces) **health systems** is also critical to mitigate indirect physical and mental health impacts during emergencies.

### 2) Empower population and community health systems

The pandemic highlighted the essential role of strong primary care and public health networks in reaching and supporting vulnerable populations. **Strengthening partnerships between local authorities, primary care actors, and social services** enhances the capacity to maintain continuity of care during crises. Preparedness planning should embed equity and accessibility criteria, ensuring that integrated care pathways and rapid recovery protocols prioritize the needs of disadvantaged groups. HELICON also demonstrated that, while highly granular data often exist to study social health inequalities, access can be restricted due to legal interpretations, and in some areas, high-quality data remain unavailable—for instance, for undocumented populations or detailed multimorbidity patterns. Addressing these **data gaps and data barriers** is crucial to enable evidence-informed interventions for specific communities.

### 3) Foster innovation and translation into policy and practice

Interdisciplinary collaboration and timely evidence generation proved crucial in HELICON. Innovation in data analytics, modelling, and health economics should be supported to guide preparedness planning and equitable response strategies. Implementation science approaches are needed to translate research into actionable public health and healthcare interventions, while adaptive governance allows policies to evolve in response to emerging evidence.

### 4) Build interoperable and FAIR data infrastructures

Reliable, timely, and accessible data are foundational for informed decision-making. Investments in **interoperable, privacy-compliant data linkages across social, health, and administrative information systems**, along with adherence to FAIR and open science principles, are essential for collaborative research. **Sustained national data infrastructures** are needed to monitor inequalities, evaluate interventions, and provide early warnings of disruptions to healthcare and population health. Legal and procedural barriers should be clarified and streamlined so that available granular data can be safely and systematically leveraged for social health inequalities research.

5) Strengthen impact assessment, policy uptake, and knowledge dissemination

Evidence must translate into real-world action to improve population health outcomes. Integrating equity and health impact assessments into preparedness and recovery plans, developing systematic feedback mechanisms, and using accessible communication platforms will help ensure that scientific findings reach decision-makers, stakeholders, and communities in real time.

## 4.5 LEVERS TO OPERATIONALIZE PANDEMIC PREPAREDNESS

The abovementioned policy recommendations are built on principles we all know -equity, prevention, resilience, data integration- but the challenge lies in the execution. Our experience in the HELICON project helped us to identify concrete levers to move from concepts to specific capabilities and actions:

1) Institutionalise preparedness within existing systems

- Instead of creating new temporary structures, embed preparedness in routine public health, primary care, and surveillance workflows.
- Integrate "pandemic sensitivity" indicators (e.g., disruption risk, continuity of care) in existing health monitoring systems.
- Link preparedness objectives to performance and funding frameworks within health services, so that resilience becomes part of normal accountability.

2) Improve collaboration between data holders

HELICON's data linkage challenges show that legal and technical barriers won't disappear on goodwill alone. We would like to put the spotlight on much-needed specific steps, that are currently being undertaken by the Health Data Agency.

- Establish a common access procedure across data holders and clarify the legal and technical requirements for data access and linkages.
- Increase predictability regarding timelines and costs for data delivery and linkage to reduce uncertainty for researchers and institutions.
- Implement standardized data-sharing agreements and "trusted third-party" models to streamline approvals while ensuring strong data protection.

3) Move from research projects to sustained infrastructures

Preparedness cannot rely on project-based funding cycles.

- Develop shared, sustainable infrastructure to guarantee data security and research innovation, rather than relying on fragmented, project-specific initiatives.
- Clearly delineate roles and responsibilities among agencies and stakeholders to ensure timely and effective action, prevent administrative bottlenecks, and allow responsible actors to carry out their duties without being blocked by conflicting interpretations or overlapping mandates.

### 4) Strengthen implementation capacity alongside knowledge generation

Pandemic experiences often highlight critical lessons, but these insights may not inform timely action due to gaps in the translation of evidence into policy. To address this, we recommend:

- Embedding researchers within ministries and health services to work directly at the science-policy interface, ensuring evidence is aligned with decision-making needs.
- Establishing rapid evidence synthesis and scenario modelling units that provide policymakers with timely, contextualized, and actionable insights.
- Investing in capacity-building for policymakers and practitioners, enabling them to interpret, assess, and apply research findings effectively in real-world settings.

### 5) Strengthen societal trust and engagement

Preparedness depends as much on trust as on technology.

- Co-create interventions with communities, care providers, and patient organisations, ensuring that measures are culturally sensitive and feasible.
- Communicate uncertainty and trade-offs transparently, to maintain legitimacy even under crisis conditions.
- Evaluate and publicly report on equity impacts of crisis measures to sustain accountability.

## 5. DISSEMINATION AND VALORISATION

### 5.1 PARTICIPATION / ORGANISATION OF SEMINARS (NATIONAL / INTERNATIONAL)

#### a) Oral Presentations

**2021**

- **Van den Borre L.** – Sciensano EpiTuesday Seminars, 29/06/2021, Brussels (videoconference)
  *"HELICON: Unravelling the long-term and indirect health impact of the COVID-19 crisis in Belgium"*
- **Van den Borre L.** – DEMO Midi de la Recherche (UCLouvain), 14/12/2021, Brussels (videoconference)
  *"HELICON: Unravelling the long-term and indirect health impact of the COVID-19 crisis in Belgium"*

**2022**

- **Cavillot L.** – IRSS Seminar, Catholic University of Louvain, 08/06/2022, Louvain
  *"Sociodemographic and socioeconomic disparities in COVID-19 vaccine uptake in Belgium"*
- **Khan Y.** – LoLaHESG 2022, Maastricht University & Maastricht UMC+, 20/05/2022, Maastricht
  *"The development of a Markov Multistate Model to evaluate the health economic impact of delayed cancer care due to the COVID-19 pandemic in Belgium: A methodology approach"*

- **Cavillot L.** – European Public Health Conference, 10/11/2022, Berlin
  *"Sociodemographic and socioeconomic disparities in COVID-19 vaccine uptake in Belgium"*
- **Khan Y.** – European Public Health Conference, 11/11/2022, Berlin
  *"Future health and health economic implications of the COVID-19 pandemic on non-COVID-19 diseases"*
- **Van den Borre L.** – European Public Health Conference, 10/11/2022, Berlin
  *"Changing social patterns: excess mortality during the first three COVID-19 waves in Belgium"*
- **Van den Borre L.** – Chaire Quételet 2022, 22/11/2022, Louvain-la-Neuve
  *"Changing social patterns: excess mortality during the first three COVID-19 waves in Belgium"*

**2023**

- **Cavillot L.** – #HELICONference Webinar, 01/02/2023, Brussels
  *"Sociodemographic and socioeconomic disparities in COVID-19 vaccine uptake in Belgium"*
- **Cavillot L.** – BY COVID-19 Seminar, 01/02/2023, Brussels
  *"Sociodemographic and socioeconomic disparities in COVID-19 vaccine uptake in Belgium"*
- **Cavillot L.** – HELICON Webinar, 26/04/2023, The Hague
  *"Sociodemographic and socioeconomic disparities in COVID-19 vaccine uptake in Belgium"*
- **Van den Borre L.** – Symposium on Infectious Diseases – Sciensano, 11/05/2023, Brussels
  *"Social Inequalities in COVID-19 Related Health Outcomes: Insights from the Helicon Project"*
- **Van den Borre L.** – Belgian Association for Public Health, 08/06/2023, Louvain-la-Neuve
  *"Unravelling the long-term and indirect health impact of the COVID-19 crisis in Belgium"*
- **Van den Borre L.** – European Public Health Conference, 11/11/2023, Berlin
  *"Understanding excess mortality during COVID in Belgium: the influence of health and social factors"*

**2024**

- **Cavillot L.** – 17th European Conference of Public Health, Nov 2024, Lisbon
  *"Unravelling demographic and socioeconomic patterns of COVID-19 death and other causes of death: results of an individual-level analysis of exhaustive cause of death data in Belgium, 2020"*
- **Cavillot L.** – Health and Society Research Institute Seminar, Oct 2024, Brussels
  *"The mediation role of vaccination, underlying health conditions and working in healthcare on the socioeconomic disparities in COVID-19 hospitalization"*
- **Cavillot L.** – Interuniversity Day for PhD Students in Public Health, Dec 2024, Brussels
  *"One-year post-acute organ complications following COVID-19 hospitalization and related social inequalities"*
- **Khan Y.** – European Population Conference, 12/06/2024, Edinburgh
  *"A nationwide exploration of social inequalities in cancer mortality amidst the COVID-19 pandemic in Belgium"*
- **Van den Borre L.** – European Public Health Conference, 15/11/2024, Lisbon
  *"Unraveling Social Health Inequalities during COVID-19 in Belgium. The vital role of data linkages"*
- **Van den Borre L.** – Health Information Study Day, 06/12/2024, Lisbon
  *"Data linkage in a crisis: Insights from the HELICON project on COVID-19 hospitalizations and long-term health outcomes"*

### b) Poster Presentations

- **Makovski T., Ghattas J., Monnier-Besnard S., et al.** – International Symposium on Multimorbidity, 01/01/2021, Amsterdam (hybrid)
  *"Etiologic and prognostic roles of frailty and multimorbidity in development of COVID-19 related severe health outcomes"* – Best Poster Award
- **Khan Y.** – European Public Health Conference, 11/11/2023, Berlin
  *"The impact of the COVID-19 pandemic on delayed care of cardiovascular diseases in Europe"* (Poster display & chaired presentation)
- **Ghattas J. -** World Congress on Public Health 04/05/2023, Rome
  *"Etiological and prognostic roles of socioeconomic characteristics in the development of SARS-CoV-2 infection and related severe health outcomes: systematic review of populationbased studies"*

### c) Participation

- **Van den Borre L.** – 2022 CLOSER Conference, 18-20/01/2022, London (videoconference)

## 5.2 SUPPORT TO DECISION MAKING

- **Van den Borre L. & Devleesschauwer B.** – Departementale Crisiscel Volksgezondheid, 21/10/2021, Brussels (videoconference)
  *HELICON: Unravelling the long-term and indirect health impact of the COVID-19 crisis in Belgium*
- Systematic review results featured in a report submitted to the **European Commission (PHIRI project)**

## 5.3 HELICONFERENCE WEBINARS

- **Burden of post-COVID conditions in Belgium: current insights and future perspectives** – 30/06/2021
- **Social health inequalities during the COVID-19 crisis: evidence from excess mortality research** – 07/10/2021
- **Impact of the COVID-19 crisis on cancer care** – 12/01/2022
- **Data needs during the COVID-19 crisis** – 27/04/2022
- **Mental health repercussions of the COVID-19 crisis** – 22/09/2022
- **Social differences in COVID-19 vaccination** – 01/02/2023
- **Impact of COVID-19 on Belgian health care** – 21/06/2023
- **Beyond the virus: Addressing gender disparities during COVID-19** – 16/01/2024
- **Health of children and young adults during the COVID-19 crisis** – 22/01/2025

## 5.4 EVIDENCE OVERVIEW ON PROJECT WEBSITE

https://www.brain-helicon.be/evidence

## 5.5 PUBLICATIONS


1. Boiy, Elin, Lisa Cavillot, Brecht Devleesschauwer, Delphine De Smedt, Sylvie Gadeyne, Niko Speybroeck, Laura Van den Borre, Katrien Vanthomme, Nick Verhaege, and Robby De Pauw. 2025. Social inequalities in in-hospital mortality following COVID-19 hospitalization in Belgium: a competing risk survival analysis. Submitted to BMJ Public Health, October 2025 (under review).
2. Boiy, Elin, Lisa Cavillot, Brecht Devleesschauwer, Robby De Pauw, Delphine De Smedt, Sylvie Gadeyne, Vanessa Gorasso, Masja Schmidt, Katrien Vanthomme, Nick Verhaege, & Laura Van den Borre. Post-acute healthcare expenditure following COVID-19 hospitalization and associated social inequalities in Belgium: a matched cohort study. Submitted to BMC Health Services Research, August 2025 (under review).
3. Cavillot, Lisa, Beatrijs Moerkerke, Brecht Devleesschauwer, Jinane Ghattas, Joris A.F. van Loenhout, Laura Van den Borre, Niko Speybroeck, Tom Loeys, and Robby De Pauw. 2024. “The Role of Vaccination, Underlying Health Conditions, and Working in Healthcare in the Socioeconomic Disparities in COVID-19 Hospitalization: A Mediation Analysis Using Interventional Effect Models.” Submitted to BMC Infectious Diseases, September 2024 (under review).
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## ANNEXES

### 1. Extended Summary

HELICON investigated **sociodemographic and socioeconomic inequalities in COVID-19 vaccination, infections, hospitalizations, and mortality in Belgium**. The project produced population-level evidence showing that men, migrants, and socioeconomically disadvantaged groups faced higher risks of infection, lower vaccine uptake, increased hospitalization, and elevated mortality (Cavillot et al., 2023; Hubin et al., 2024; Meurisse et al., 2022; Vanthomme et al., 2023; Van den Borre et al., 2024, 2025). Younger age was associated with lower COVID-19 vaccine uptake, while older age was associated with increased hospitalization and mortality risks. Analyses incorporated intersectionality and accounted for the dynamic course of the epidemic, using both individual- and municipality-level data, as well as systematic reviews of multimorbidity, frailty, and socioeconomic determinants. While Task 1.1 on inequalities in COVID-19 testing could not be completed due to data limitations, all other planned analyses were executed successfully, providing comprehensive evidence on social inequalities in COVID-19 outcomes.

- ✓ **Vaccination inequalities:** By 31 August 2021, 10% of Belgian adults (536,716 out of 5.3 million) had not received a first COVID-19 vaccine dose. Vaccine uptake was significantly lower among younger individuals, men, persons with a migration background, single parents, one-person households, and socioeconomically disadvantaged groups defined by lower income, lower education, and unemployment (Cavillot et al., 2023).
- ✓ Disparities in vaccination coverage were observed at both the individual and municipality level. Individual characteristics -especially migration background, income, and age- explained most inequalities, while municipality-level factors added complementary information. Individual-level data provided more granularity and statistical power, revealing that personal demographic and socioeconomic conditions were the main drivers of vaccine uptake (Hubin et al., 2024).
- ✓ **Testing inequalities:** Task 1.1 on social inequalities in COVID-19 test reimbursements could not be completed due to the lack and limited quality of population-level testing data. The approved dataset contained only hospitalized patients, preventing a valid analysis of testing inequalities.
- ✓ **Infection inequalities:** Municipality-level analyses showed that the most deprived areas experienced 24% higher COVID-19 incidence than the least deprived areas, with the largest disparities during the second and third waves (Meurisse et al., 2022). These patterns were shaped by changing testing strategies, viral circulation, and lockdown measures. At a broader level, a systematic review demonstrated that individuals with multiple chronic conditions and higher frailty had poorer COVID-19 outcomes, mainly in terms of mortality (Makovski et al., 2024). Another review found that disadvantaged socioeconomic groups and certain ethnic populations faced higher infection rates and more severe outcomes (Ghattas et al., 2024). Together, these studies confirm the strong and consistent link between social disadvantage and COVID-19 risk and severity.
- ✓ **Hospitalization inequalities:** Individuals with low education were substantially overrepresented among hospitalized COVID-19 patients: 56% during the Delta wave and

66% during the Omicron wave, compared to 32% in the general Belgian adult population. Low education was associated with a higher probability of hospitalization, partly mediated by vaccination and underlying health conditions, especially during the Delta wave (Cavillot et al., 2024).

- ✓ **Mortality inequalities:** Elderly men experienced the highest absolute mortality burden across all three COVID-19 waves, while elderly women and middle-aged men and women followed (Van den Borre et al., 2024). Care home residents were particularly affected during the first and second waves. The educational mortality gap widened among middle-aged persons during waves 2 and 3, suggesting the importance of education-related knowledge and resources. Elderly Turkish men and women experienced notably higher excess mortality compared to native Belgians -over 26% for men and around 40% for women- illustrating persistent inequalities even after adjusting for sociodemographic and socioeconomic background (Vanthomme et al., 2023).
- ✓ Further analyses showed that pre-existing health, age, and sex were key to understanding patterns of excess and deficit mortality, yet inclusion of sociodemographic and socioeconomic variables substantially improved the accuracy of mortality risk estimates (Van den Borre et al., 2025). Finally, an individual-level analysis identified living in collectivities, age, sex, education, and income as the strongest predictors of COVID-19 death. First-generation migrants had 24% higher COVID-19 mortality compared to survival, even after adjusting for socioeconomic factors, indicating that structural conditions and barriers to healthcare access played a key role (Cavillot et al., 2024).

HELICON assessed the **direct long-term health impacts of COVID-19 following hospitalization and evaluated related healthcare expenditures and mortality in Belgium**. The project provided robust evidence of the post-acute burden of severe COVID-19 in Belgium, highlighting that demographic and socioeconomic factors strongly influence post-hospitalization health outcomes, healthcare costs, and mortality.

- ✓ **Healthcare expenditures:** COVID-19 hospitalization was associated with 18.5% lower post-acute healthcare costs in the calendar year following hospitalization compared to non-COVID hospitalizations, potentially reflecting differences in severity among non-COVID patients. Higher post-acute costs were observed among patients with lower education or income, older age, and those living in collective households, whereas patients with a migration background had lower costs (Boiy et al., 2025).
- ✓ **Long-term organ complications:** Among hospitalized survivors, severe COVID-19 increased the odds of post-acute cardiovascular complications by 1.19-fold (excess burden: 20.16 per 1,000 persons), with higher risk among critical patients. Pulmonary complications were more pronounced, with 2.05- to 2.72-fold higher odds and excess burdens up to 38.7 per 1,000 persons (Cavillot et al., 2025). Socioeconomic disparities were observed for pulmonary complications, with lower-income patients at higher risk, while cardiovascular outcomes were primarily driven by pre-existing health conditions.

- ✓ **Premature mortality:** In-hospital mortality among COVID-19 patients was 14.8%, with higher hazards for patients with lower education, lower income, unemployment, living in collective households, male sex, older age, and residence in Walloon or the Brussels Capital Region (Boiy et al., 2025). These findings demonstrate substantial social and demographic disparities in survival following COVID-19 hospitalization.

HELICON quantified the **indirect health and economic consequences of COVID-19-related disruptions**, producing robust estimates for cancer and highlighting important patterns for cardiovascular diseases, even though a full quantitative analysis was not feasible for the latter.

- ✓ **Cardiovascular diseases:** A review building on European evidence indicated marked reductions in acute cardiovascular admissions during the early pandemic (acute coronary syndrome: −40–50%; stroke emergencies: −12–40%) and increases in cardiac arrests and mortality (Khan et al., 2023). Later waves showed partial recovery as healthcare systems adapted. Higher mortality was linked to delayed treatment, more severe presentations, and indirect pandemic effects such as stress and reduced secondary prevention opportunities.
- ✓ **Cancer:** HELICON developed a Markov model to assess the health and economic consequences of delayed cancer diagnoses due to the COVID-19 crisis, focusing on breast, colorectal, lung, and head-and-neck cancers (Khan et al., 2023).
- ✓ For breast cancer specifically, delays resulted in 21 QALYs lost, six additional deaths, and €3.2 million in extra healthcare costs, with aggressive subtypes like triple-negative breast cancer disproportionately affected (Khan et al., 2025). Rapid recovery measures likely mitigated larger impacts, though uncertainty remains for fast-progressing subtypes. Analysis of cancer mortality revealed overall declines in reported deaths during 2020, probably reflecting competing risks with COVID-19 rather than real improvements in outcomes (Khan et al., 2025). Existing educational disparities persisted, particularly for preventable cancers (colorectal, lung), with men aged 45–59 and women 60–74 showing elevated relative mortality. Less preventable cancers (e.g., prostate, breast) showed no significant educational differences. These findings indicate that short-term pandemic disruptions did not substantially alter long-standing social inequalities in cancer mortality.

**HELICON's data approach provided comprehensive coverage of during- and post-pandemic health information, socio-demographic and socio-economic characteristics, healthcare use, and related costs.** The project established a population-linked database, the HELICON database, by connecting individual-level data from Sciensano, Statistics Belgium, and the InterMutualistic Agency. This enabled the study of social inequalities in COVID-19 hospitalizations and the long-term impact of severe COVID-19 infections. In parallel, methodological frameworks (Markov models) were developed to harmonize and combine diverse data sources in order to investigate the indirect health (economic) impact of the crisis.

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