The rising cost of
Long COVID and ME/CFS in Germany

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Risklayer

ME/CFS Research Foundation

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Questions specifically about the data and model can be sent to Johannes Brand at Risklayer GmbH: johannes@risklayer.com

Data availability
This modelling study is based on secondary data obtained from multiple publicly-accessible sources. The specific data sources used are referenced within the text (including in the Annexes) and included in the reference list wherever possible.

All data are publicly available for verification and further research, via Johannes Brand. A copy of the model can be found on GitHub at https://github.com/risklayer.

Conflict of interest
All authors declare that they have no competing financial and non-financial conflicts of interest.

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Foreword

In addition to causing acute illness and global disruption, the COVID-19 pandemic triggered a growing wave of long-term health conditions that continue to affect millions of people, resulting in rising socio-economic costs.

Among the most significant of these is Long COVID, a post-infection syndrome that is life-altering for affected individuals. Long COVID has also brought renewed attention to the chronic condition ME/CFS (Myalgic Encephalomyelitis/Chronic Fatigue Syndrome), which shares many overlapping symptoms and may in some cases develop as a consequence of SARS-CoV-2 infection. Although ME/CFS has been recognised for decades, the scale of infection-associated chronic illness has expanded dramatically in the wake of the pandemic.

Both Long COVID and ME/CFS are associated with substantial disability, reduced quality of life, increased demand for medical care, and prolonged absence from work and social life. To date, no official data about the burden and cost of Long COVID and ME/CFS is available for Germany. Our work here fills this data gap.

We apply a state-of-the art modelling and damage assessment technique to publicly-available data about the two diseases, providing a robust and comprehensive estimate of the cost of Long COVID and ME/CFS to German society.

The results are significant: between 2020 and 2024, Long COVID and ME/CFS cost Germany more than €250 billion. In 2024 alone, Long COVID and ME/CFS cost Germany €63.1 billion, equating to 1.5% of the nation's GDP.

Our findings are in line with comparable studies from other countries, and have been strengthened by the many expert contributions from which we benefited while carrying out this work.

The modelling approach was created and validated by Risklayer GmbH, a company that has provided public risk analytics and management solutions on crisis and catastrophe risk to multilateral organisations and governments around the world for over a decade. Among its wide-ranging work, Risklayer provided independent, comprehensive data collection and analysis to the Federal Government and media outlets of Germany during the COVID-19 pandemic.

To inform the assumptions used in the model, the ME/CFS Research Foundation contributed expertise and literature reviews on Long COVID and ME/CFS, as well as advice from its extensive network.

We are indebted to researchers and colleagues who responded to an invitation to review an early version of the model and report. Their input significantly strengthened the work. In particular, we thank Alexander Haering (RWI - Leibniz Institute for Economic Research, Germany) and Marco Leitzke (University of Leipzig Medical Centre, Germany), as well as the many anonymous reviewers who commented on particular aspects of the model. We also thank Martin Hechler, Rutger Verbeek, Stefan Neefischer and Harald Dormann for their work modelling and publishing the caseload of SARS-CoV-2-infections in Germany for 2020-2024, an important parameter used in the analysis.

As SARS-CoV-2 continues to circulate widely, the number of people affected by Long COVID and ME/CFS is expected to rise further, resulting in growing costs to healthcare systems, labour markets, and the wider economy. The disease burden calculated in this comprehensive report will help policy makers develop and prioritise policy measures across biomedical research, public health, medical care, and social welfare in order to reduce costs and improve outcomes for German society.

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Karlsruhe & Hamburg, May 2025

Contributors

This report was created through a collaboration between two expert organisations.

Risklayer

The data-based modelling in this report was performed by risk management experts from Risklayer GmbH. Risklayer has been providing risk analytics and risk management to governments all over the world since 2014.

For the initial years of the COVID-19 pandemic, Risklayer maintained a detailed day-by-day SARS-CoV-2 infections caseload dataset for all 401 districts in Germany, based in part on a novel crowdsourcing approach for data. Risklayer's independent data collection highlighted delays and inconsistencies in official reporting (Dambeck, 2021). By identifying and addressing these inconsistencies, it was possible to provide more accurate estimates of active cases, hospitalisations, and fatalities than any other entity (CEDIM, 2021). The comprehensive data provided by Risklayer was utilized and frequently cited by major German media outlets (see e.g. Wittlich and Lehmann, 2022; Schäfer, 2021). It was used by Zweites Deutsches Fernsehen (ZDF), Tagesspiegel, Johns Hopkins University and Worldmeters (among others) as the basis for official counting of cases and trends in Germany through the first two years of the pandemic. Risklayer staff engaged in extensive government and global discussions, along with media and TV outreach, to support other countries in the adoption of similar methods.

Through this practical experience, Risklayer has cultivated extensive expertise in COVID-19 caseload data within Germany. This proficiency is augmented by Risklayer's ongoing practice of modelling the consequences of critical events and natural disasters, from seismic activity and severe meteorological occurrences to conflict. The reliability of Risklayer's models is evidenced by their daily use of governments, non-governmental organisations and companies globally.

Risklayer originated from the Center for Disaster Management and Risk Reduction Technology (CEDIM) at the Karlsruhe Institute of Technology (KIT) in Germany, and the General Sir John Monash Foundation in Australia.

ME/CFS Research Foundation

Input on the assumptions used in the model, as well as literature reviews and engagement with networks of experts, was provided by the ME/CFS Research Foundation gGmbH. As a non-profit organisation based in Germany and with an international scientific advisory board, the Foundation funds biomedical research, enables the networking of researchers and experts in the field, and informs patients and the public about the status quo of research relating to both ME/CFS and subtypes of Long COVID.

With the help of private donations, ME/CFS Research Foundation funds research projects on the diagnosis and treatment of ME/CFS and Long COVID at leading research institutions and university clinics, including the Technical University of Munich (TUM) and Charité — Universitätsmedizin Berlin. The Foundation organises a regular international scientific conference and a public symposium on ME/CFS research in cooperation with Charité — Universitätsmedizin Berlin. With the ME/CFS Research Register, the Foundation hosts and administers an openly-available data register on ME/CFS research, and regularly reports on the state of ME/CFS research on its website.

Executive summary

This report describes the cost of Long COVID and ME/CFS (Myalgic Encephalomyelitis/ Chronic Fatigue Syndrome) in Germany for the five-year period from 2020 to 2024.

The approach combines (1) prevalence data for SARS-CoV-2 infections, (2) probabilities that COVID-19 patients may develop Long COVID or ME/CFS, and (3) a state-of-the art simulation model, to calculate the combined personal, employer, society and medical losses (hereafter "costs") resulting from reduced value-add and increased expenditure around these patients.

Our analysis finds the combined annual cost of Long COVID and ME/CFS in Germany ranged from a baseline of €22.3 billion in 2020 (resulting mostly from pre-pandemic ME/CFS cases) to €72.8 billion in 2022 (at the peak of the COVID-19 pandemic), subsequently decreasing to €64 billion in 2023 and €63.1 billion in 2024. For the five-year period from 2020 to 2024, the model calculates a total cumulative cost of Long COVID and ME/CFS in Germany of more than €250 billion.

Put into the context of Germany's annual Gross Domestic Product (GDP), the cost burden of ME/CFS and Long COVID combined ranged from 0.7% of GDP in 2020, to 1.8% of GDP in 2022, to 1.5% of GDP in 2024. These figures are in line with findings from existing reports from other countries (summarised in Annex 1).

In terms of Long COVID specifically, our model indicates that Long COVID cases were at their peak during 2022. Hence, annual costs attributable to Long COVID also peaked during 2022 at €47.2 billion. For ME/CFS, the modelled annual costs continued to rise (from €20.9 billion in 2020 to €30.9 billion in 2024) as more cases arose than resolved. Under the current scenario, modelling points to likely further increasing costs in the years ahead, as a result of new Long COVID and ME/CFS cases originating from a projected continued SARS-CoV-2 infection caseload.

The model in this paper was created by Risklayer GmbH, in collaboration with the ME/CFS Research Foundation. Risklayer has provided risk analytics and risk management services to many governments worldwide for over a decade; it was also central to Germany's COVID-19 surveillance efforts during the pandemic. Both the combined cost assessment methodology and the applied probability modelling (Monte Carlo simulation) which form the basis of this report have been widely used for national governments and multilateral agencies to assess the cost impact of a range of crises and disasters. The model and its underlying assumptions are detailed in Annex 2.

Overall, this study provides an up-to-date and robust data set to inform decisions around policy creation, research funding allocation, and health systems transformation in Germany, towards more effectively reducing the cost of Long COVID and ME/CFS and improving outcomes for people living with these diseases.

Zusammenfassung

Dieser Bericht zeigt die gesellschaftlichen Kosten von Long COVID und ME/CFS (Myalgische Enzephalomyelitis/Chronisches Fatigue-Syndrom) in Deutschland für den Fünfjahreszeitraum von 2020 bis 2024 auf.

Grundlage der Analyse ist die Kombination aus (1) Prävalenzdaten zu SARS-CoV-2-Infektionen, (2) Wahrscheinlichkeiten für die Entwicklung von Long COVID oder ME/CFS infolge von COVID-19 auf Basis aktueller Forschungsergebnisse und (3) einem probabilistischen Simulationsmodell. Aus diesen Daten werden die gesamtwirtschaftlichen Verluste — persönliche, unternehmerische, medizinische und gesamtgesellschaftliche Kosten — ermittelt, die durch verminderte Wertschöpfung und erhöhte Ausgaben im Zusammenhang mit diesen Erkrankungen entstehen.

Insgesamt zeigt unsere Analyse, dass die kombinierten jährlichen Kosten von Long COVID und ME/CFS in Deutschland von 22,3 Milliarden Euro im Jahr 2020 (vor allem durch bereits präpandemisch bestehende ME/CFS-Fälle) auf 72,8 Milliarden Euro im Jahr 2022 (dem Höhepunkt der COVID-19-Pandemie) stiegen und in den Jahren 2023 und 2024 leicht auf 64 bzw. 63,1 Milliarden Euro sanken. Für den gesamten Zeitraum von 2020 bis 2024 berechnet das Modell kumulierte Gesamtkosten von über 250 Milliarden Euro.

Bezogen auf das Bruttoinlandsprodukt (BIP) Deutschlands entspricht dies einer Kostenbelastung von 0,7 % des BIP im Jahr 2020, 1,8 % im Jahr 2022 und 1,5 % im Jahr 2024. Diese Werte liegen im Rahmen internationaler Vergleichsstudien (siehe Annex 1).

Bezogen auf Long COVID zeigt das Modell, dass die Fallzahlen im Jahr 2022 ihren Höchststand erreichten. Infolgedessen erreichten auch die damit verbundenen Kosten in diesem Jahr mit 47,2 Milliarden Euro ihren höchsten Wert. Für ME/CFS stiegen die modellierten jährlichen Kosten hingegen im Zeitverlauf an — von 20,9 Milliarden Euro im Jahr 2020 auf 30,9 Milliarden Euro im Jahr 2024 —, da mehr neue Erkrankungsfälle entstanden als Menschen genasen. Unter den derzeitigen Rahmenbedingungen ist laut Modell auch in den kommenden Jahren mit weiter steigenden Kosten zu rechnen — bedingt durch neue Fälle von Long COVID und ME/CFS infolge einer projizierten fortlaufenden Anzahl an SARS-CoV-2-Infektionen.

Das in dieser Studie verwendete Modell wurde von der Risklayer GmbH in Zusammenarbeit mit der ME/CFS Research Foundation entwickelt. Risklayer hat in den vergangenen zehn Jahren zahlreiche Regierungen weltweit im Bereich Risikoanalytik und Risikomanagement beraten und spielte in Deutschland eine zentrale Rolle bei der COVID-19-Datenüberwachung während der Pandemie. Die hier angewandte Methodik zur Kostenabschätzung und Wahrscheinlichkeitsmodellierung (Monte-Carlo-Simulation) wird auch in anderen Krisen- und Katastrophenszenarien regelmäßig von Regierungen und internationalen Organisationen eingesetzt. Details zum Modell und zu den zugrundeliegenden Annahmen finden sich in Annex 2.

Diese Studie liefert eine aktuelle und belastbare Datengrundlage für politische Entscheidungen — etwa zur Ausgestaltung von Strategien, zur gezielten Forschungsförderung und zur Weiterentwicklung des Gesundheitssystems —, mit dem Ziel, die Kostenbelastung durch Long COVID und ME/CFS wirksam zu reduzieren und die Versorgung sowie Lebensqualität der Menschen, die mit diesen Erkrankungen leben, nachhaltig zu verbessern.

Introduction

Chronic health conditions arising from infections are increasing in prevalence and impose significant, but largely unmeasured, costs. With SARS-CoV-2 becoming endemic and no effective treatments for post-acute infection syndromes, millions of people in Germany will be affected by conditions such as Long COVID and/or ME/CFS, leading to costs relating to reduced workforce participation, pressures on healthcare systems, and lower overall well-being. This report applies advanced disease burden modelling to estimate these costs, providing a foundation for informed policy making. Given the overlap in symptoms and economic impact of Long COVID and ME/CFS, improvements in addressing one condition will likely benefit the other.

Chronic health conditions caused by infections have long posed a hidden burden to human societies (Honigsbaum and Krishnan, 2020). The challenges arising from these so-called post-acute infection syndromes (PAIS) have only accelerated since the start of the COVID-19 pandemic (Choutka et al., 2022). A number of diverse sequelae of SARS-CoV-2, which continue beyond the acute stage of infection, commonly referred to as Long COVID, have been observed to occur in a considerable share of people infected with the virus (Parotto et al., 2023).

As SARS-CoV-2 becomes endemic in society, it continues to cause an estimated tens of millions of infections per year in Germany (Figure 1), although these are no longer correctly accounted for in official data (Paessler et al., 2025). Other authors corroborate the mismatch between likely infection rate and official data; for example, a paper by the Robert Koch Institute (RKI) demonstrated that in 2023/2024 the likely actual number of infections was 80-100 times higher than the RKI's official data (Loenenbach et al., 2024).

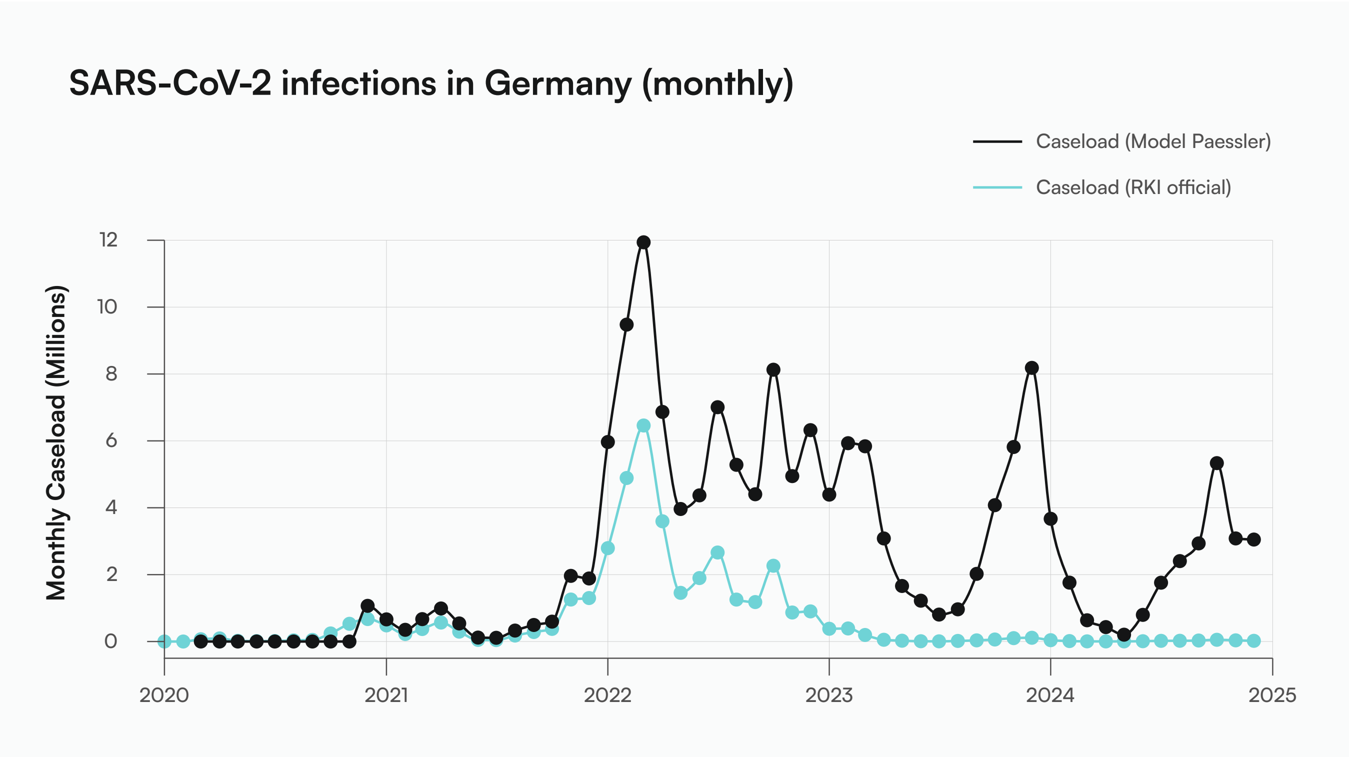

Figure 1: SARS-CoV-2 infection caseload in Germany, official data from RKI compared to corrected model data from Paessler et al. (2025). In 2023/2024 the actual number of infections was 80-100 times higher than the official data suggests.

In dynamic policy contexts where data is limited, as is the case with post-infection health conditions, sophisticated disease burden modelling has proven to provide a stable evidence base for effective decision-making, helping identify emergent high-burden diseases, allocate resources and target interventions (Jit and Cook, 2024). It is applied here to Long COVID and ME/CFS in Germany.

We model the costs of Long COVID as well as ME/CFS for two reasons. First, Long COVID and ME/CFS share many key symptoms and thus many of the same costs (Komaroff and Lipkin, 2023). Second, a subset of people living with Long COVID over time also present with symptoms typical of ME/CFS, so the COVID-19 pandemic will likely lead to an increase in the prevalence of ME/CFS (Sepúlveda and Westermeier, 2024). Improvements in responding to one condition will therefore likely lead to improvements in the other.

The complexity and severity of symptoms that characterise Long COVID and ME/CFS often profoundly impact the quality of life of people affected, as well as their ability to participate in daily life, including in paid work, caring for family and community activities. As a result, Long COVID and ME/CFS exert a notable negative impact on individuals, employers and society in terms of production disturbance, human capital, medical, administrative, welfare, travel, support and assistance costs, as well as costs and losses linked to reduced quality of life and well-being. These diverse factors are reflected in the final model underlying this report.

As the recovery rate from Long COVID is very low and no cure exists, the number of people living with Long COVID and/or ME/CFS will likely continue to grow, leading to increasing costs. The magnitude of these costs — the combined personal, employer, society and medical losses resulting from reduced value-add and increased expenditure around Long COVID and ME/CFS patients (hereafter “costs”) — is currently unknown.

In the main body of this report, we detail why this work was carried out, explain how the model was developed, and describe the costs calculated; in the discussion we then recommend some possible next steps. There are two Annexes; in Annex 1, we compare our results to other available findings, and in Annex 2, we provide further detail on the model, data sources, assumptions and limitations.

Our findings are intended to form the basis for shaping public policy, research funding, and health systems towards improving overall outcomes and reducing costs for people living with Long COVID and ME/CFS, communities, governments and society at large.

What is Long COVID?

Long COVID, a condition first recognised in May 2020, is characterised by persistent symptoms following acute SARS-CoV-2 infection which affect multiple body systems and significantly reduce quality of life. Symptoms such as fatigue, brain fog, and muscle pain can occur regardless of the severity of the initial infection. To date, no cure or widely-effective treatment exists, and recovery times remain uncertain. The definition of Long COVID continues to be debated; this report follows the German Federal Ministry of Health in understanding Long COVID as symptoms which persist beyond four weeks post-infection.

The COVID-19 pandemic, caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), spread worldwide in early 2020. With acute COVID-19 not limited to respiratory symptoms, early reports by patients weeks after symptom onset pointed to the persistence of post-acute symptoms in a subset of those infected. These symptoms were often independent of the degree of severity of the acute infection. Subsequently, the term Long COVID was first used by patients on social media in May 2020; the term was eventually adapted by medical researchers and practitioners (Callard and Perego, 2021), with an International Classification of Diseases (ICD) code for Long COVID surveillance introduced in October 2021 (Pfaff et al., 2023).

Long COVID implicates multiple body systems, ranging from the heart, lungs, and other organs to the gastrointestinal, immune, nervous, vascular and reproductive systems (Davis et al., 2023). Common symptoms of Long COVID include fatigue, shortness of breath, cognitive dysfunction/brain fog, post-exertional malaise (PEM), memory issues, and muscle pain/spasms (WHO, 2021); overall, affected individuals experience loss of ability to function and a considerable decrease in quality of life. Recent studies have provided important insights on the potential mechanisms underlying the various symptoms (Davis et al., 2023; Al-Aly et al., 2024). Research on identifying different disease subgroups and phenotypes, and uncovering corresponding biomarkers, is ongoing. Only a limited number of clinical trials has been initiated so far and there is no known cure to date (Peluso and Deeks, 2024; Vogel et al., 2024). Recovery from Long COVID remains under debate in terms of time and degree of recovery, with limited data available. What is available is summarised in Annex 2.

As a result of its relatively new status and patient-led journey into public health, the terminology around Long COVID remains inconsistent across time and place (e.g. Komaroff and Lipkin, 2023; AWMF 2024; Greenhalgh et al., 2024; Ely et al., 2024). This report adopts the framing promoted by the Federal Ministry of Health in Germany: "Long COVID is an umbrella term that encompasses all COVID-related symptoms which are present for longer than 4 weeks" (BMG, 2024, see Figure 2). It is important to note, however, that not all studies we cite use the same definition, and care has been taken to use secondary data with this diversity of definitions in mind.

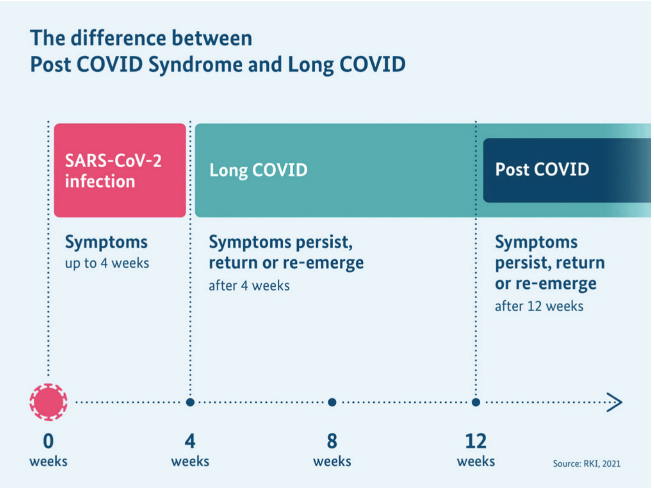

Figure 2: Long COVID and Post-COVID Syndrome according to the Federal Ministry of Health in Germany (BMG, 2024). Long COVID is described as health impairment following a SARS-CoV-2 infection which persists beyond the four-week acute phase of the disease.

What is ME/CFS?

ME/CFS (Myalgic Encephalomyelitis/Chronic Fatigue Syndrome) is a debilitating chronic health condition often triggered by infections. Key symptoms include post-exertional malaise (PEM), fatigue and pain, with diagnosis requiring symptom persistence for at least six months. Research remains limited for a range of reasons, and no effective treatment exists. The condition's terminology and diagnostic criteria vary internationally. This report follows the consensus statement for Germany, Austria, and Switzerland.

While worldwide outbreaks of what became known as Myalgic Encephalomyelitis (ME) were first documented in the medical literature in 1934, the term ME was only coined in the 1950s to describe a London-based outbreak of similarly debilitating symptoms (IOM, 2015). The World Health Organization first recognised the illness as a neurological condition in 1969 (WHO, 1969). Large illness outbreaks in the United States (US) in the mid-1980s led the US Centers for Disease Control (CDC) to convene a working group to reach consensus on the disease, and their investigations led them to the ME outbreaks documented earlier in the century. The working group recognised the illness they were studying was typically referred to as ME in most other parts of the world, but for a range of reasons chose the name chronic fatigue syndrome (CFS) (IOM, 2015). Following international consensus statements since that time, the term commonly used in Germany today is ME/CFS (Nacul et al., 2021; Hoffmann et al., 2024).

In terms of symptoms, ME/CFS is commonly characterised by PEM, fatigue, difficulty sleeping, pain, cognitive dysfunction/brain fog, and dysfunction of the autonomic nervous system. In addition, it often displays multiple other and severe symptoms. Diagnostic criteria define ME/CFS as the persistence of a set of specific symptoms for a period of at least six months (Hoffmann et al., 2024). Due to the condition's complexity and heterogeneity, as well relative underfunding, research on ME/CFS today is still mainly concerned with identifying the underlying disease mechanisms, with very limited evidence on potential treatments available to date (Toogood et al., 2021; Gandjour, 2024).

The name ME/CFS, its definition and diagnostic criteria continue to be debated. This report follows the D-A-CH (Germany, Austria and Switzerland) consensus statement on ME/CFS, as well as the German S3-Guideline on Fatigue/Tiredness and S1-Guideline on Long/Post-COVID, which define ME/CFS largely according to the Canadian Consensus Criteria (CCC) (Hoffmann et al., 2024; AWMF, 2022; AMWF, 2024). For the diagnosis of ME/CFS according to the CCC, all five primary criteria must be fulfilled (PEM, pathological fatigue with limitations of everyday functioning, sleep disorders, pains, neurological/cognitive manifestations), plus two of the three secondary criteria (manifestations of the autonomic nervous system, neuroendocrine manifestations, immunological manifestations), and there must be an illness duration of at least 6 months in adults and 3 months in children and adolescents. Again, however, not all studies cited in this report adopt the same definition, and care has been taken to use secondary data with this in mind.

Why address Long COVID and ME/CFS together?

This study models the cost of Long COVID and ME/CFS separately, as well as cases where diagnostic criteria are met for both conditions. The two illnesses share key symptoms and possibly have similar underlying biological causes, including immune system dysfunction triggered by viral infection. Since the onset of the COVID-19 pandemic, ME/CFS cases in Germany have increased significantly, further implying a link between Long COVID and the rise in ME/CFS diagnoses. A subset of Long COVID patients eventually fulfills diagnostic criteria for ME/CFS. Given their overlapping symptoms, potential causes, and societal impact, it makes sense to analyse the cost burden for both in order to inform resource allocation and policy responses.

The model developed here covers Long COVID and ME/CFS separately, as well as the sub-group of people who fulfil diagnostic criteria for both conditions at the same time. It addresses them together for two reasons. First, the two conditions share many key symptoms, potentially indicating shared disease mechanisms (Komaroff and Lipkin, 2023). While the biological causes of ME/CFS continue to be investigated, evidence available to date points to viral infections and an ensuing dysfunctional immune response, leading to neurological, vascular, and metabolic changes, as the leading cause of disease onset. Similar mechanisms have also been identified as probable drivers of Long COVID pathophysiology (Annesley et al., 2024). In both cases, overall degree of disability, as well as recovery rates, remain contested. That so many unknowns remain is at least partly an outcome of lack of research attention (particularly in the case of ME/CFS), and partly a result of the relative novelty of Long COVID.

Second, a subgroup of people living with Long COVID presents with symptoms typical of ME/CFS (Wong and Weitzer, 2021). Indeed, medically-reported ME/CFS cases in Germany have increased since the onset of the pandemic (Kassenärztliche Bundesvereinigung (KBV) [National Association of Statutory Health Insurance Physicians], personal communication, 10 December 2024). It is plausible to assume that the COVID-19 pandemic will continue to lead to an increase in the prevalence of ME/CFS, as a notable share of Long COVID cases (13% to 40%, according to IQWiG, 2023) go on to meet the diagnostic criteria for ME/CFS over a time period of several months. According to the KBV, 620,000 people were treated for ME/CFS in Germany in 2023 (personal communication, 10 December 2024). This significant increase, up from 400,000 people in 2019 (KBV, personal communication, 10 December 2024; see Figure 4), broadly aligns with other publications that have projected an increase in ME/CFS cases as a direct result of COVID-19 (Hoffmann et al., 2024; Komaroff and Bateman, 2021).

Importantly for our model, their shared symptom profile, similar driving mechanisms and epidemiological links mean both Long COVID and ME/CFS have comparable cost profiles. It makes sense, therefore, to aggregate data on the cost for both diseases on the basis of their shared features.

Why use a modelling approach to estimate costs?

As SARS-CoV-2 becomes endemic, cases of Long COVID and ME/CFS are expected to rise due to the ongoing spread of SARS-CoV-2 infections. ME/CFS cases unrelated to COVID-19 will also likely continue to increase. Both conditions are already straining the healthcare sector, labor markets, and welfare systems in unprecedented and unpredictable ways, making it crucial to anticipate future caseloads and costs. Germany lacks sufficient direct surveillance data for this purpose, and while several government-funded research projects are underway, they will not yield results for some years. This report fills the current evidence gap with a dynamic simulation model that incorporates the latest data on infections, immunity, and costs. Compared to previous cost estimates, this model offers a more comprehensive and up-to-date analysis to better guide health policy and resource planning.

With SARS-CoV-2 becoming endemic, the number of people living with Long COVID and/or COVID-19-related ME/CFS is expected to grow due to repeated reinfections of the population (Otto et al., 2024). The number of ME/CFS cases unrelated to SARS-CoV-2 infection is also expected to grow as more people are diagnosed each year than recover (Mirin et al., 2022).

In a context where both diseases are already putting pressure on communities, labour markets, welfare systems, and the medical sector, it is timely to better anticipate caseloads and costs in order to inform research, policy, funding decision-making, and health system planning. However, Germany lacks adequate direct surveillance data to securely guide policy making (Germany is not alone here, see Angeles et al. (2024) for a discussion of the Australian context).

Several publicly-funded research projects have been initiated to address the current evidence gap in Germany. These include the BD-LC-PS project funded by the Federal Joint Committee (G-BA, 2024), the MultiCARE and HELoCO projects funded by the Federal Ministry of Health (BMG, 2025a; BMG, 2025b), and the Post-COVID Data Model under the newly established data institute of the Federal Ministry of the Interior and Community (BMI, 2024). However, preliminary data and/or results from these projects are not anticipated for several years at the earliest. Hence the simulation model developed in the present report fills this evidence void in the interim.

One study has previously attempted to estimate the costs of Long COVID in Germany. In it, the "costs of long/post-COVID-19 syndrome with new onset in 2021" were calculated at €10.8 billion (Gandjour, 2023). This is an important starting point, although the model only considers costs of people with new onset in 2021 and does not take into account accumulation of cases or effects of vaccination and immunity through prior infection. Much has changed since 2021; in particular, new research has provided improved insights on the incidence, surveillance, costs and outcomes of Long COVID and, importantly, also of ME/CFS.

In terms of ME/CFS, at least one study has previously estimated the cost to health services and society of ME/CFS in Europe to be some €40 billion per year (Pheby et al., 2020). However, the study notes that there are no economic analyses on the costs of the disease in Europe, and their estimate is an imprecise calculation based on data from the United Kingdom (UK). Underdiagnosis is likely to add to this imprecision.

In the model developed here, the latest available data on SARS-CoV-2 infections and immunisations is used to simulate the overall incidence and prevalence of both conditions until the end of 2024; the simulation is dynamic, its assumptions collaboratively developed, and a wide range of costs, including personal loss, employer loss, medical loss and society loss are considered. To the authors' knowledge, the present model therefore provides the most up-to-date and comprehensive cost estimate for Long COVID and ME/CFS in Germany.

Approach

At its core, this study uses a Monte Carlo simulation to model the health and economic impact of Long COVID and ME/CFS in Germany from 2020 until the end of 2024. This method, widely used in government and industry, accounts for real-world variability and uncertainty regarding reinfections, vaccination status, and demographics. The model tracks individual disease progression from acute COVID-19 to Long COVID and ME/CFS as well as recovery from disease at each stage of the caseload flow. It then calculates costs based on established economic metrics which are routinely used to assess the impact of other types of crises and disasters. The model integrates both available findings from existing literature, and informed assumptions arising from cross-disciplinary debate to address data limitations. Hence it provides a robust and plausible tool for policy planning and decision-making.

Modelling approach

In the simulation, the methodology and assumptions which are detailed briefly here and further in Annex 2, each person living in Germany (around 84 million people in 2024) is individually modelled as they go through the five years from 2020 to 2024. The progression of infection(s), the eventual post-acute infection sequelae and disability impact are calculated for each person for each day, resulting in a numerical severity index value for illness, healthcare cost and lack of participation in everyday life, consumption, and value generation. By multiplying this severity index with average cost and average productivity metrics, the economic burden is calculated for each person and each day, after which the corresponding values are summed together.

The Long COVID and ME/CFS simulation model developed here is based on a Monte Carlo framework. Monte Carlo simulation traces its origins to the 1930s when Enrico Fermi used random sampling techniques to study neutron diffusion in nuclear physics. However, his approach remained informal and largely unrecognised (Metropolis, 1987). It was during the 1940s that Stanislaw Ulam, John von Neumann, and Nicholas Metropolis formalised the method as a computational technique to solve complex nuclear reaction problems (Metropolis and Ulam, 1949). Named after the Monte Carlo Casino in Monaco due to its reliance on randomness and probability, it is today widely used across industry, governments (including by the German Federal Ministry of Health) and multilateral organisations to predict possible outcomes of an uncertain event (see e.g. Lopez et al., 2006; IQWiG, 2023).

In our work, the Monte Carlo method allows for the simulation of disease progression and cost estimation under varying conditions such as reinfections, vaccination status, and age group distributions. Instead of relying on fixed values, the approach applied here utilises probability distributions at multiple calculation steps to reflect real-world variability. One key example of the model's stochastic nature is how the duration of Long COVID symptoms is handled. For the first 365 days, the model applies a lognormal distribution to simulate the progression of symptoms, ensuring that most Long COVID cases peak between 80 and 100 days, while some persist much longer. Additionally, for cases that last beyond a year, the model uses a Weibull distribution, which gradually decreases the probability of recovery over time rather than imposing a fixed recovery threshold. This approach allows for the realistic representation of long-tail effects where some individuals may experience symptoms for many years, mirroring recent findings from literature based on real-world observations.

Additionally, by incorporating dynamic probability adjustments, the model accounts for real-world uncertainties, such as the long-term impact of reinfections, which are still being studied in ongoing research. This ensures that outcomes are not static but instead fluctuate based on a range of plausible values, making the model more robust in capturing the uncertainty surrounding Long COVID and ME/CFS.

The model relies on several key assumptions to estimate Long COVID and ME/CFS progression, recovery rates, and economic impact. These assumptions are grounded in established epidemiological research and economic analysis. Informed estimates were used where sufficient long-term data was lacking. The main assumptions that guide the model's calculations are:

- Demographic and population factors (baseline cases, caseload, age distribution),
- Disease progression and probabilities (Long COVID onset probability by variant, vaccination, and reinfection risk; share of ME/CFS in the Long COVID patient pool), and
- Recovery rates from Long COVID and ME/CFS.

Extensive research in published science formed the basis for our assumptions, especially concerning caseload, infection risks and disease progression, as well as monetary metrics.

In the end, the model was run in four permutations using two different age group scenarios and two different severity scenarios. The model result we report took the averages of outcomes across these four permutations.

Limitations

There are three main types of limitation in this study. They were all discussed in detail in online meetings throughout the modelling process.

The first relates to lack of data. This includes infection surveillance (including, but not limited to, cases of COVID-19 overall, Long COVID and ME/CFS incidence and prevalence, fluctuation of non-COVID-19-related ME/CFS cases during the various stages of the pandemic and related public health measures, data on recovery rates for both Long COVID and ME/CFS), as well as lack of long-term data due to the relative newness of Long COVID. This means there is insufficient longitudinal data to understand completely the effects of vaccination, infection-derived immunity, different virus strains, geographical location, or other factors on disease progression and resolution. Where necessary, assumptions were made in the model about these based on the best available secondary data; if anything, our conservative approach to making assumptions in lieu of data means the model is more likely to underestimate costs rather than overestimate them.

The second relates to biased data. Where the model draws on secondary data, such as employer and health insurer data, a number of biases might be present. How consistently is data being collected across the country? How consistently do medical practitioners apply diagnostic codes, and what are the implications for health insurer data of any inconsistency? As disease classifiers have changed over time, how has this been reflected in the model? Do stigma, wealth, and/or social welfare parameters encourage and/or discourage people from seeking diagnosis? Does disease progression make it impossible for patients to seek or attend treatment or consultation, effectively hiding them from data collection? Such questions were debated by the research team, and where necessary assumptions in the model were adjusted. In other cases, the question was not relevant, or impossible to answer. Overall, this limitation is one of the reasons the group opted to report the average cost estimation of the four permutations calculated, rather than any one single permutation.

The third relates to the modelling method. Monte Carlo simulations can be computationally intensive and require significant expertise to carry out; as a result, they cannot easily be re-run, explained for non-specialists to understand, or replicated by all reviewers for complete verification. It is hoped that the details provided in Annex 2 and on GitHub address this limitation somewhat. That the model's various findings broadly align with research published by others lends further weight to its reliability.

Results

The number of active Long COVID cases in Germany has stabilised, with Long COVID cases peaking in 2022 at 1.75 million and then receding to around 870,000 at the end of 2024. Meanwhile, the number of ME/CFS cases has continued to rise, surpassing 650,000 at the end of 2024. Together, ME/CFS and Long COVID have cost the German economy €254.4 billion since the COVID-19 pandemic began. In 2024 alone, Germany faced €63 billion in costs from Long COVID and ME/CFS — equivalent to nearly 1.5% of its annual Gross Domestic Product (GDP). The ME/CFS caseload will likely continue to increase, mostly driven by a continued progression from the pool of Long COVID cases to ME/CFS cases and low recovery rates. Long COVID cases may also increase over time under the current scenario of repeat SARS-CoV-2 infections.

Estimated caseloads and trends

In lieu of surveillance data and reporting, active COVID-19 cases per day and the resulting disease burden are calculated using the model for each calendar day of 2020-2024 (as described in Annex 2). Active Long COVID cases peaked at just over 1.75 million in 2022, reducing to a steadier number of around 800,000 thereafter (Figure 3). Over the same time period, ME/CFS prevalence rose to over 600,000 active cases. The fluctuations in case numbers are characterised by the number of infections within waves of different variants, vaccinations and reinfections as well as recovery rates.

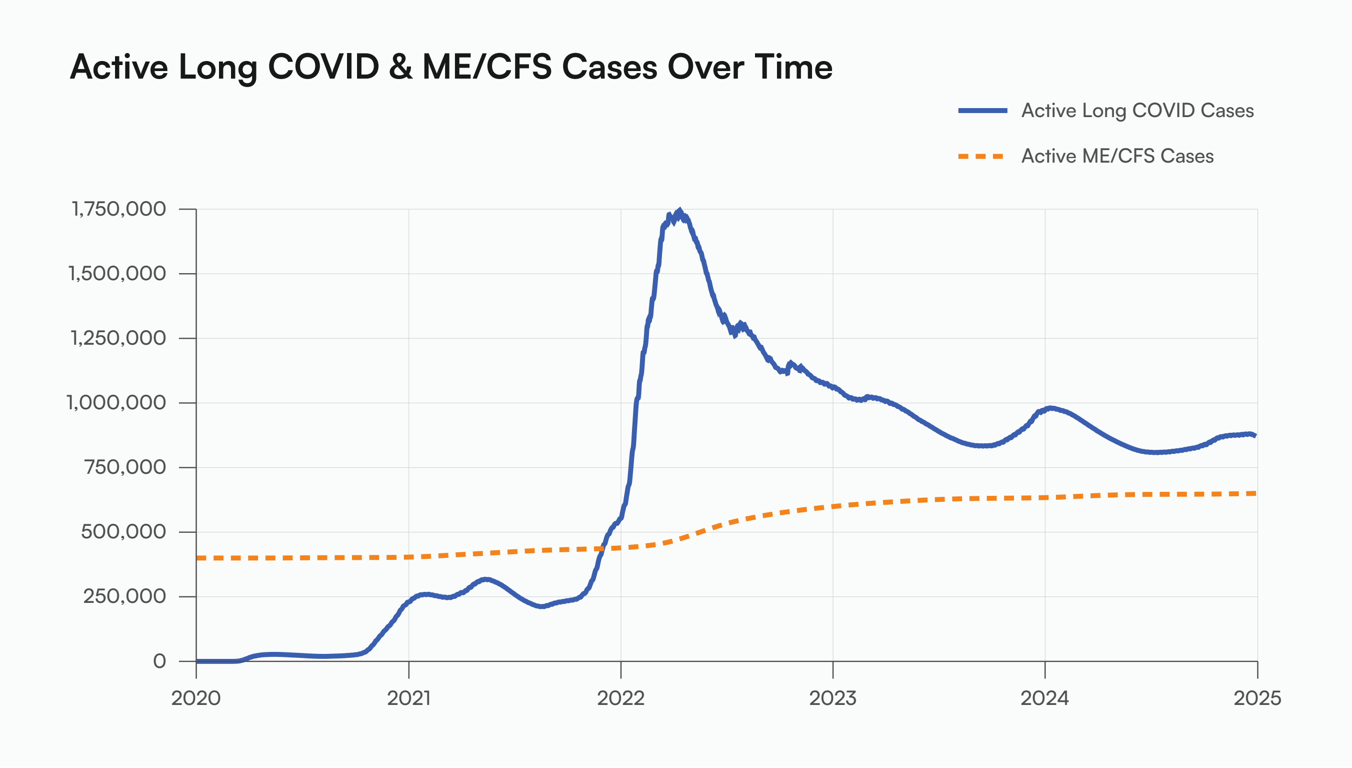

Figure 3: Active Long COVID cases per day and active ME/CFS cases per day in Germany (average of four models), 2020-2024. The number of ME/CFS cases increased during the pandemic, while Long COVID cases peaked in 2022, before reducing to a more stable level as SARS-CoV-2 became endemic in the population.

The figures calculated broadly align with documented numbers of reported cases of people treated for ME/CFS (based on the International Statistical Classification (ICD) code G93.3) by the KBV (shown in Figure 4). This adds confidence to other findings in our model; however, variation in data collection methods, clinical case definitions and diagnostic criteria applied means some differences exist. For example, in 2021, the KBV published higher numbers than our model returned.

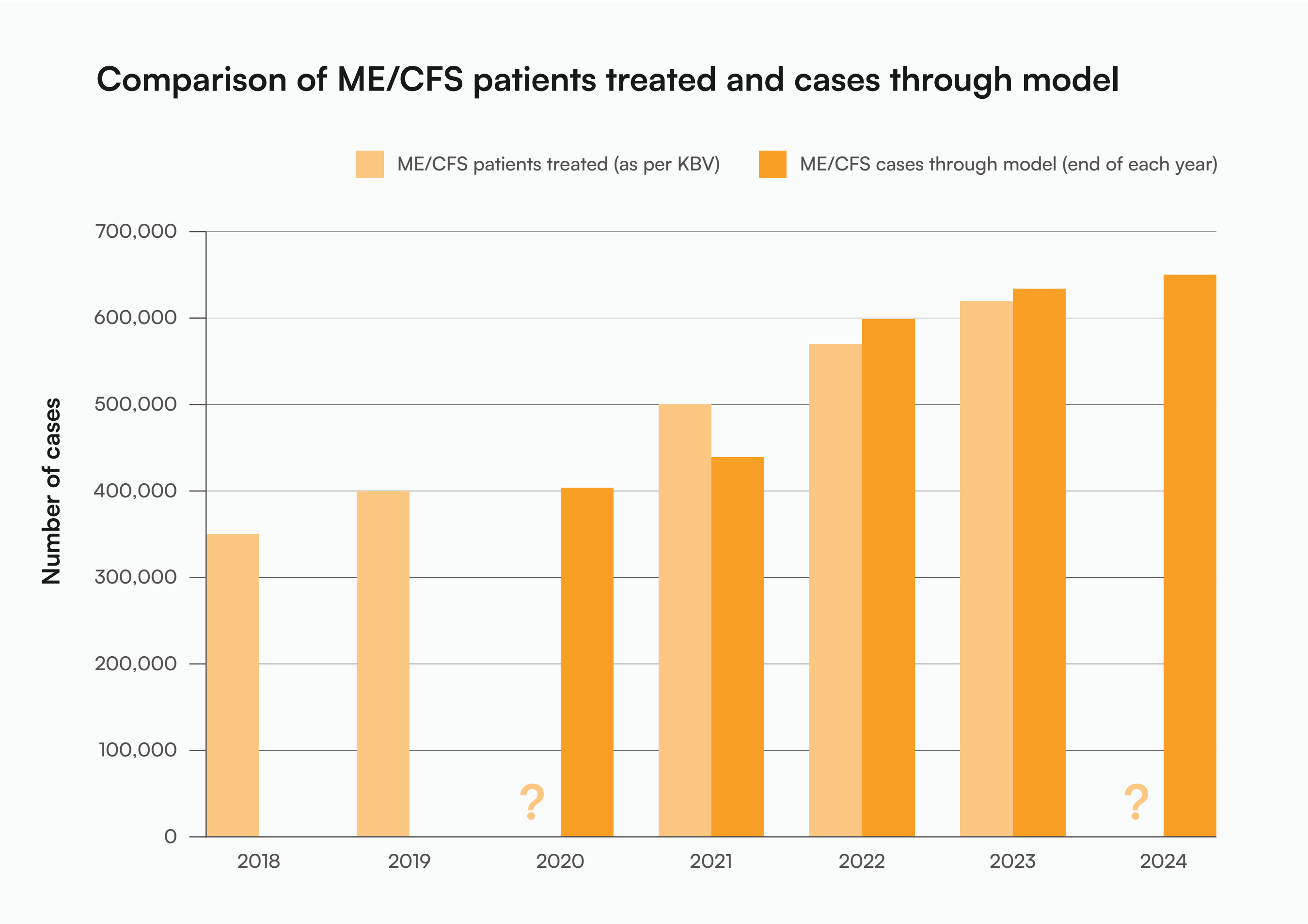

Figure 4: Comparison of number of ME/CFS cases calculated through the model (cases estimated at the end of each year) with number of patients treated ("Behandlungsfälle," as reported by KBV). Source: KBV (personal communication, 10 December 2024). Data for 2018, 2019 and 2021 are also published in KBV (2023); data for 2022 and 2023 are also published in Rücker (2024). KBV did not provide any data for 2020 and 2024.

Estimated costs of Long COVID and ME/CFS

Long COVID peaked in terms of cases and costs in 2022, and continues to incur significant costs in Germany, which it can be projected to do for some time to come. The costs of ME/CFS increased over time, with more new-onset cases developing due to COVID-19 than resolving over time. Figure 5 shows the model output of the monthly costs of Long COVID (blue) and ME/CFS (orange) for each month since the beginning of 2020.

Since the start of the COVID-19 pandemic until the end of 2024, the total national cost (personal, employer, medical and society losses) of Long COVID and ME/CFS is estimated at €254 billion (see Table 1). According to our modelling, Long COVID and ME/CFS combined cost Germany €63 billion in the year 2024 (see Figure 6). For context, total health expenditure in Germany in 2024 was €538 billion (Destatis, 2025a), accounting for 12.4% of the 2024 GDP (Eurostat, 2025).

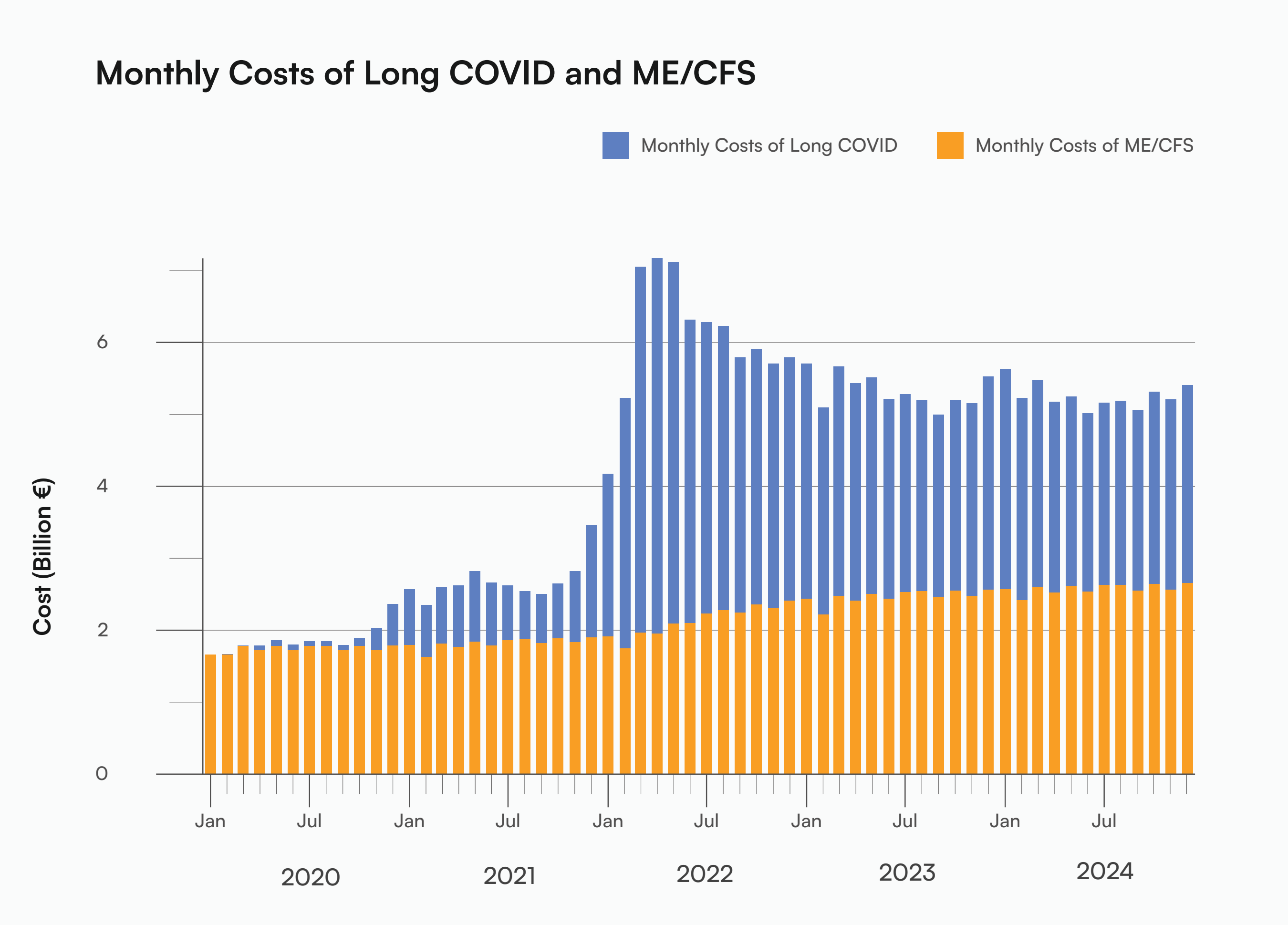

Figure 5: Monthly costs of Long COVID and ME/CFS in Germany (average of four models), 2020-2024 (in billions of Euros).

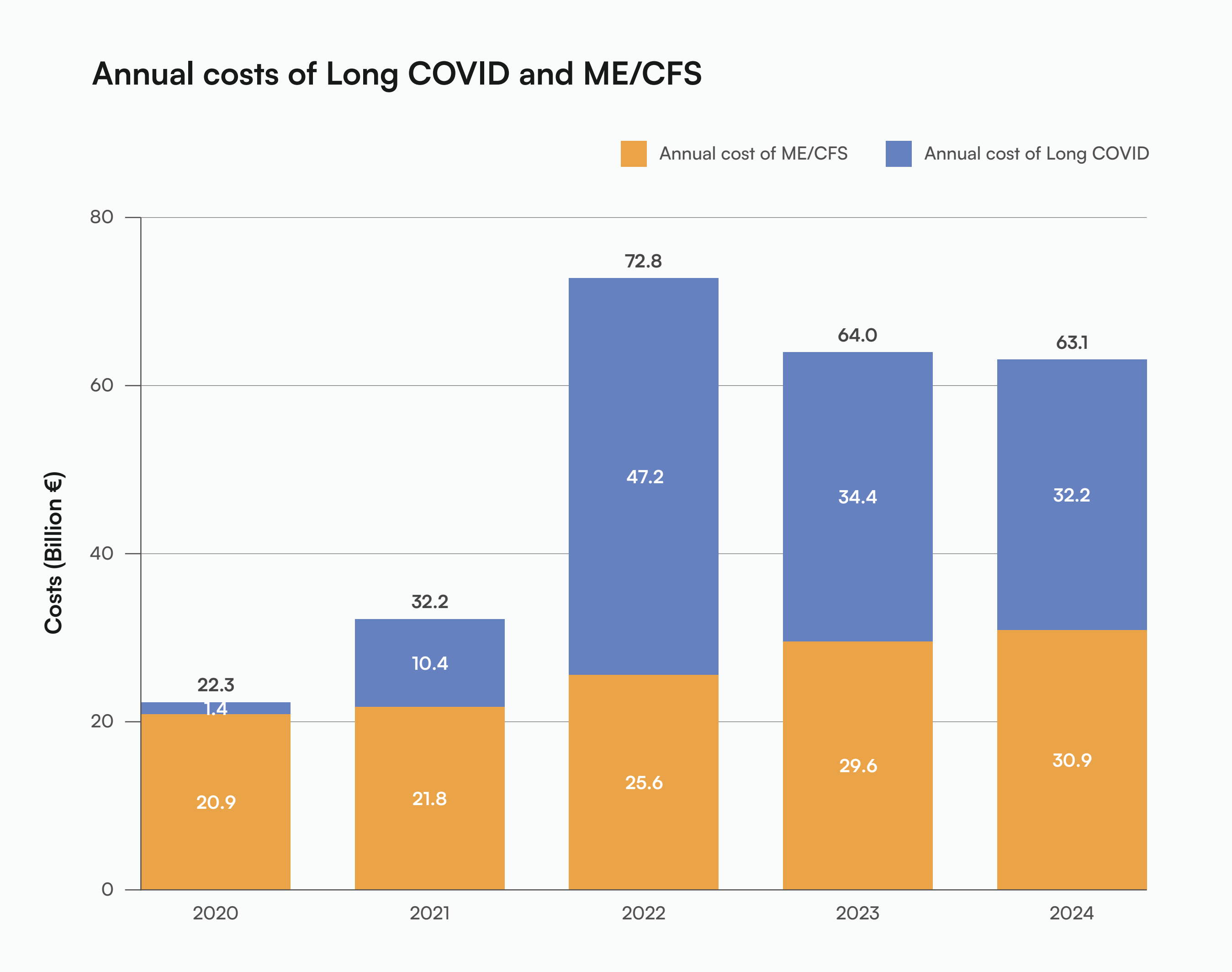

Figure 6: Annual costs of Long COVID and ME/CFS in Germany (average of four models), 2020-2024 (in billions of Euros). Corresponding numbers of Long COVID and ME/CFS cases at year end are shown in Table 1.

Table 1: Cases and costs of Long COVID and ME/CFS in Germany, 2020—2024. Average of the four variations of the model developed in this paper (see Annex 2 for details).

Year	Long COVID			ME/CFS			Long COVID & ME/CFS
	New cases	Cases at year end	Cost (€ billion)	New cases	Cases at year end	Cost (€ billion)	Combined cost (€ billion)
2020	272,829	227,560	1.4	3,481	403,432	20.9	22.3
2021	805,773	547,306	10.4	36,593	438,896	21.8	32.2
2022	2,743,384	1,064,373	47.2	165,849	598,620	25.6	72.8
2023	527,594	970,917	34.4	46,168	635,838	29.6	64.0
2024	282,381	871,086	32.2	28,792	650,183	30.9	63.1
Total			**125.6**			**128.8**	**254.4**

Costs mapped against GDP

The yearly costs of Long COVID and ME/CFS as a percentage of Germany's GDP (2020—2024) illustrate their significant economic impact (see Figure 7). Long COVID costs were highest in 2022, due to widespread infections and high case numbers caused by the emergence of the more-transmissible COVID-19 Omicron variant. This was followed by a slight decline as the number of infections stabilised; however, the annual cost of Long COVID in 2023 and 2024 was still in the order of 0.75% of GDP or above.

ME/CFS costs have remained persistently high because of long-term disability and substantially lower recovery rates compared to Long COVID. As a result, these costs have continued to grow over time nearly proportionately with GDP growth due to increasing case numbers. As of 2024, the cost of ME/CFS to the German economy was in the order of 0.7% of GDP.

Together, Long COVID and ME/CFS consume a sizable share of Germany's annual GDP — almost 1.5% — affecting economic productivity (due to reduced workforce participation and productivity losses), healthcare spending (increased demand for diagnostics, long-term care, rehabilitation and disability support), and other parts of the economy (where societal impacts are more far-reaching than workforce participation, such as unpaid care work, reduced expenditure on tourism and entertainment, community participation, insurance markets and more).

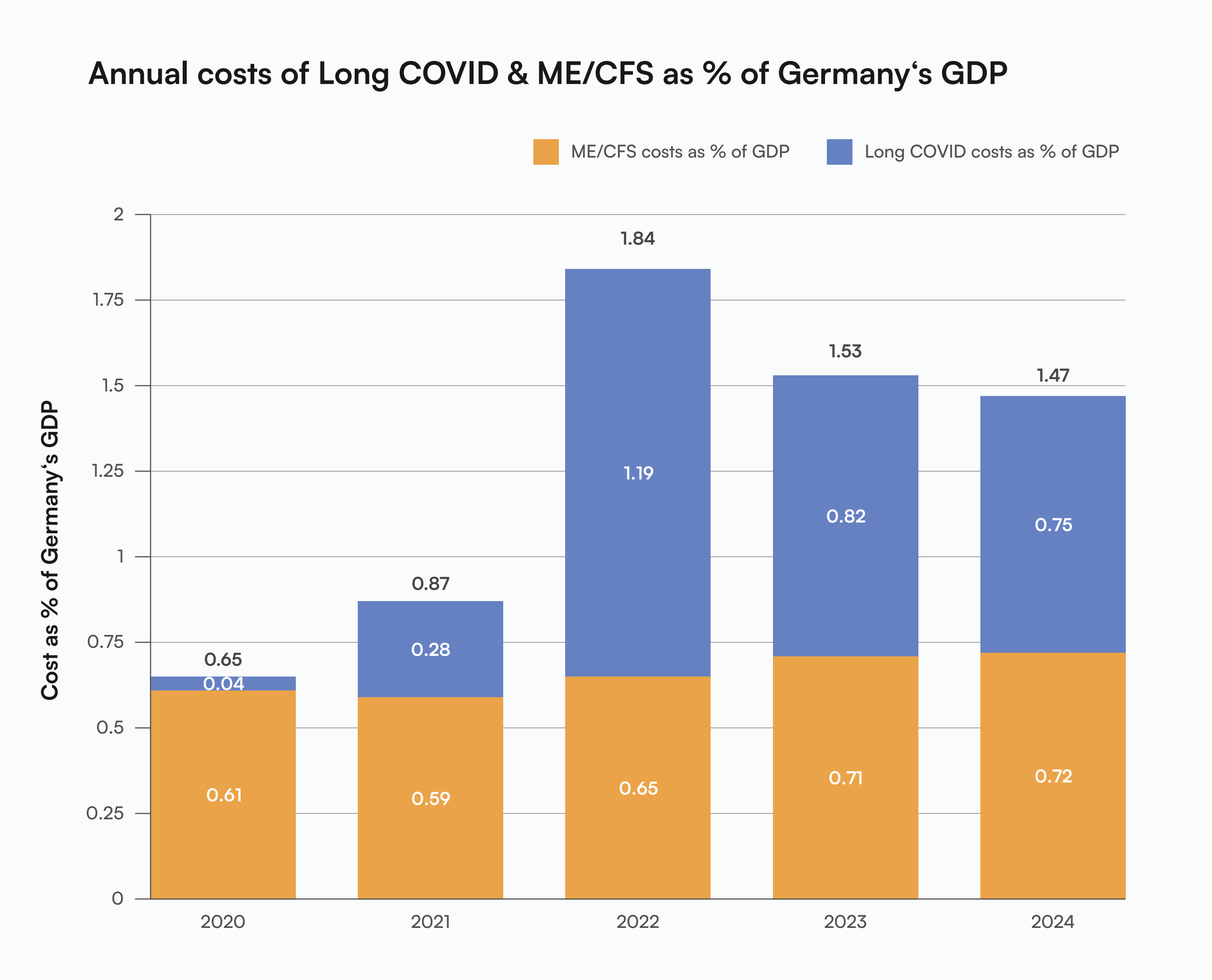

Figure 7: Model-based costs of Long COVID and ME/CFS per year for 2020-2024. Costs are mapped against annual GDP of Germany (Eurostat, 2025).

Model plausibility check and comparison

To ensure the robustness of our findings, we conducted a plausibility check by comparing our model's cost estimates for Long COVID and ME/CFS with existing economic evaluations. Various available costing studies were collected and analysed, allowing us to assess the consistency of our results and refine key assumptions where necessary. This benchmarking process not only enhances the credibility of our estimates but also helps identify potential methodological differences and gaps in current research.

When comparing related studies, it is important to note that they do not all consider the same set of costs. While our model takes a holistic approach by considering personal loss, employer loss and society loss (also capturing medical costs therein) other publications may only look at a subset of these (e.g. cost of lost work hours).

With this in mind, we found that our model results align with broader economic assessments of Long COVID and ME/CFS. For Long COVID (Table 2 in Annex 1), global estimates suggest that Long COVID incurs an economic burden of approximately US$1 trillion annually, equating to around 1% of global GDP (Al-Aly et al., 2024). In comparison, our model results indicate that Long COVID had the greatest economic impact in 2022, accounting for 1.2% of Germany's GDP that year (see Figure 7). Specifically for Germany, Gandjour (2023) finds the cost of Long COVID cases with new onset in 2021 to be €10.8 billion, which is close to our 2021 data point of €10.4 billion. Both studies look at very similar cost structures. Kielstra (2024) reports the 2024 cost of Long COVID at 0.5-0.6% of GDP for several European countries (France, Spain, UK), while only looking at the cost of lost work hours. Our more holistic estimate of 0.75% of GDP for Germany in 2024 is compatible with this.

Looking at ME/CFS (Table 3 in Annex 1), European annual cost estimates in previous studies and reports are often based on extrapolations of existing studies. Pheby et al. (2020) estimate that the annual burden of ME/CFS in Europe could be in the region of €40 billion. They based this estimate on a UK study by McCrone et al. (2003), who calculated the total cost of care services (health care and informal care) and lost employment/productivity per ME/CFS patient over a three-month-period. The German and Swiss Societies for ME/CFS again used the estimate by Pheby et al. (2020) to calculate the national annual economic cost of ME/CFS for Germany (€7.4 billion, see Deutsche Gesellschaft für ME/CFS, 2020) and Switzerland (CHF3 billon, Schweizerische Gesellschaft für ME & CFS, 2023). In general, literature on the clinical and economic burden of ME/CFS predominantly features studies from Australia, the US, and the UK (see Table 3 in Annex 1). A recent Australian study which covers various direct and indirect costs puts the total annual costs of ME/CFS between A$1.38 and A$10.09 billion (between 0.06 and 0.45% of GDP) (Zhao et al., 2023). In a study regarding the US, Mirin et al. (2022) estimated the annual economic burden due to ME/CFS to be US$149 to $362 billion.

By grounding our analysis within existing economic evaluations (Annex 1), we ensure that our approach is sound. That our model broadly reflects others' results gives further confidence to its findings, although this does not confirm causality or rule out the possibility of shared assumptions or errors between models. Where these exist, they may become apparent over time, through improved data collection, surveillance and research.

Discussion

The rising burden of Long COVID and ME/CFS is reshaping how post-infection chronic diseases are perceived in Germany. While German state and federal governments have taken steps to raise awareness and fund research, investment remains disproportionately low. The burden calculated in our model — that between 2020 and 2024, Long COVID and ME/CFS cost Germany more than €250 billion — points to a need for much greater attention and investment. The model points towards some areas where significant gains might be made: first, improving our baseline understanding of Long COVID and ME/CFS; second, lowering the overall infection rate; and third, reducing severity and increasing recovery rates.

Costs are likely to increase

The recent emergence of Long COVID, along with the rising profile of chronic diseases more broadly, is driving a shift in how chronic post-infection illnesses are perceived and treated in Germany. This issue will not naturally attenuate. COVID-19 is now endemic, with continued high rates of infections. Based on our model data, we can estimate that the number of active ME/CFS cases will likely rise by a total of around 34,000 in the period of 2025-2028, based on the SARS-CoV-2 infections and Long COVID cases that have already taken place. This number is already locked in at this point in time, even without accounting for potential future waves of SARS-CoV-2 infections, unless cures or effective treatments become available in the meantime.

Investments remain disproportionately low

German state and federal governments have recently been proactive in raising awareness and improving the overall care situation for people living with Long COVID and ME/CFS, as well as providing funding for basic, clinical and epidemiological research (see e.g. BMG, 2025c; BMBF, 2024; Deutscher Bundestag, 2022).

That said, general efforts and levels of funding allocated to advance and improve the research, care and treatment of ME/CFS historically, and both ME/CFS and Long COVID to the present day, remain disproportionately low compared with similarly burdensome diseases (Froehlich et al., 2021). This can be attributed to a range of factors, a lack of sound evidence upon which to base funding decisions being one of them (Sepúlveda and Westermeier, 2024; The Lancet Infectious Diseases, 2023). The model presented here contributes to a growing evidence base in this space.

Greater attention and investment is needed

The cost of Long COVID and ME/CFS calculated in this model — an estimated €254 billion until the end of 2024 (an average of €51 billion per year) and growing — makes a strong case for a strategic and coordinated approach to improving outcomes relating to Long COVID and ME/CFS, through a range of measures. The model developed for this report cannot predict with certainty the best strategies to reduce costs, although future iterations of the model could potentially be used to simulate the relative cost implications of different interventions. However, the model can point towards areas where most significant gains might be made. In particular, (1) improving our baseline understanding of Long COVID and ME/CFS, (2) lowering the overall infection rate (e.g. through public health measures and vaccinations) and (3) reducing severity and increasing recovery rates (e.g. by improving treatment and/or developing cure) are important areas to target.

First, improving the general understanding of the significance of Long COVID and ME/CFS matters. In developing our model, lack of surveillance, inconsistent diagnostic practices underpinned by multiple systems of classification, and patchy knowledge amongst medical practitioners, employers and the public, stood out as barriers to improving baseline data about the two diseases. These factors also contribute to poor health, social, and economic outcomes in a variety of ways, including via stigmatisation and chronic stress. Improved surveillance, including through research projects already underway, will help, and more can be done in terms of improving education and knowledge about these conditions in a wide range of settings. In order to improve our knowledge of these conditions, there is also a clear need to invest in biomedical research proportionate to the calculated disease burden. This is discussed further below.

Second, in terms of lowering the overall infection rate, public health interventions, strategies, technologies and policies have the potential to reduce future costs, alongside vaccinations. In this context, given that it is well-established that SARS-CoV-2 is primarily transmitted by airborne route (Greenhalgh et al., 2021; Hyde et al., 2021; Morawska et al., 2024), improving air quality in public buildings by enforcing existing regulations in Germany (Arbeitsstättenverordnung ArbStättV) as well as in health, education, school and childcare settings, should be considered.

Third, reducing severity and increasing recovery rates may be achieved through a combination of targeted biomedical research and improved health systems infrastructure. Resourcing basic, clinical, and translational research to identify underlying disease mechanisms, uncover biomarkers, build diagnostic capabilities and develop effective treatments, including novel drugs, could significantly reduce the costs of these conditions and improve quality of life for the hundreds of thousands of patients in Germany (and millions of people globally). This aligns with recommendations made elsewhere: Gandjour (2024), for example, has estimated that an optimal national investment in Germany into research and development of €676 million has the potential to generate €2.6 billion in savings, should a curative treatment for ME/CFS be successfully developed as a result.

In terms of health systems infrastructure, at present, inconsistent access to expert medical care and treatment facilities appear to drive up costs as patients have to consult multiple practitioners in multiple places over many months or years. Patients who remain symptomatic after the initial 12 months of their illness often remain sick for years due to a lack of available treatments and inconsistent access to health experts, with poor outcomes exacerbated over time by diagnostic delays or errors, associated stigma, and the cumulative detrimental health effects of the conditions themselves. Thus, investments relating to developing improved diagnostics, as well as the overall provision of specialised medical care nationwide, might also be strong levers to reduce the very significant burden calculated here.

Crucially, the literature reviewed in developing this model also points to the need for research funding that incentivises working across multiple domains of expertise, and in collaboration with patients, who have both lived experience of these diseases and often accumulated expertise from months and years managing their own conditions.

Overall, this is far from a comprehensive list of possibilities. The cost figures calculated and reported here are instead intended to inform wide-ranging discussions about how best to shape public policy, funding, research, and health systems to improve overall outcomes and reduce costs for people living with Long COVID and ME/CFS, communities, governments and society at large.

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Annex 1: Comparison with other publications

Table 2: Comparison between Long COVID cost estimates from our model and previous research. If the referenced publication did not report the cost as a percentage of GDP of the relevant country, we have calculated it for this table using World Bank GDP estimates.

Source	Country	Year	Costs included	Cost estimate	As % of GDP
Own model findings	Germany	2020	Personal loss, employer loss, society loss	€ 1.4 billion	0.04%
Own model findings	Germany	2021	Personal loss, employer loss, society loss	€ 10.4 billion	0.28%
Own model findings	Germany	2022	Personal loss, employer loss, society loss	€ 47.2 billion	1.19%
Own model findings	Germany	2023	Personal loss, employer loss, society loss	€ 34.4 billion	0.82%
Own model findings	Germany	2024	Personal loss, employer loss, society loss	€ 32.2 billion	0.75%
Gandjour, 2023	Germany	2021	Production loss, gross value-added loss, financial burden on the health care and pension systems	€ 10.8 billion	0.29%
Constantino et al., 2024	Australia	2022	GDP loss caused by the projected decline in labour supply and reduced use of other production factors	AUD$ 9.6 billion	0.5%
Angeles et al., 2024	Australia	2022	proxy cost estimates from people living with ME/CFS including direct health care costs (including out-of-pocket costs (OOP)), lost work and productivity costs, and informal carer costs	AUD$ 1.7 - 6.3 billion	0.07-0.26%
Kwon et al., 2023	UK	2023	Productivity loss since the incident infection, informal caregiving costs	GBP£ 6 billion[1]	0.22%
Bartsch et al., 2025	US	2024	Societal costs, productivity losses, third-party payer costs	US$ 4 billion[2]	0.01%
Kielstra, 2024	France	2024	GDP cost of the lost work hours	US$ 21 billion	0.6%
Kielstra, 2024	Spain	2024	GDP cost of the lost work hours	US$ 7.8 billion US$	0.5%
Kielstra, 2024	UK	2024	GDP cost of the lost work hours	US$ 15.5 billion	0.5%
Kielstra, 2024	US	2024	GDP cost of the lost work hours	US$ 152.6 billion	0.5%
Kielstra, 2024	Brazil	2024	GDP cost of the lost work hours	US$ 11 billion	0.5%
Kielstra, 2024	Japan	2024	GDP cost of the lost work hours	US$ 72.2 billion	1.6%
Kielstra, 2024	Saudi Arabia	2024	GDP cost of the lost work hours	US$ 24.4 billion	2.3%
Kielstra, 2024	Taiwan	2024	GDP cost of the lost work hours	US$ 12.2 billion	1.5%
Cutler, 2022	US	2020 - 2022[3]	Reduced quality of life based on the reduction in quality adjusted years of life (QALY), reduced earnings, increased medical spending	US$ 734.8 billion[4]	3.4% (2019 GDP)
Bach, 2022	US	2022	Lost wages	US$ 168 billion	~1%
Alexandri et al., 2024	UK	2030	GDP loss, household income loss, Long COVID health expenditure	GBP£ 7 billion	N/A

1 Adjusted to per year cost; the productivity loss since the incident infection amounted to around £277.7 million per month. For the value of informal care the respective estimate was £218.2 million per month.
2 Lower bound.
3 Cutler (2022) refers to at least 9.6 million people with three or more symptoms of Long COVID, based on 80.5 million confirmed cases between January 2020 and May 2022, and assumes that 12-17% will have three or more symptoms 12 weeks after initial onset.
4 Adjusted to per year economic impact; Cutler (2022) assumes that Long COVID lasts five years on average and calculates the impact for a five-year period.

Table 3: Comparison of ME/CFS cost estimates from our model with previous research. If the referenced publication did not report the cost as a percentage of GDP, it was calculated using World Bank GDP estimates.

Source	Country	Ref. year	Costs included	Cost estimate	As % of GDP
Own model findings	Germany	2020	Personal loss, employer loss, society loss	€ 20.9 billion	0.61%
Own model findings	Germany	2021	Personal loss, employer loss, society loss	€ 21.8 billion	0.59%
Own model findings	Germany	2022	Personal loss, employer loss, society loss	€ 25.6 billion	0.65%
Own model findings	Germany	2023	Personal loss, employer loss, society loss	€ 29.6 billion	0.71%
Own model findings	Germany	2024	Personal loss, employer loss, society loss	€ 30.9 billion	0.72%
Mirin et al., 2022	US	2022	Medical expenses (direct costs), lost income (indirect costs)	US$ 149 - 362 billion	0.57-1.39%
Jason and Mirin, 2021	US	2020	Medical expenses (direct costs), lost income (indirect costs)	US$ 35.9 - 50.9 billion	0.17-0.24%
Jason et al., 2008	US	2008[1]	Direct medical costs, indirect costs (loss of household income)	US$ 18.7 - 24 billion	0.13-0.16%
Reynolds et al., 2004	US	2002	Lost productivity (household + labor force)	US$ 9.1 billion	0.08%
Close et al., 2020	Australia	2019[2]	Lost income, OOP expenditure on health and medical expenditure, cost to government and the health care system	AUD$ 14.5 billion	0.74%
Zhao et al., 2023	Australia	2021	Direct cost (prescription + non-prescription medication, health care professional visits and investigation costs, hospital costs, special + digital equipment purchased, travelling, community service, everyday living, special modification/renovation done to home, special diet), indirect cost (lost wages, productivity loss due to absenteeism and presenteeism)	AUD$ 1.4 - 10.1 billion	0.07-0.48%
Lloyd and Pender, 1992	Australia	1988	Direct medical cost, cost to federal government, direct and indirect cost to community	AUD$ 97 million	0.03%
Collin et al., 2011	UK	2010	Productivity costs of patients who access specialist services	GBP£ 102.2 million	0.01%
Pheby et al., 2020	Europe	2020	Total cost of care services (health care + informal care) and lost employment/ productivity	€ 40 billion[3]	0.3%
Deutsche Gesellschaft für ME/CFS, 2020	Germany	2020	Total cost of care services (health care + informal care) and lost employment/ productivity	€ 7.4 billion[4]	0.21%
Schweizerische Gesellschaft für ME & CFS, 2023	Switzerland	2023	Total cost of care services (health care + informal care) and lost employment/ productivity	CHF 3 billion[5]	0.38%

1 Based on 1999 prevalence estimates and US Census 2000 population estimates.
2 Based on 2013 prevalence estimates and 2019 prices.
3 Based on an extrapolation of a study for the UK by McCrone et al. (2003).
4 Based on the study for Europe by Pheby et al. (2020).
5 Based on the estimate for Germany by Deutsche Gesellschaft für ME/CFS (2020) and a doubling of the prevalence due to the COVID-19 pandemic.

Annex 2: Long COVID and ME/CFS simulation model

Purpose

This model simulates the progression of Long COVID and ME/CFS cases over time within Germany. It integrates vaccination data, reinfection rates, and age group distributions to estimate the number of Long COVID cases and ME/CFS cases. It then uses established risk modelling approaches to calculate the costs incurred by these cases. By running four permutations of the model with various parameters, and cross-checking against known and expected figures wherever possible, the model provides both overall figures and insights into how factors like age distribution, reinfection adjustment, and vaccination status may impact long-term illness and disability outcomes.

This model serves as a tool to understand the progression and cost impact of Long COVID and ME/CFS in a population, particularly as influenced by vaccination rates and reinfections.

By simulating various scenarios with permutations, it can offer insights into:

- **The long-term impact of COVID-19:** Estimating the burden of chronic illness stemming from COVID-19 on health systems and individuals.
- **The effect of vaccination and reinfection:** Observing how reinfection rates and vaccinations influence the likelihood and severity of Long COVID cases.
- **The effects of age and disability factors:** Showing how age and individual disability ratings affect the socio-economic burden of Long COVID and ME/CFS over time.

This simulation model provides a valuable framework for public health analysis, helping policy makers and key stakeholders anticipate potential long-term healthcare needs and resource allocation based on current COVID-19 trajectories and vaccination efforts.

Model workflow and assumptions

The script underpinning this work is a Monte Carlo simulation framework for modelling the progression of SARS-CoV-2 infections to Long COVID and/or ME/CFS, as well as ME/CFS in its own right. Key elements include (1) Dynamic adjustment of probabilities based on time, reinfections, and vaccinations; (2) Assignment of severity, disability ratings, and age groups; and, (3) Detailed tracking of case data for subsequent analysis. This modular approach enables exploration of different scenarios by varying key parameters, producing insights into long-term disease outcomes and their societal impacts.

A schematic of the model indicating key assumptions is provided in Figure 8.

Model flowchart: SARS-CoV-2 infections and the potential progression to Long COVID and ME/CFS

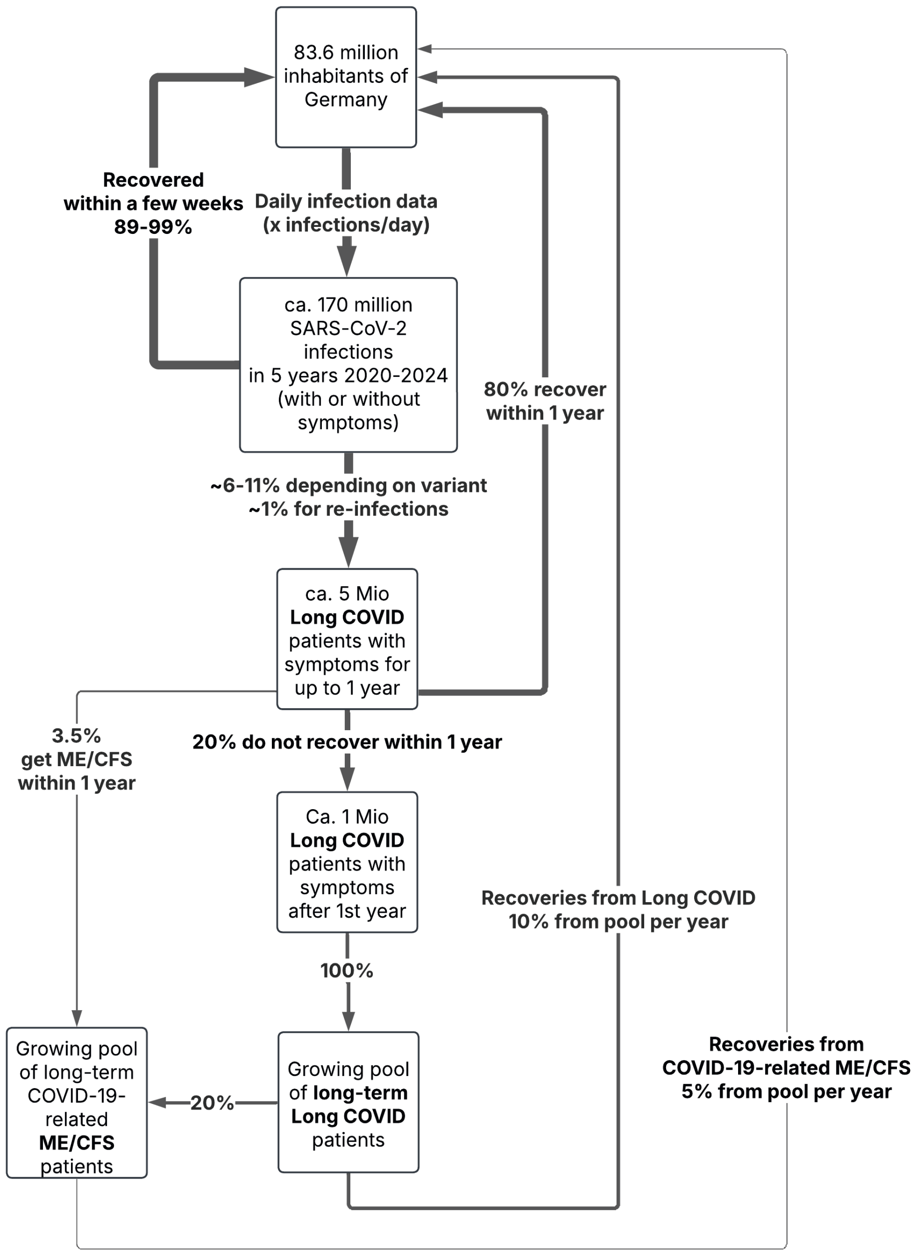

Figure 8: Schematic indicating key assumptions used in the model. Note that the percentages stated in the figure are the indicative rather than the exact values used in the model, as the model internally uses stochastic distributions for most calculation steps.

1. Load and prepare data on COVID-19 cases and vaccinations

First, the model loads a base dataset containing daily COVID-19 case counts. Case counts are based on data collected daily from each district and uploaded and aggregated via RKI (RKI, 2025).

Unfortunately, this RKI data does not cover all SARS-CoV-2 infections. Especially after 2022, following changes in public health surveillance approaches, the estimated number of unreported / undetected cases became in the order of 80-100 times higher (Loenenbach et al., 2024) than the official data from the RKI.

To correct for this, the daily COVID-19 case counts of RKI data are adjusted based on case count models carried out by Paessler et al. (2025). Here, three different approaches were used to estimate the actual number of SARS-CoV-2 infections in Germany in the years 2020 to 2024. The approaches were based on (1) various datasets from the RKI, (2) an independent emergency room COVID-19 hospitalisation dataset from Deutsche Gesellschaft Interdisziplinäre Notfall- und Akutmedizin (DGINA), and (3) a fully-synthetic numerical model of infections. The resulting figures have been validated by the authors against various publicly-available data sets (e.g. COVID-19-related hospitalisations, death and emergency room patient data, wastewater SARS-CoV-2 levels, and panel-based public health surveillance) and published in a peer-reviewed journal. For the final four model permutations, an adjustment based on the second approach (DGINA dataset) was applied, as it yielded the most conservative estimates and resulted in the lowest total number of infections.

Second, another dataset is loaded with vaccination numbers over time, sourced from the COVID-19 vaccination dashboard that was developed by the Federal Ministry of Health (BMG, 2023). This data helps determine the likelihood of individuals in the model having various vaccination levels at each date, influencing Long COVID susceptibility and severity (see Long COVID probability below).

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2. Define constants and parameters

A series of constants and parameters are sourced from the existing literature, with assumptions made (following discussion and debate amongst the research team) where noted below. The model starts on 1 January 2020.

Initial Long COVID cases: This is initially set to zero.

Initial ME/CFS cases: The model assumes a baseline count of 400,000 pre-existing ME/CFS cases. This figure was sourced from the KBV, who estimated between 350,000 (2018) to 400,000 (2019) pre-pandemic ME/CFS cases. The assumption is that non-COVID-19-related ME/CFS case numbers remained constant over time (recoveries and new non-COVID-19-related cases are balanced), while new COVID-19-related ME/CFS has increased as per calculations below.

Population characteristics: Age groups and population size are defined according to the official population for Germany in 2024 of approximately 83.6 million people (Destatis, 2025b), along with probabilities of belonging to each age group (ibid.). This figure is not adjusted for births, deaths or migration year-on-year (especially around the influx of migrants from Ukraine since 2022), as the fluctuations are small enough to have a near-negligible effect on the overall result.

Long COVID probability: Initial and final probabilities of developing Long COVID are computed for each case and adjusted as needed for vaccination and reinfection status.

Per Table 2 in the paper by Mikolajczyk, et al. (2024), we conservatively assume that 11% (wild-type), 8-9% (Alpha/Delta) and 6-8% (Omicron) of infections are followed by Long COVID for up to one year after the infection (Mikolajczyk et al., 2024; Al-Aly et al., 2024). In the model, vaccinations lower the risk of Long COVID by around 5—10% per dose, with limited additional benefit beyond two doses. Infections have a substantially larger impact, with the first infection significantly reducing Long COVID risk and subsequent infections further halving it.

Transition probability to ME/CFS: A subset of Long COVID cases is randomly assigned to transition to ME/CFS based on defined probabilities. The model assumes a 3.5% chance of meeting ME/CFS diagnostic criteria within the first 12 months of Long COVID, and a 20% chance for Long COVID longer than 12 months, taking into account findings from Peter et al. (2025) and Vernon et al. (2025).

Recovery probability from Long COVID: The model assumes that 20% of COVID-19 patients continue to experience Long COVID symptoms for more than 12 months; a proportion go on to recover, while others will fit diagnostic criteria of ME/CFS (see Figure 8). While the time progression of Long COVID is undoubtedly more complex than this for a variety of reasons discussed below, paucity of long-term studies makes this an area where it is reasonable to make informed assumptions rather than rely on published data alone.

Chronic illness rarely fits a pattern of recovery seen in acute illness. Instead, it tends to be lumpy (periods of severity then periods of relative health and vice-versa, so called 'wax and wane' or 'relapsing-remitting'), with a long tail over many years. The tail is exacerbated by the fact that there are cumulative deleterious or 'deconditioning' effects on other body systems (e.g. systemic low-grade inflammation, new occurrence of comorbid health conditions, decline in musculoskeletal strength due to deconditioning, decline in mental health due to stigma, loss of social networks, etc.), which are largely irreversible and so will continue to affect lives and incur costs. This is not taken into account in studies seeking to define recovery from Long COVID, and adds weight to the need to make informed estimates around Long COVID progression and recovery.

One of the challenges of estimating recovery is the fact that the process of scientific research (from proposal to final publication) is slow and poorly funded; it can be expedited by limiting variables and reducing sample sizes. In terms of data which do exist, one early study suggests that patients who did not recover within the first seven months of their illness may go on to remain symptomatic for an unknown period of time (Davis et al., 2021). A recent study from Germany found that 67% of patients who did not recover within the first 6-12 months of their illness went on to remain symptomatic for a median of another 8.5 months (Peter et al., 2025). Other studies indicate that Long COVID symptoms can persist for a period of at least three years (Cai et al., 2024; Zhang et al., 2024). One study has investigated return to work following Long COVID (Huang et al. 2022). Given that 'return to work' cannot be used as a proxy for 'recovery' (it neither speaks to overall well-being, nor level of social functioning outside of work, nor ongoing use of health services, and also excludes people with no formal role in the labour market), figures in this work are interpreted as a ceiling at best.

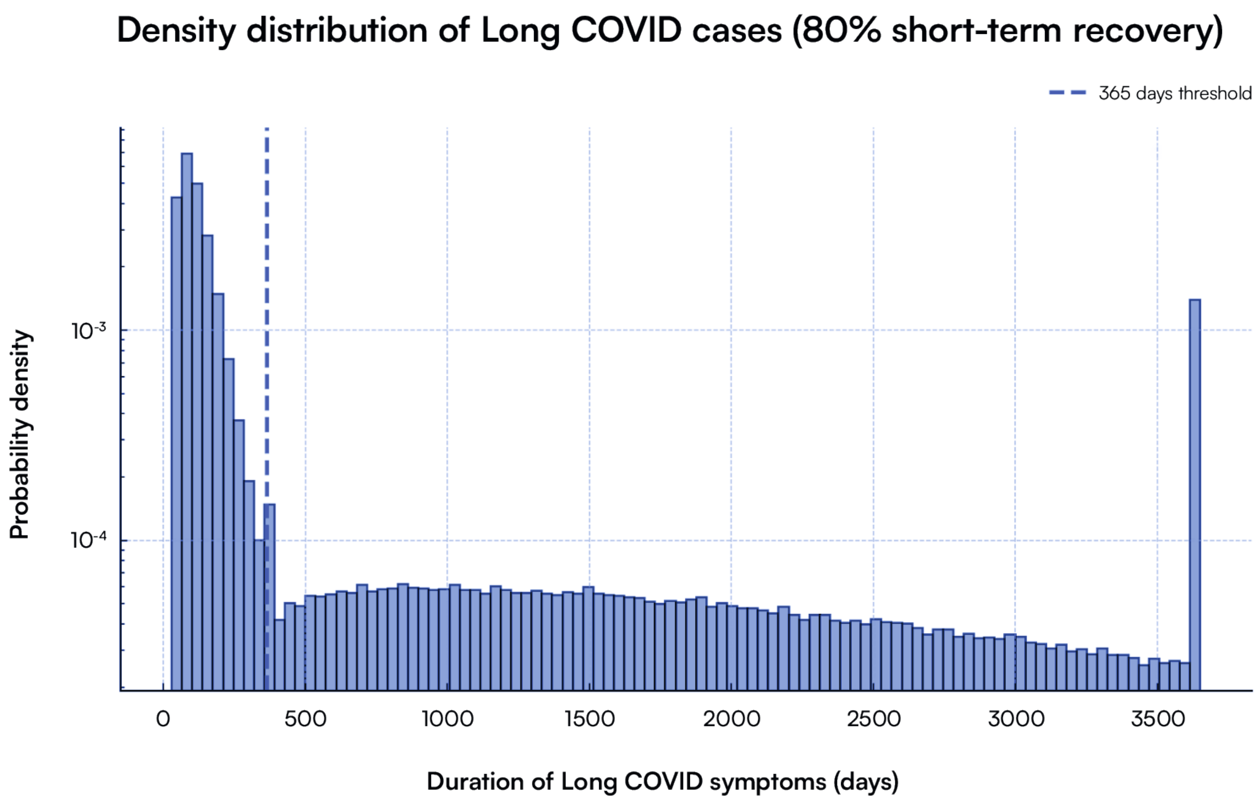


Figure 9: Duration of Long COVID symptoms and probability of recovery as applied in the model, indicating that 20% of Long COVID cases are still active after 365 days.

Overall, for the purposes of this report, the authors assume that, of the pool of long-term Long COVID patients, 20% still experience symptoms after the first year, and 10% per year recover and return to the healthy pool, reflecting existing findings (Al-Aly et al., 2024) (see Figure 8).

The majority (80%) of Long COVID cases fall within 28 to 365 days (Figure 9). The peak occurs between 80 and 100 days, reflecting the most common symptom duration. The shape of this segment follows a lognormal distribution, ensuring a gradual increase up to the peak, followed by a smooth decline towards the 365-day threshold.

Twenty percent of cases persist beyond 365 days, following a gradual decay rather than an abrupt drop. This segment follows a Weibull distribution, where cases can last out well past ten years and beyond, where the probability density slightly decreases in time in line with the 10% recovery rate per year. For the purposes of this model, the longest cases are only shown to extend up to 10 years (3,650 days); however, given the model run of five years, where most Long COVID cases have only been experienced for maximum of three years to date, the distribution can be treated as being as long as a human life in some patients who are most affected.

Based on our model data, we can estimate that the number of active ME/CFS cases will likely rise by a total of around 34,000 in the period of 2025-2028, based on the SARS-CoV-2 infections and Long COVID cases that have already taken place. This number is already locked in at this point in time, even without accounting for potential future waves of SARS-CoV-2 infections, unless curative treatments become available in the meantime.

Recovery probability from ME/CFS: A subset of ME/CFS cases is randomly assigned to recover. The model assumes 5% recovery from COVID-19-related ME/CFS (Cairns and Hotopf, 2005).

Severity multipliers: Fixed severity multipliers are set for Long COVID and ME/CFS cases, representing how severely these conditions affect individuals in cost terms, by reducing value-add and increasing costs by a specified proportion.

Put another way, a disability or severity weighting is a factor on a scale from 0 to 100% which reflects the severity of health loss associated with the particular condition, where 0 represents full health and 100% represents a full burden and not being able to work.

There are two permutations for disability rating used in the model, testing two scenarios in the absence of consensus in the literature and/or amongst the research group:

- **Mild disease**: Assumes 24% average disability impact for Long COVID and 31% for ME/CFS (simulating mild cases) under normal population conditions.

- **Severe disease**: Assumes a higher severity, 40% for Long COVID and 58% for ME/CFS (simulating more severe cases) under normal population conditions.

There is less confidence around these disability multipliers than other assumptions in the model because Long COVID research remains nascent, with countries like Germany leading the way. Over time, tables reporting established severity multipliers may be created, but these do not yet exist. Instead, equivalents from other disability scenarios are used, with two versions being run to test the differences. The more conservative disability multiplier points to mild disease that goes entirely unreported, while patient testimonies encountered by the research team point towards a higher multiplier, and one that fluctuates over time. A summary of work identified to date is given in Table 4, and the figures used in the model are broadly in line with these findings rather than selecting any single source.

Table 4: Summary of research relating to severity, disability and health-related quality of life (HR-QOL) effects of Long COVID and/or ME/CFS that was reviewed as a part of the modelling process.

Author/year	Disease	Country	Summary
Kirchberger et al., 2024	Long COVID	Germany	Study from Germany (n=304 of which Long COVID=210, Long COVID according to WHO clinical case definition. At follow-up, median physical HRQOL (VR-12) in Long COVID was 48.48 vs 54.76 in non-Long COVID (see Table 3 of paper).
Smith et al., 2023	Long COVID	Belgium	Study from Belgium (n=5727 of which Long COVID=2829, Long COVID according to NICE). "..decline in HRQoL (...) among people reporting Long COVID (β=-11.15, 95%CI=-11.72;-10.51)."
Smith et al., 2025	Long COVID	UK	Study from UK (n=1434 Long COVID, Long COVID according to NICE). "The test set for the mapping algorithm comprised 734 participants. The mean EQ-5D-3L health utility value was 0.54 (SD: 0.264, minimum: −0.346, maximum: 1; 95% CI: 0.52, 0.56)."
Carlile et al., 2024	Long COVID	UK	Study from UK (n=6070 of which Long COVID=1495, Long COVID defined as self-reported symptoms >4 weeks, note: quite different to others). "Participants self-reporting long COVID were highly likely to report loss of HRQoL compared to participants who did not report long COVID (OR 4.7 (3.72; 5.93) for returning a loss of HRQoL and 0.056 (0.04, 0.07) unit lower quality of life). (...) The mean EQ-5D score for those who self-reported long COVID was 0.49 compared to 0.71 among those without long COVID. (...) To put in perspective the loss of HRQoL from long COVID, our results showed lower EQ-5D scores than from patients experiencing heart failure (mean 0.60), multiple sclerosis (mean 0.59),34 and end-stage renal disease (mean 0.68)."
Zhu et al., 2024	Long COVID	US	Study from US (n=10,945,079 of which Long COVID=31%, Long COVID according to CDC). "An estimated 59,514 QALYs (range: 10,372—180,257 QALYs from LHS), or 148.3 QALYs/100,000 population, were lost due to long COVID among confirmed COVID-19 cases in California between March 1st, 2020, and December 31st, 2022."
Rafferty et al., 2023	Long COVID	Canada	Review from Canada (n=740.000-2.880.000, definition=?). "Post-COVID-19 condition costs per COVID-19 case ranged from CAD 1,675 to CAD 7,340, and QALY decrements ranged between 0.047 to 0.206, in the first year following COVID-19 infection."
Malik et al., 2021	Long COVID	US	Review from US (n=4828 Long COVID). "We found that amongst PCS patients, the pooled prevalence of poor quality of life (EQ-VAS) was (59%; 95% CI: 42%—75%)."
Muirhead et al., 2024	ME/CFS	UK	Study from UK (n=876 ME/CFS, self-reported diagnosis of ME/CFS by health professional). "In this study, the mean EQ VAS score was 36.4, and the mean EQ VAS score for the UK population is 82.75 [12], demonstrating the huge detrimental impact of ME/CFS on the QoL of individuals with this condition. Similarly, the EQ-5D index value in this study was found to be 0.38, whereas the EQ-5D index value for the UK population norm is 0.86 [12], emphasising the negative impact of ME/CFS on QoL."
Hvidberg et al., 2015	ME/CFS	Denmark	Study from Denmark (n=105, self-reported ME/CFS). "Based on the present findings, ME/CFS patients in this study have an unadjusted EQ-5D-3L HRQoL utility score of 0.47 and an adjusted one of 0.56. Compared to other conditions shown in Fig 3 from another more recent study [23], the ME/CFS patients of the current study have the lowest, unadjusted EQ-5D-3L measured HRQoL of 20 conditions, thus even worse than multiple sclerosis and stroke."

Table 4: Continued from previous page			
Author/year	**Disease**	**Country**	**Summary**
Dimmock et al., 2016	ME/CFS	US (+ Denmark)	Report from US (incl data from the above study from Denmark). "When the YLL of 0.226M is combined with the YLD of 0.488M, we get a DALY of 0.714M." The same study also looked at a disability rating for ME/CFS: "Based on this information, we estimate that 27% (midrange of NAM estimate) of patients are severely ill, 19% (average of Chu's and CDC's estimates) are mildly ill, and the remaining 54% have an illness of medium severity. These estimates result in a combined DW across all levels of severity of 0.4748 (see Table 2)." (...) The second method of estimating disability weight is based on the 2015 Hvidberg study, which uses EQ-5D to compute quality of life for a number of diseases. We derived the disability weight from the adjusted EQ-5D utility score, QoL, based on the assumption that DW = 1 — QoL [28,29]. This results in an estimated disability weight (DW) of 0.44 for ME/CFS. Among the set of diseases studied by Hvidberg, et al., ME/CFS was found to have the lowest adjusted QoL score and thus the largest estimated DW. The disease with the next largest calculated DW was multiple sclerosis, with an estimated DW of 0.27 based on Hvidberg's catalog of EQ-5D scores for chronic conditions in Denmark."
Eaton-Fitch et al., 2020	ME/CFS	Australia	Study from Australia (n=480 ME/CFS, ME/CFS according to repurposed criteria based on Fukuda, CCC and ICC). "As reported in Table 3, mean HRQoL scores were significantly reduced in ME/CFS patients across all domains ($p < 0.001$). Scores were particularly low for limitations due to physical health (4.11 ± 15.1) and energy/fatigue (13.54 ± 13.94)."
Weigel et al., 2024	ME/CFS	Australia	Study from Australia (n=61 ME/CFS / 31 Long COVID / 54 controls, Long COVID according to WHO, ME/CFS according to CCC/ICC): "For all PROMs, poorer QoL scores were observed among pwME/CFS and pwPCC in every domain (except HADS Anxiety) when compared with controls ($p < 0.001$, uncorrected). PwME/CFS and pwPCC did not differ significantly in any domain of the QoL PROMs."

3. Define costs

Costs resulting from reduced value-add and increased expenditure are calculated according to standard economic parameters, then multiplied by the above severity multipliers. The main cost categories are summarised in Table 5. Table 6 summarises the costs assumed in the model, although it should be noted that the table is indicative only, as many of the costs cross multiple categories listed. Overall, methods for defining costs are well-established in the literature, and well-explained by authors such as Steinhauser and Lancsar (2022) (pages 23 and 28 in particular).

There are many methods to cost human lives and disability adjusted life years, and the approach underlying this report is just one of them. For the purpose of our analysis, it is assumed that an individual's impact is not only linked to the GDP they produce or the costs they incur. They also have an inherent impact on wider society, as well as their direct community, which far exceed their individual GDP-linked cost. Similar studies will only look at GDP, but taking broader factors into account is more accurate when it comes to accounting for the wider impact of disease.

In 2020, illnesses and health problems led to costs of €431.8 billion in Germany (Destatis, 2022). However, the economic costs associated with disability are very complex. There exist several methods to determine the costs associated with human life, as has been widely discussed through papers comparing human capital (the value associated with working and production of a person) and willingness-to-pay (WTP) (survey approaches to assess how much a certain life year cost is worth to an individual). There is often a 10-fold scatter in such values (Schlander et al., 2017).

The DALY (disability-adjusted life year) is also often used as a measure of how many years of life are lived in good health. An early comprehensive study for human capital approaches was done by the Australian Bureau of Transport Economics (BTE, 2001). BTE developed a systematic human capital approach for Australian and New Zealand life costs by applying the findings to bushfire and storm victims. In this case, road death and injury data comparisons were made with natural disasters using the following human capital elements: workplace labour lost (time left in working life); household labour lost (the contribution to the household/community of the individual); lost quality of life (this figure takes into account the lost quality of life left — an innovative and important addition to the usual methods of loss analysis) (ibid.). This equates to the personal, employer and societal costs shown in the present study, with medical costs distributed across all three categories (Table 5).

In the BTE (2001) study, and subsequent adaptations of it (e.g. Deloitte, 2021; Handmer et al., 2018; Butterfly Foundation and Deloitte Access Economics, 2024), the approach gives a robust value of the combined costs of impacted human life. These costs are usually well in excess of GDP per capita; for instance, the VSLY (value of statistical life year) used by the Butterfly Foundation and Deloitte Access Economics (2024) is 4.5 times the GDP per capita. Nandi et al. (2022) calculate similar figures with regard to Alzheimer's disease.

The GDP per capita in Germany amounts to € 51,500 per year, or €141/day. The gross value-added per employed individual is around €235/day. The VSLY in Europe via WTP approaches has been calculated to be close to 5.2 times the annual GDP per capita (equivalent to €730/day) (Schlander et al., 2017; Schlander et al., 2023). In the present study, the total average day value assigned (taking into account population) is €288/day using own modelling via SARS-CoV-2 statistics, which is just over two times the GDP per capita — significantly lower than the aforementioned WTP approaches. While the human capital approach of BTE is applied here for Long COVID and ME/CFS, future studies could investigate using the higher costs of WTP approaches.

Table 5: Overview and description of the costs and losses included in calculating costs per day for Long COVID and ME/CFS. Compiled based on rules of thumb developed by other, similar studies (see e.g. Steinhauser and Lancsar, 2022). Note that the table is indicative only; it is not an exhaustive list, and many of the costs cross multiple categories listed.

Burden	Total consts	Personal losses	Employer losses	Society losses
Production disturbance costs	Lost productivity and overtime due to reduced capacity	Remaining income losses	Overtime premium, employer excess payments, production	Welfare payments to partially offset lost wages, tax losses prior to reaching permanent disability status (PDS), productivity
Human capital costs	Reduced lifetime productivity and earnings capacity	Remaining income losses after PDS, partially offset by welfare and compensation	Sick leave costs, staff turnover costs	Welfare and compensation for reduced earnings capacity, tax losses after PDS (excluding worker welfare portions)
Medical costs	Medical and rehabilitation expenses due to Long COVID or ME/CFS	Gap payments, private health insurance contributions	Employer's threshold for medical payments	Public health system expenses, compensation medical payments
Administrative costs	Legal and administrative costs associated with support and compensation systems	Worker's own legal costs (minimal compensation for these)	Employer's legal fees, investigation costs, any penalties	Costs of enforcement and running the legal/ compensation system, society's share of travel-related compensation
Travel costs	Travel to and from treatment or support services	Out-of-pocket travel expenses to access treatment (reduced by compensations and concessions)	Minimal or negligible	Society's compensation portion for travel-related expenses
Support and assistance costs	Ongoing costs of care and support for daily life with reduced capacity	Personal expenses for in-home carers, necessary aids, and modifications (net of compensations received)	Minimal or negligible	Government support payments for carers, deadweight costs on welfare and tax losses associated with caregiving and aids
Deadweight costs of transfer payments	Administrative and economic inefficiencies from welfare and transfer systems	None	Minimal or negligible	Deadweight costs linked to welfare payments
Quality of life and well-being costs	Impacts on well-being and independence, including social and psychological support needs	Personal suffering and limitations in quality of life, net of any compensation, future capital	None	Deadweight costs due to tax losses, additional social support payments (e.g. community or disability services), lost consumer goods

Table 6: Costs per day calculated as part of this study, in 2024 constant €. Such figures are well-established in the literature for other similar health conditions and disasters, and are explained further in the text.

Age group	Personal loss (€/day)	Employer loss (€ /day)	Society loss (€ /day)	Total loss (€/day)
0-19	111	25	68	204
20-39	178	93	124	395
40-59	184	108	137	429
60+	118	49	94	261

4. Make dynamic probability adjustments based on reinfections and vaccinations

The model considers whether to adjust probabilities based on reinfections and vaccination status, calculating Long COVID probabilities (min, max) based on time progression, and severity-modifying events (i.e. reinfections and vaccinations). Each day's probabilities of developing Long COVID (and subsequently COVID-19-related ME/CFS) are adjusted (based on Mikolajczyk et al., 2024, Table 2):

- **Reinfections**: The per-infection risk of developing Long COVID decreases with an increasing number of reinfections (while the per-person risk increases over time with increasing reinfection count).
- **Vaccination status**: Individuals vaccinated more often have a slightly lower risk of developing Long COVID.

These adjustments allow the model to simulate more realistic scenarios by considering accumulated immunity. An informed assumption is made here because findings from literature are mixed and longitudinal data is lacking. This is to be expected when COVID-19 is less than five years old, vaccination for SARS-CoV-2 less than four years old, and surveillance remains limited.

5. Simulate each permutation

For most model assumptions, the authors could define plausible input metrics based on literature as shown in this Annex. Since it was not possible to define just one plausible assumption for the two model input parameters discussed previously, population distribution of the caseload and severity multipliers of the individual symptom burden per person, we tested our assumptions by modelling four permutations of the model as described above with the results in Table 7. For the report the averages of these 4 model outputs were used.

The model iterates through different parameter combinations, simulating cases across varying assumptions (age group probabilities and disability ratings for each condition). For each day in the COVID-19 cases dataset:

Assign age group: Age groups are randomly assigned to each case based on the population distribution. There are two permutations for the caseload distribution by age group.

1) Age group distribution skews to middle-aged groups as per the population distribution as seen in the 2022 census of Germany (census population conditions).

2) Proportions are increased for the youngest (0-19 years) and oldest (60+ years) groups as per the expected SARS-CoV-2 infection response (SARS-CoV-2 infection response population conditions).

Assign disability ratings as above: Each respective Long Covid and ME/CFS case is assigned a disability rating associated with the total percentage of costs expected to occur to that individual via the combined personal, employer and societal costs.

- **Permutation 1**: Assumes 24% average disability impact for Long COVID and 31% for ME/CFS (simulating mild cases) under census population conditions
- **Permutation 2**: Assumes 40% average disability impact for Long COVID and 58% for ME/CFS (simulating more severe cases) under census population conditions.
- **Permutation 3**: Assumes 24% average disability impact for Long COVID and 31% for ME/CFS (simulating mild cases) under SARS-CoV-2 infection response population conditions
- **Permutation 4**: Assumes 40% average disability impact for Long COVID and 58% for ME/CFS (simulating more severe cases) under SARS-CoV-2 infection response population conditions

Looking only at the costs for the year 2024, along the four model permutations (for the parameters of caseload distribution by age group and disability severity), variations in cost estimates arise as shown in Table 8.

Table 7: Total modelled cost results for Long COVID and ME/CFS for four different model permutations, for the five-year time period **2020-2024**.

	Long COVID costs	ME/CFS costs	Long COVID & ME/CFS costs
Model permutation 1 (Population distribution 1, low severity)	€ 97.9 billion	€ 91.7 billion	€ 189.6 billion
Model permutation 2 (Population distribution 1, high severity)	€ 163.1 billion	€ 167.8 billion	€ 330.9 billion
Model permutation 3 (Population distribution 2, low severity)	€ 90.5 billion	€ 90.3 billion	€ 180.8 billion
Model permutation 4 (Population distribution 2, high severity)	€ 150.6 billion	€ 165.4 billion	€ 316.0 billion
Average	**€ 125.6 billion**	**€ 128.8 billion**	**€ 254.4 billion**

Table 8: Total modelled cost results for Long COVID and ME/CFS for four different model permutations, for the year **2024**.

	Long COVID costs	ME/CFS costs	Long COVID & ME/CFS costs
Model permutation 1 (Population distribution 1, low severity)	€ 25.1 billion	€ 22.4 billion	€ 47.5 billion
Model permutation 2 (Population distribution 1, high severity)	€ 41.8 billion	€ 40.3 billion	€ 82.1 billion
Model permutation 3 (Population distribution 2, low severity)	€ 23.2 billion	€ 21.8 billion	€ 45.0 billion
Model permutation 4 (Population distribution 2, high severity)	€ 38.6 billion	€ 39.3 billion	€ 77.9 billion
Average	**€ 32.2 billion**	**€ 30.9 billion**	**€ 63.1 billion**

6. Track daily and cumulative data

In daily case tracking, the model tracks:

- **New Long COVID and new ME/CFS cases**: Calculated for each day based on probabilities and transitions.
- **Active cases**: Running totals of Long COVID and ME/CFS cases.
- **Recovered cases**: According to assumptions stated above.

For memory efficiency, data is stored in memory in batches and written to disk after processing each permutation, avoiding memory overflow.

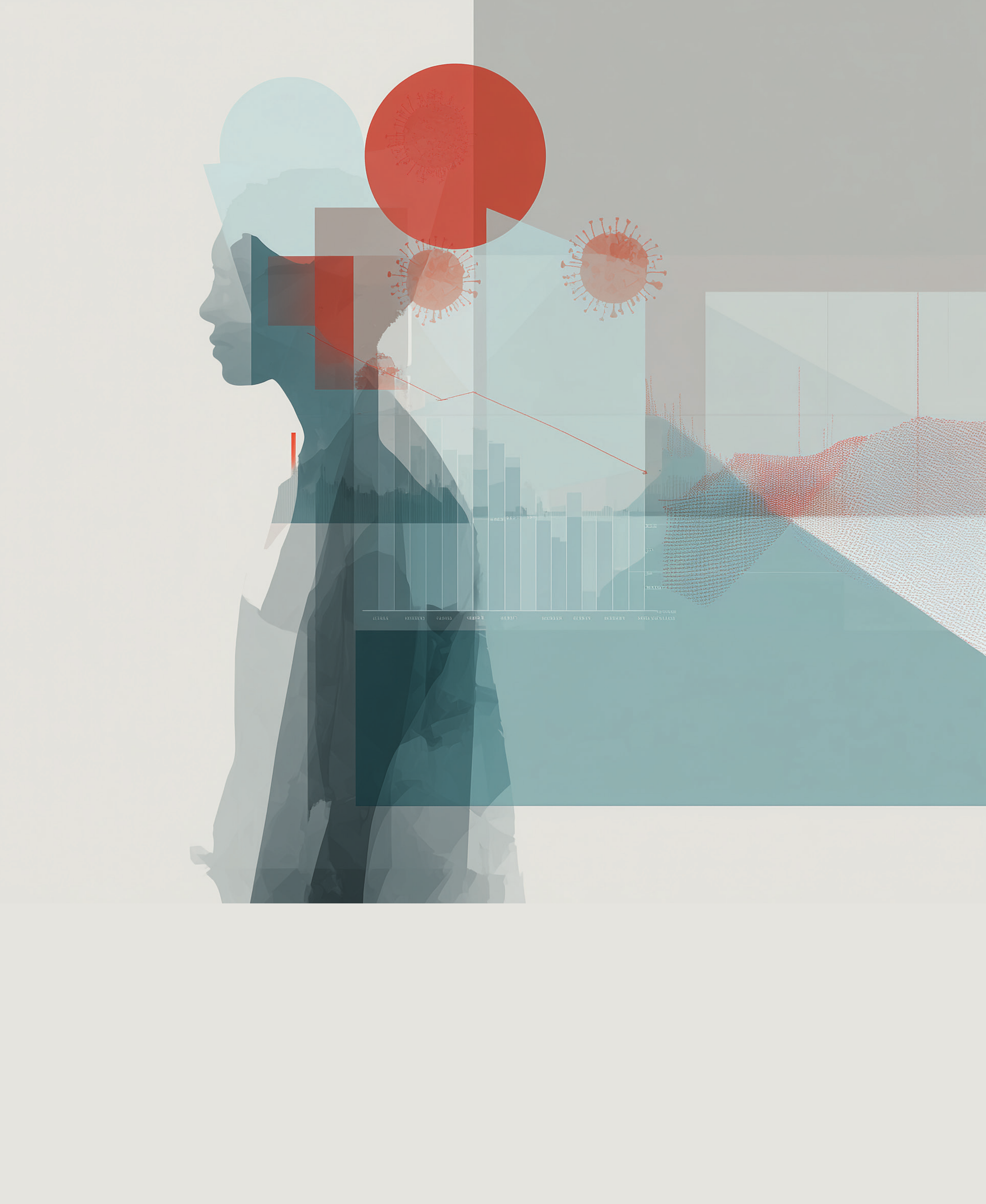
7. Generate output

For each permutation, the model generates a range of CSV outputs (more detail is available on GitHub at https://github.com/risklayer).

8. Loop

The script uses permutations of parameters and iterates over daily case counts, assigning probabilities, disability ratings, and severity, while tracking outcomes like reinfections and transitions to ME/CFS.

The detailed structure and inner workings of the main loop, including how Long COVID and ME/CFS cases are stored, tracked, and exported, is available on request. It includes a detailed explanation of the main loop, the mechanisms for case assignment, and the logic behind reinfections, severity, and transitions.



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