LOKI Pandemics
HELMHOLTZ

MONID

LOKI-Pandemics

Integrated Early Warning System for Local Recognition, Prevention, and Control for Epidemic Outbreaks

Martin J. Kühn
(on behalf of the whole LOKI Pandemics Team)
2025/02/2x

HZI HELMHOLTZ Zentrum für Infektionsforschung
DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center
JÜLICH Forschungszentrum
AGW AKADEMIE FÜR ÖFFENTLICHES GESUNDHEITSWESEN
CISPA HELMHOLTZ-ZENTRUM FÜR INFORMATIONSSICHERHEIT
UFZ HELMHOLTZ Zentrum für Umweltforschung

Mission and objectives: Targeted local control

HELMHOLTZ LOKI Pandemics

Localized approach

- → **prevent untargeted interventions** such as country-wide lockdowns to **reduce economic damage and social harm**
- → enable **suitable local control** through local **information** and situation's **assessment**
- → **support** (local) **decision makers and health authorities** with **software** tool **on the spot**

Diese Regeln gelten seit 16. Dezember

Einzelhandel geschlossen, Supermärkte bleiben offen

Seit dem 16. Dezember sind die Maßnahmen in Kraft, die Bund und Länder am 13. Dezember zur Eindämmung der Corona-Infektionszahlen beschlossen haben. Die Regelungen sollen vorerst bis zum 10. Januar gelten. Ein Überblick.

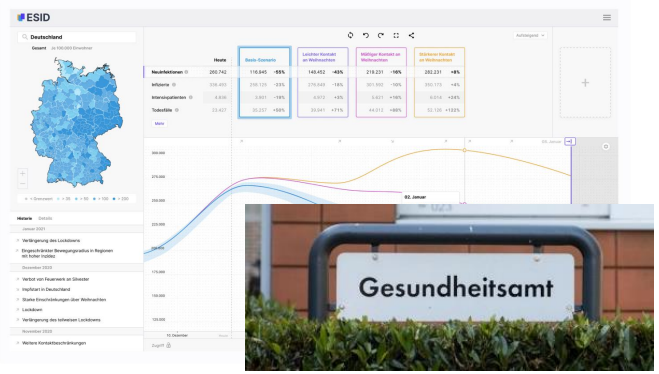
Donnerstag, 17. Dezember 2020

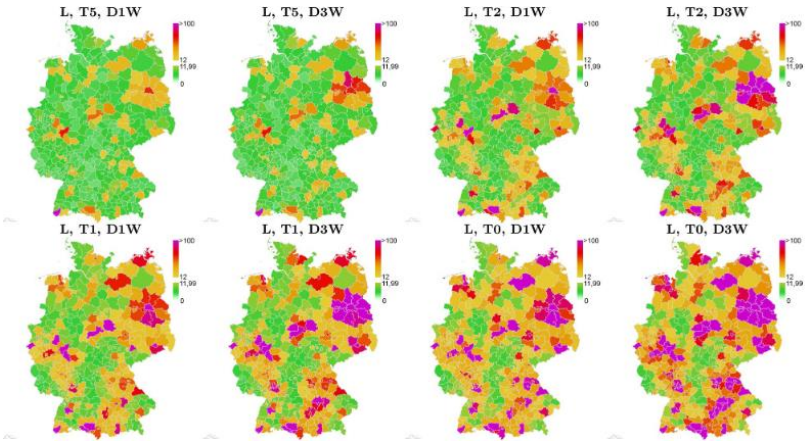
POLITICS | GERMANY

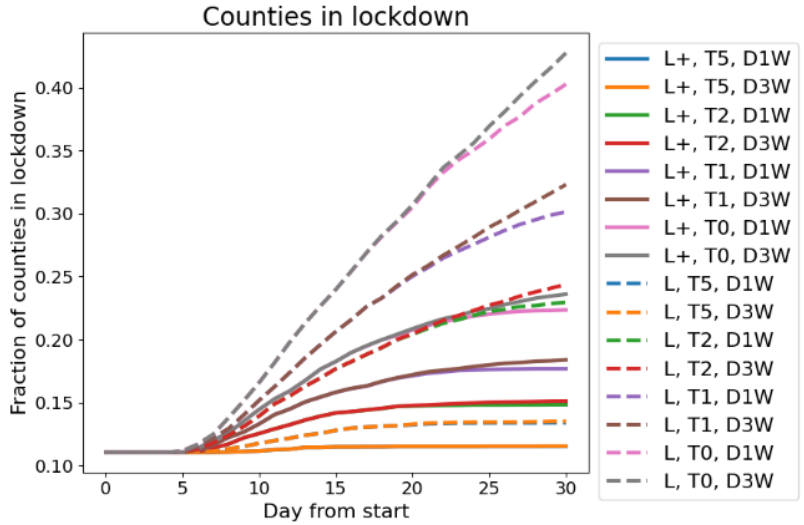
Germany faces €1.3 trillion COVID bill

12/31/2020

The German government has calculated it will cost €1.3 trillion to pay for the coronavirus pandemic. One senior politician is worried that the poorest will end up footing the bill.







Project structure: Partners, work packages and project backbone

HELMHOLTZ LOKI Pandemics

HZI HELMHOLTZ Zentrum für Infektionsforschung

DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

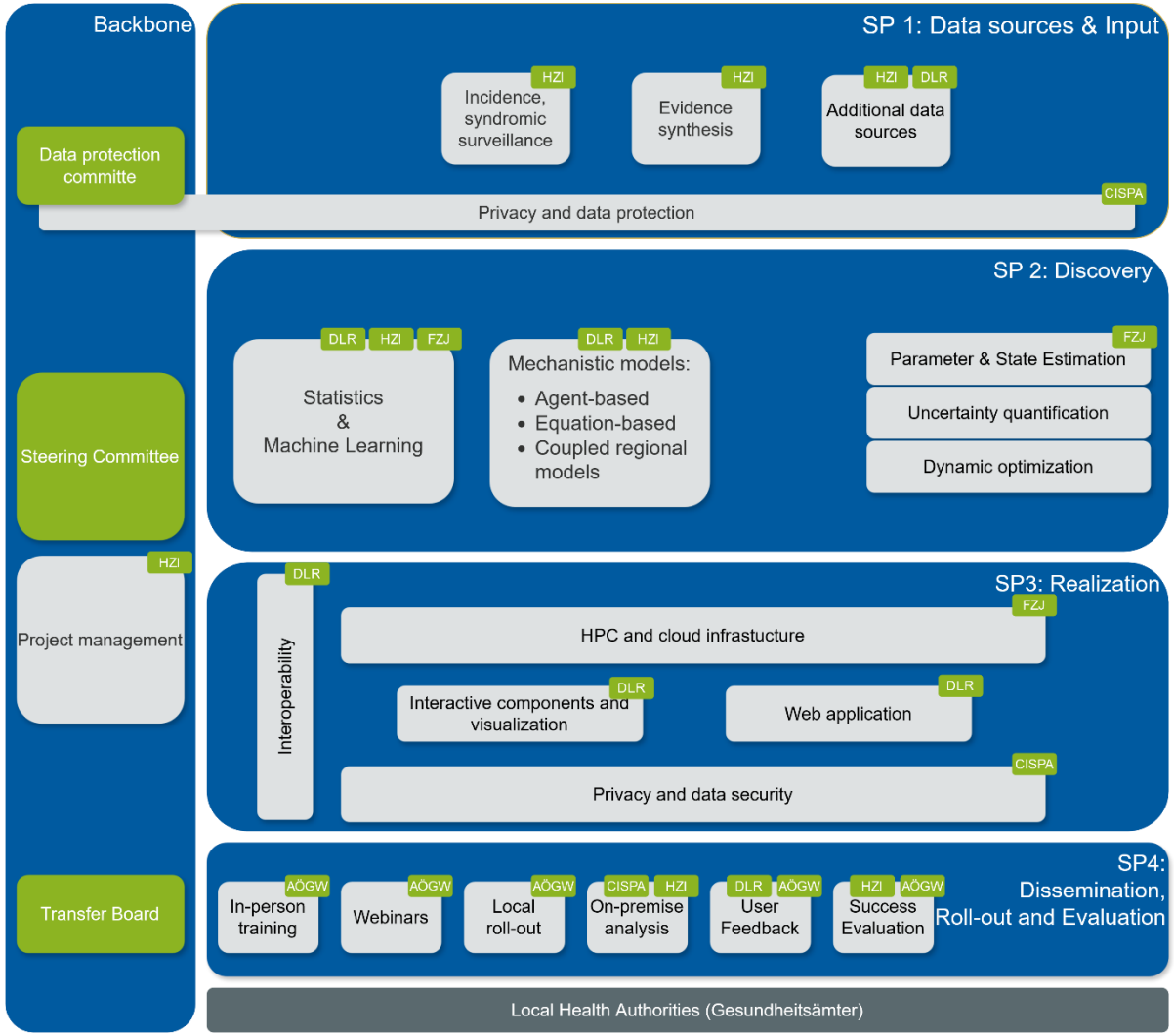
JÜLICH Forschungszentrum

CISPA HELMHOLTZ-ZENTRUM FÜR INFORMATIONSSICHERHEIT

AÖGW AKADEMIE FÜR ÖFFENTLICHES GESUNDHEITSWESEN

UFZ HELMHOLTZ Zentrum für Umweltforschung

ROBERT KOCH INSTITUT



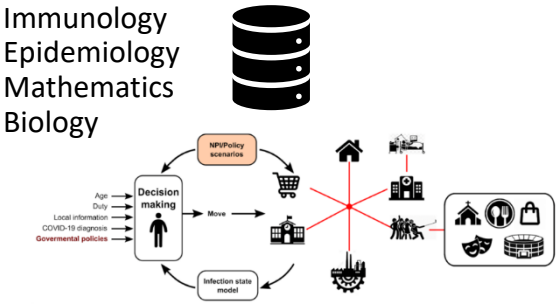
Realization of objectives: User-centered and just-in-time

HELMHOLTZ LOKI Pandemics

User-centered & interdisciplinary approach

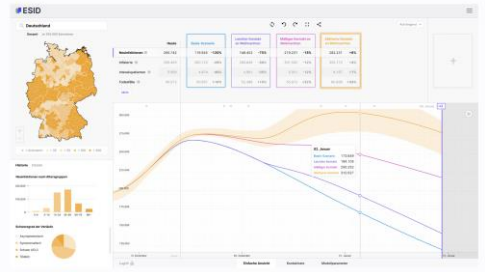
- → developed according to needs
- → regular exchange and testing
- → combine expertise of many different domains

Immunology
Epidemiology
Mathematics
Biology



Design
Visualization
User experience

Public health



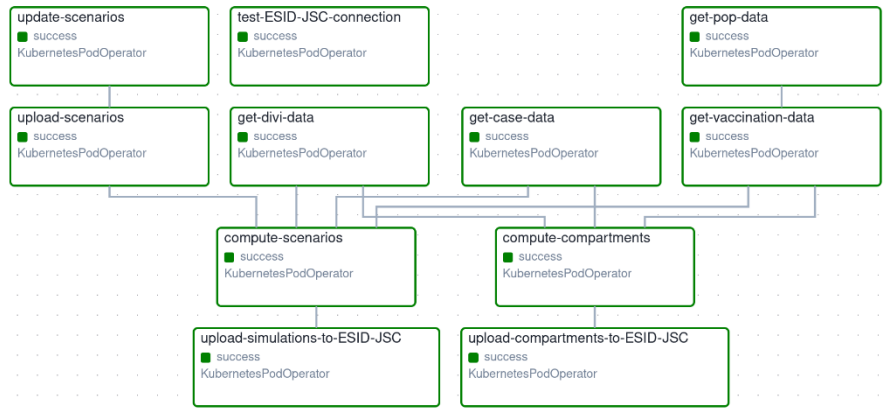
Visualization
Web development

Computer Science
High-Performance Computing

LOKI Project Feedback Loop
Success of an interdisciplinary approach

Automatized & scalable approach

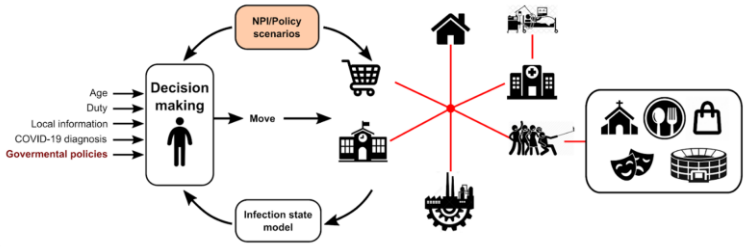
- → combine *science and transfer*
- → immediate processing of data
- → just-in-time computation through HPC
- → no delay through human interaction



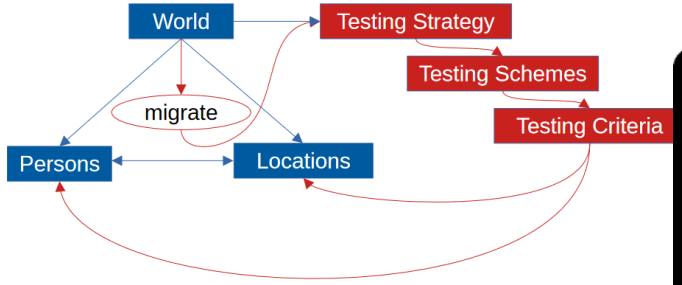
Local and reliable results on time: Stochastic individual model

HELMHOLTZ LOKI Pandemics

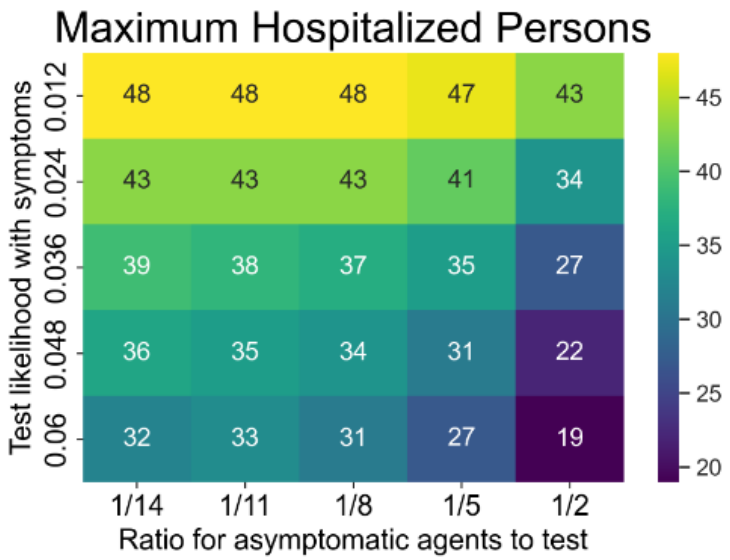
Individual stochastic model

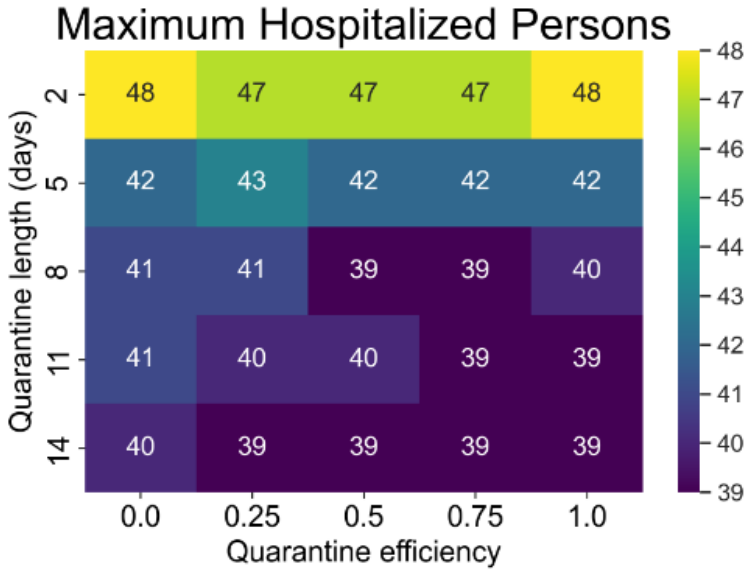


Evaluation of test strategies



HPC capable software framework





Very fast city-scale simulation

Per 1 million agents (on consumer laptop):

- 500 MB memory
- 0.08 sec run time

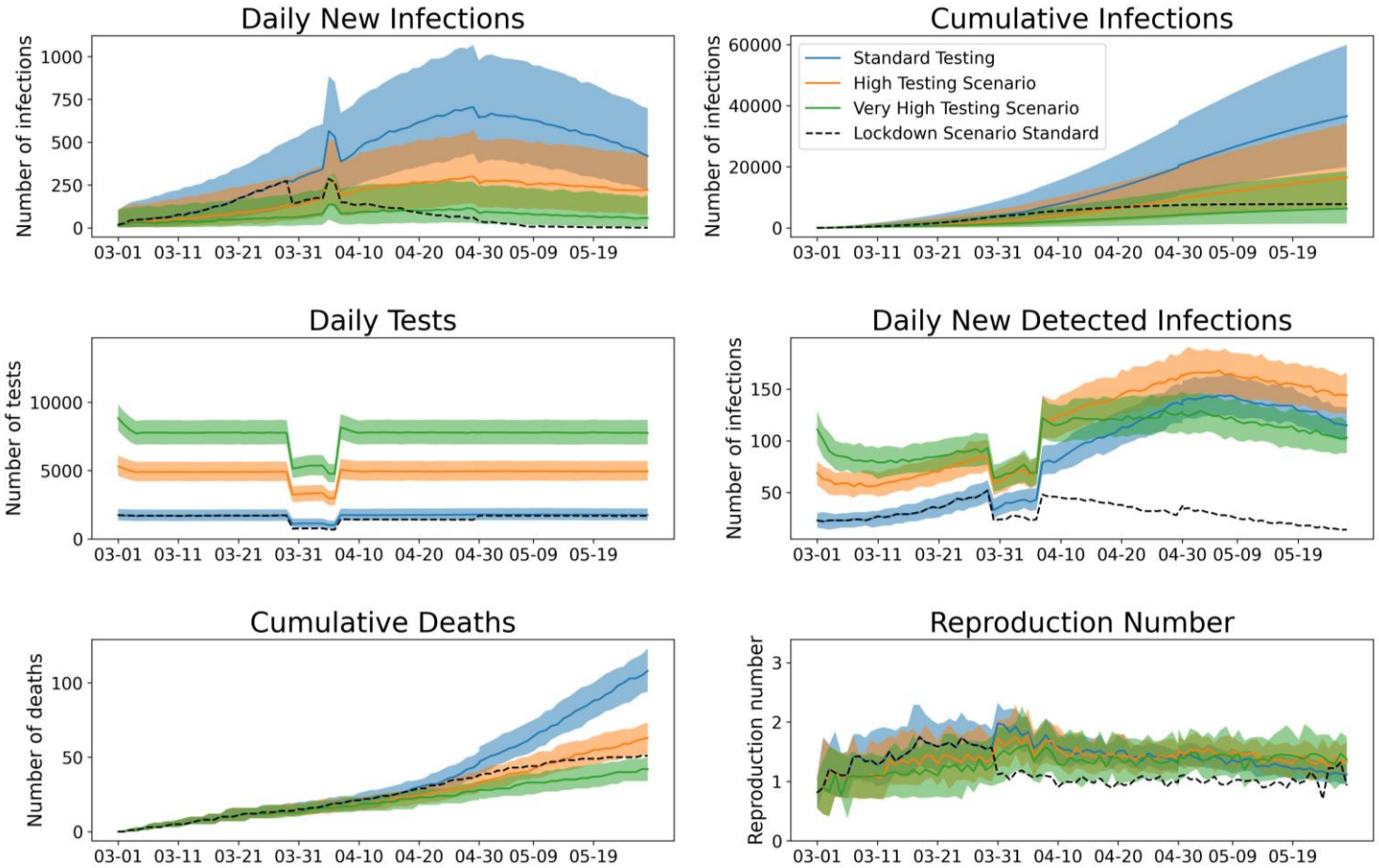
HPC-capable

- Ensemble runs conducted on 3,456 cores of JURECA-DC at FZJ

Detailed results in
Kerkmann, Korf et al., *Agent-based modeling for realistic reproduction of human mobility and contact behavior to evaluate test and isolation strategies in epidemic infectious disease spread. Computers in Biology and Medicine 193 (2025): 110269.*

Local and reliable results on time: Stochastic individual model

HELMHOLTZ LOKI Pandemics



HPC capable software framework

Very fast city-scale simulation

Per 1 million agents (on consumer laptop):

- 500 MB memory
- 0.08 sec run time

HPC-capable

- Ensemble runs conducted on 3,456 cores of JURECA-DC at FZJ

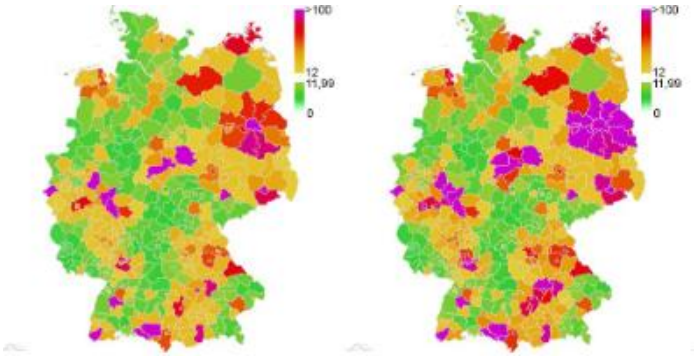
Detailed results in
Kerkmann, Korf et al., *Agent-based modeling for realistic reproduction of human mobility and contact behavior to evaluate test and isolation strategies in epidemic infectious disease spread. Computers in Biology and Medicine 193 (2025): 110269.*

Local, surrogate and Machine Learning + privacy preservation

HELMHOLTZ LOKI Pandemics

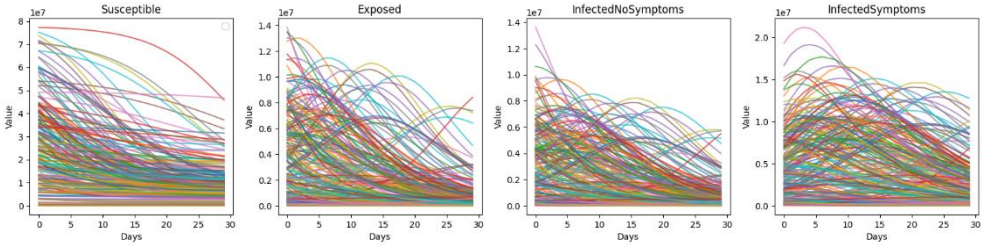
Spatially resolved models and dynamics NPIs

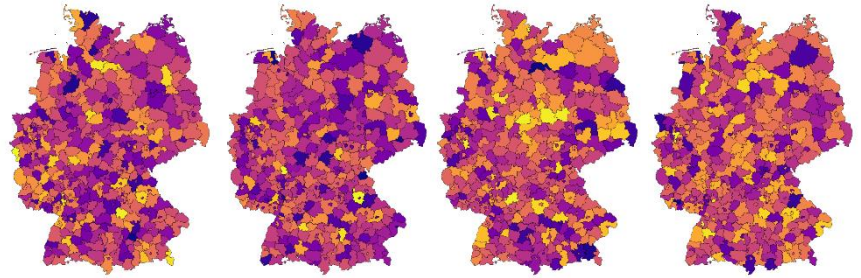
"NoCovid" or "Bundesnotbremse" for Counties

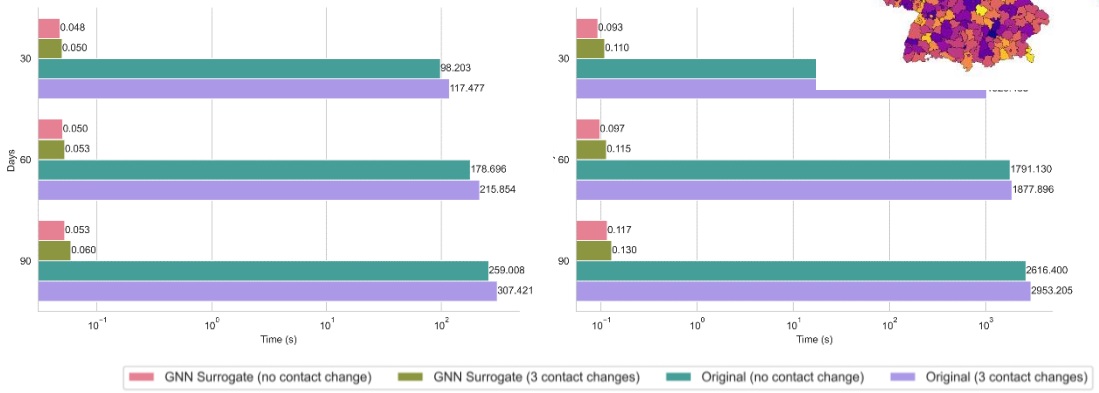


Kühn et al (2022)

Towards just-in-time and on-demand for LHAs



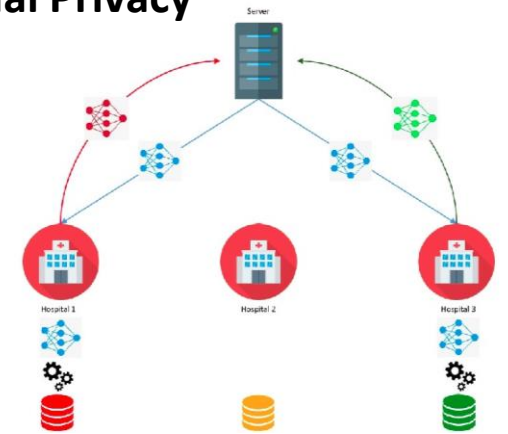


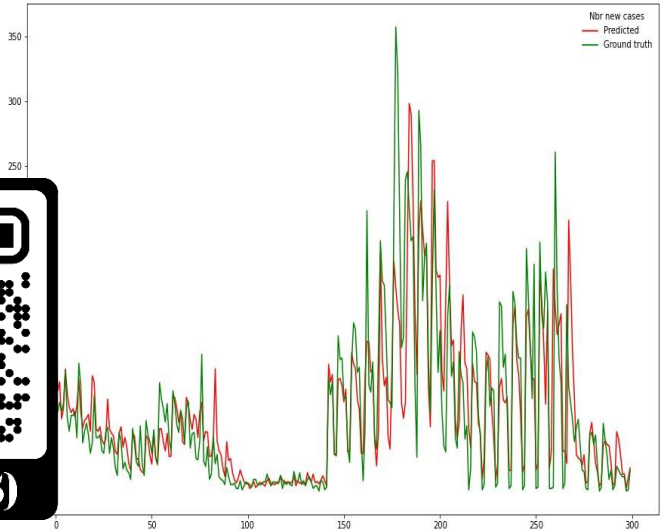


→ **speed-up: 220 – 28,000**

A. Schmidt, H. Zunker, A. Heinlein, M. J. Kühn *Graph Neural Network Surrogates to leverage Mechanistic Expert Knowledge towards Reliable and Immediate Pandemic Response (2025).*

Federated Learning with Differential Privacy

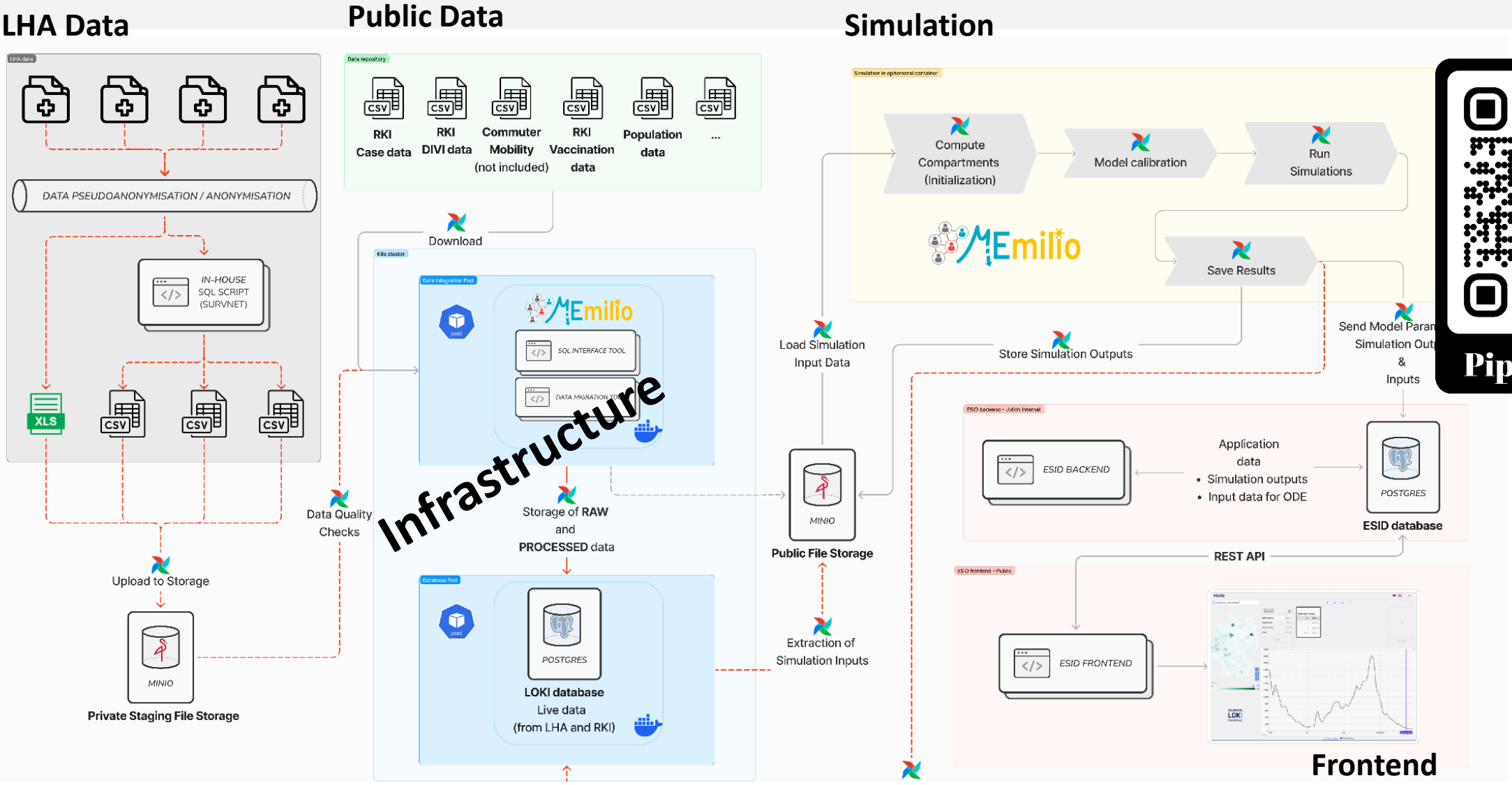




GNN (2025)

Kerkouche et al (In preparation, 2024)

Fully automated data flow and processing pipeline



S. Memon, J. F. Jadebeck, M. Osthege, A. Wendler, D. Kerkmann, H. Zunker, J. H. Göbbert, W. Wiechert, K. Nöh, M. Riedel, M. J. Kühn *Automated Processing of Pipelines Managing Now- and Forecasting of Infectious Diseases (2024). 47th MIPRO ICT and Electronics Convention (MIPRO), Opatija, Croatia, 2024, pp. 1157-1162*

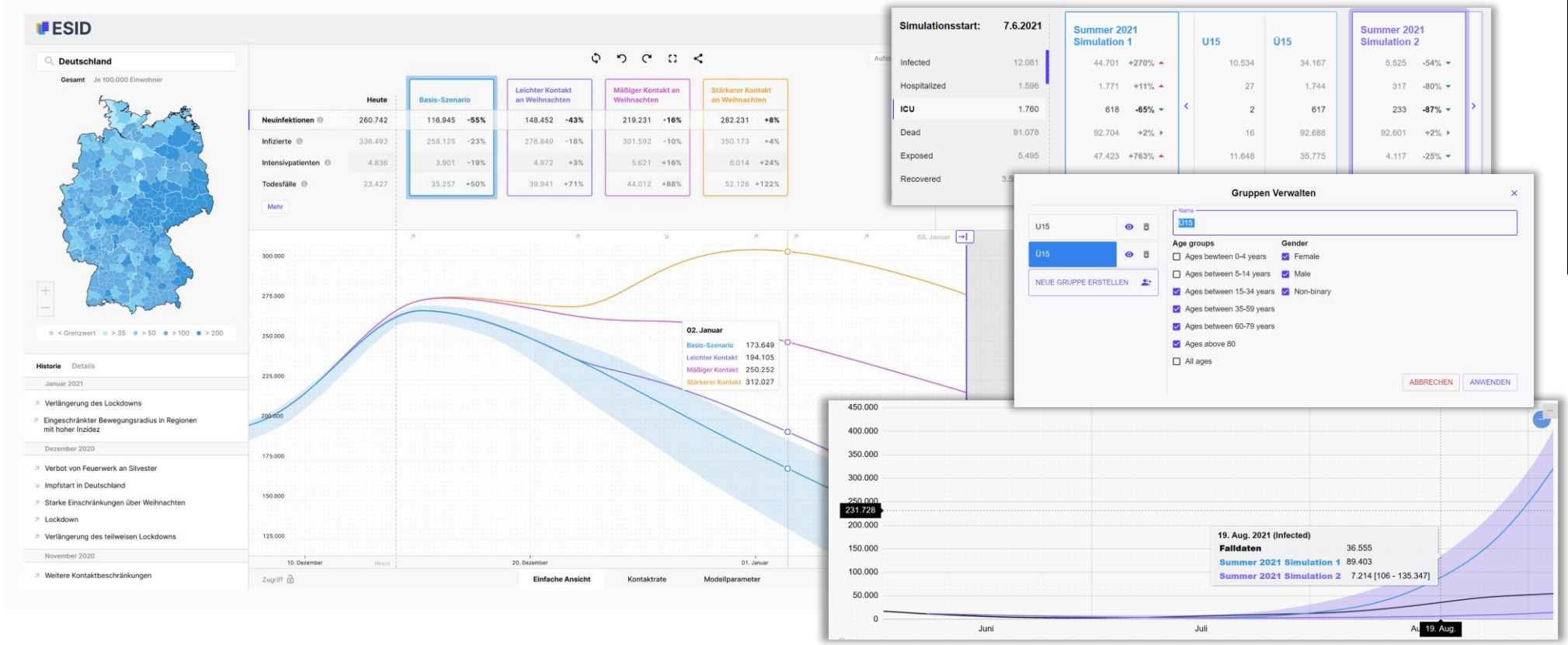
Intuitive User Interface and User Experience

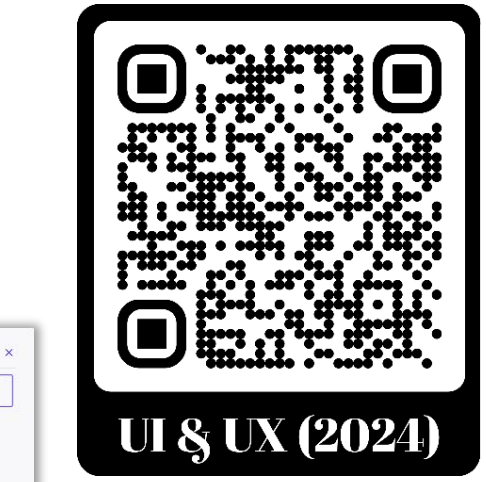
HELMHOLTZ LOKI Pandemics

System Usability Scale (SUS), John Brooke

Initial Score: Ø 79,5% (76,4%;82,6%)

>85%: Excellent
71%-85%: Good
51%-71%: Ok
<51%: Poor





P. Kaur Betz, J. Stoll , V. Grappendorf, J. Gilg, M. Zeumer , M. Klitz, L. Spataro, A. Klein, L. Rothenhäusler, H. Bohnacker, H. Krämer M. Meyer-Hermann, S. Somogyi, A. Gerndt and M. J. Kühn *ESID: Exploring the Design and Development of a Visual Analytics Tool for Epidemiological Emergencies. IEEE VIS Workshop on Visualization for Pandemic and Emergency Responses (Vis4PandEmRes) (2023)*

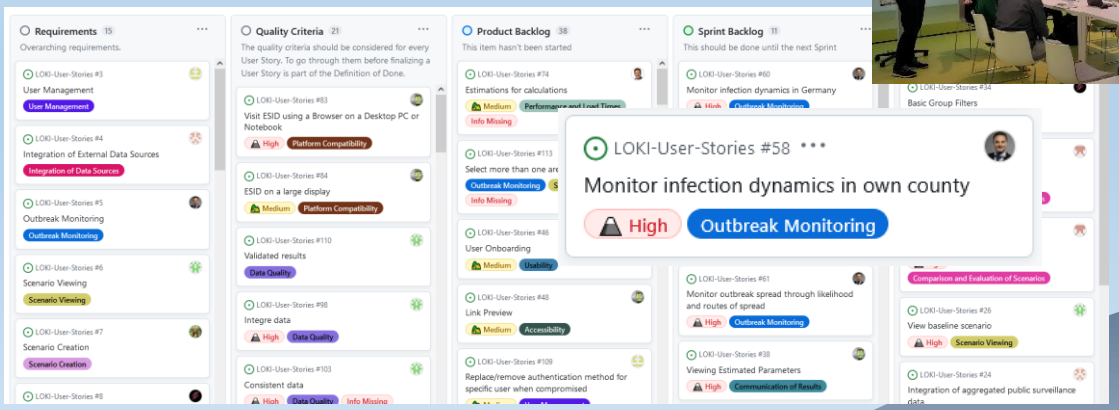
HZI HELMHOLTZ Zentrum für Infektionsforschung
DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center
JÜLICH Forschungszentrum
AOGW AKADEMIE FÜR ÖFFENTLICHES GESUNDHEITSWESEN
CISPA HELMHOLTZ-ZENTRUM FÜR INFORMATIONSSICHERHEIT
UFZ HELMHOLTZ Zentrum für Umweltforschung

User-centered: From user requirements to implementation

HELMHOLTZ LOKI Pandemics

Workshop on user story refinement

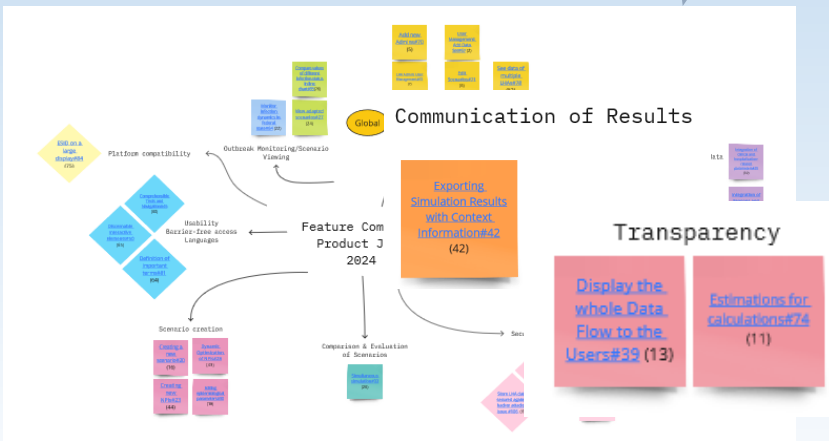
Kanban-Board for user stories



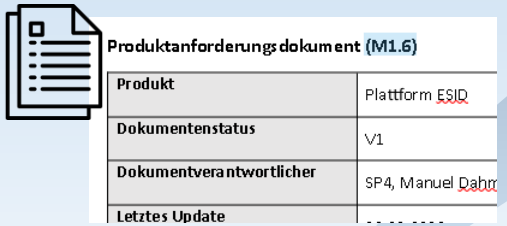
Designing **roadmap**

Monitoring of practical **implementation**

Development of **user stories**



Development of **user specified requirements**

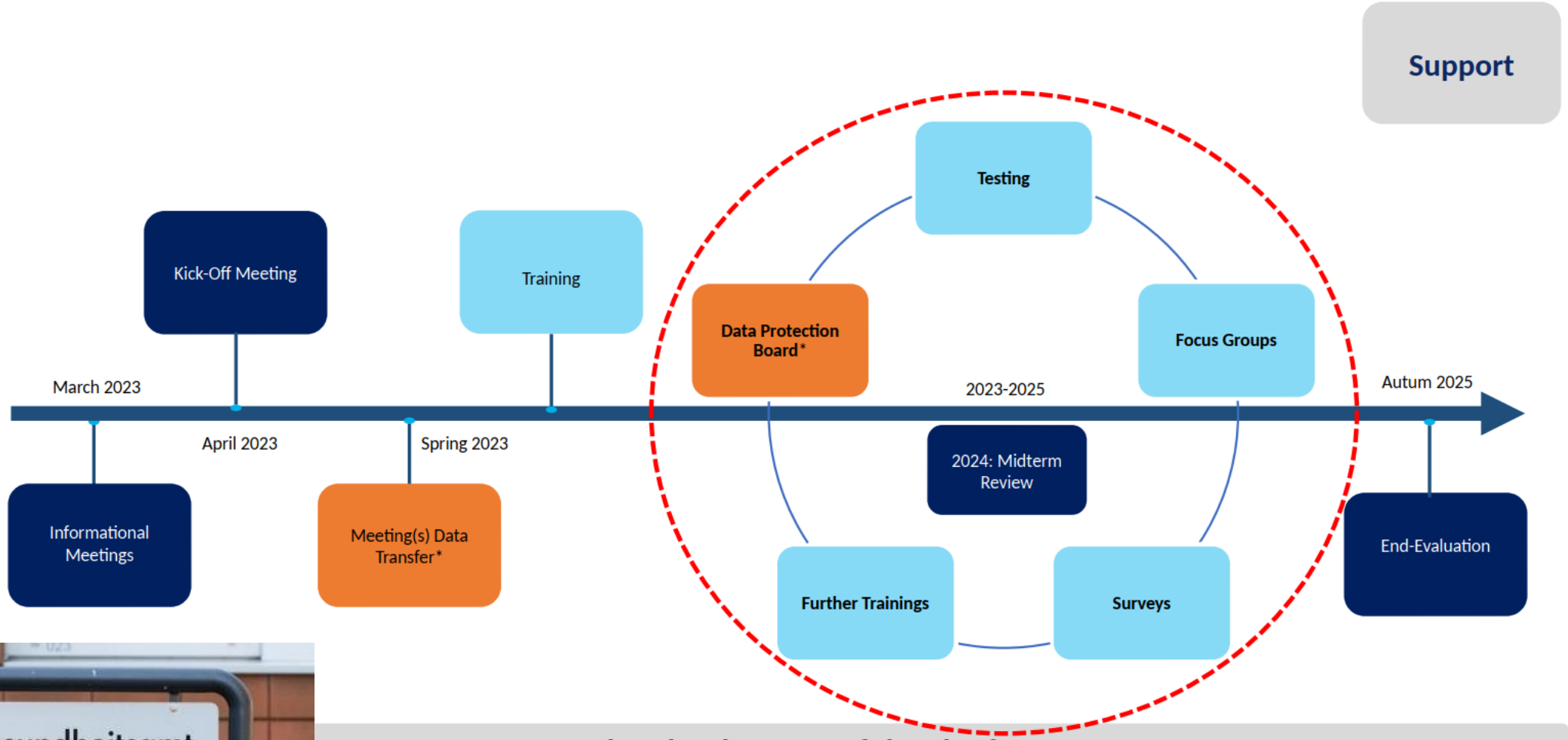


Produktanforderungsdokument (M1.6)

Produkt	Plattform ESID
Dokumentenstatus	V1
Dokumentverantwortlicher	SP4, Manuel Dahm
Letztes Update	

User-centered: User involvement and progress cycle

HELMHOLTZ LOKI Pandemics

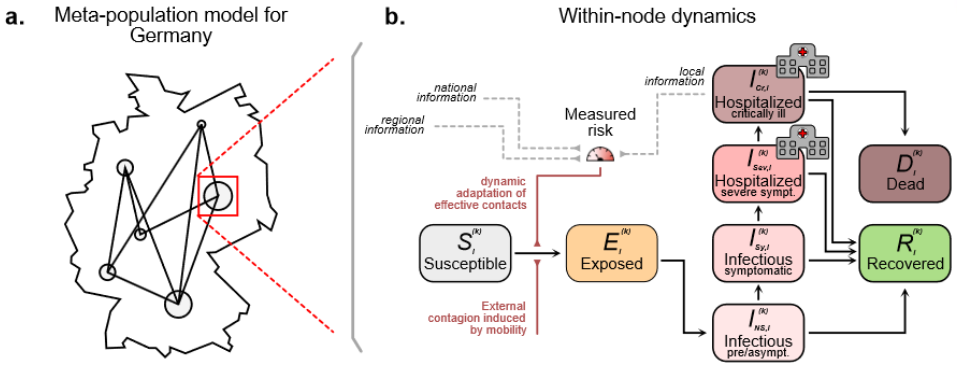


Side project: Inclusion of behavior

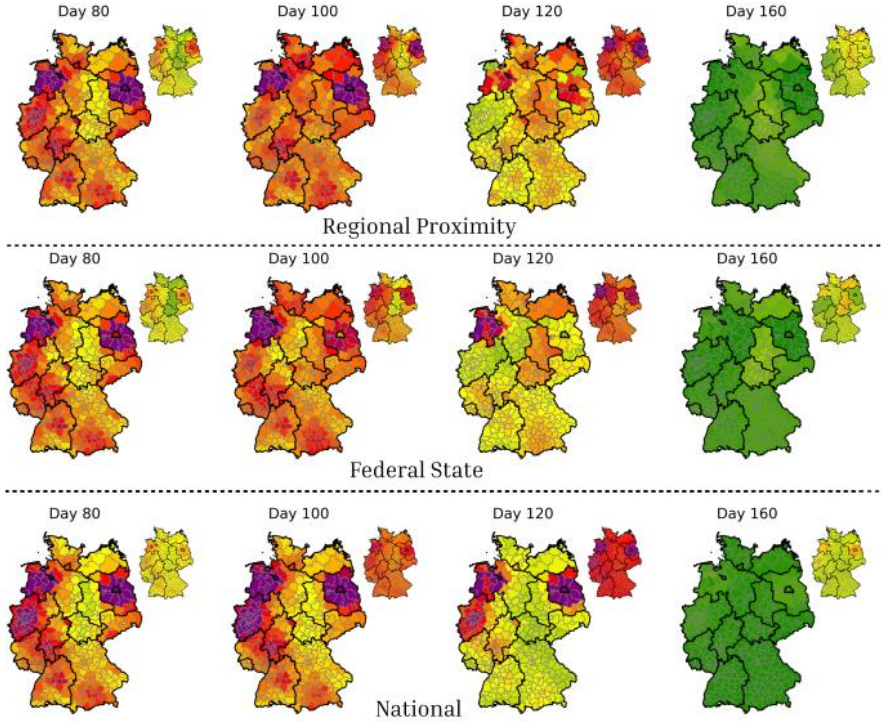
Cooperations with

- UFZ / COCAP / H. Zozmann
- MPG / S. Contreras

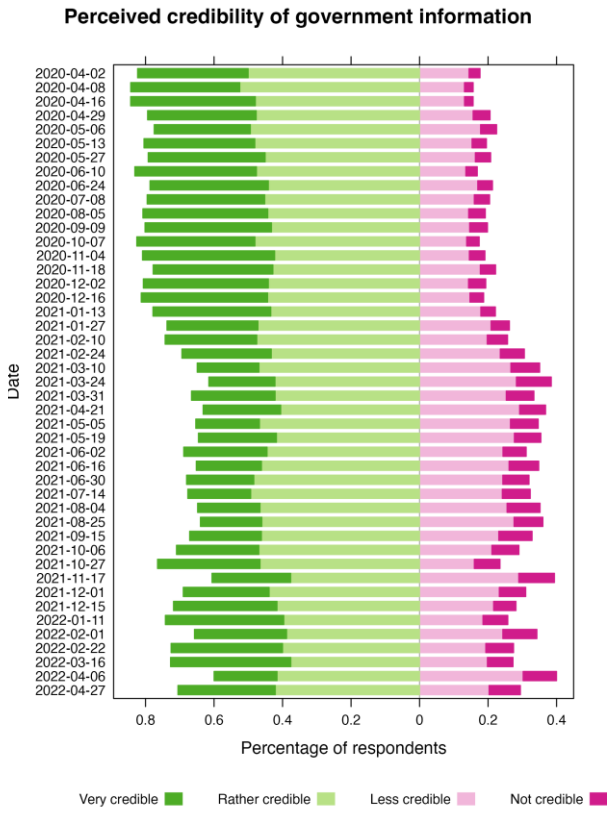
to integrate feedback and perception
to model disease dynamics



Zunker et al (submitted, 2025)



Risk (2025)

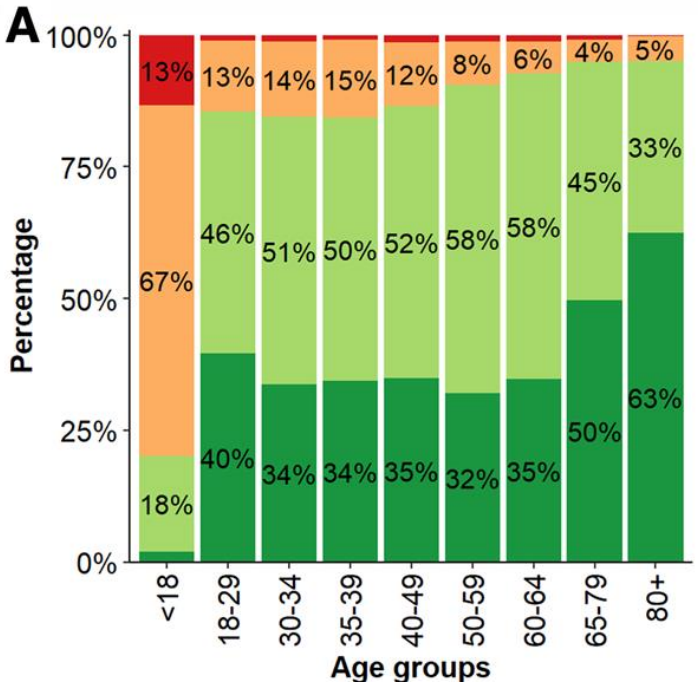


Zozmann et al (PLOS One, 2024)

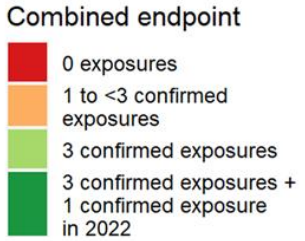
Dynamic immunity and dynamic public health system

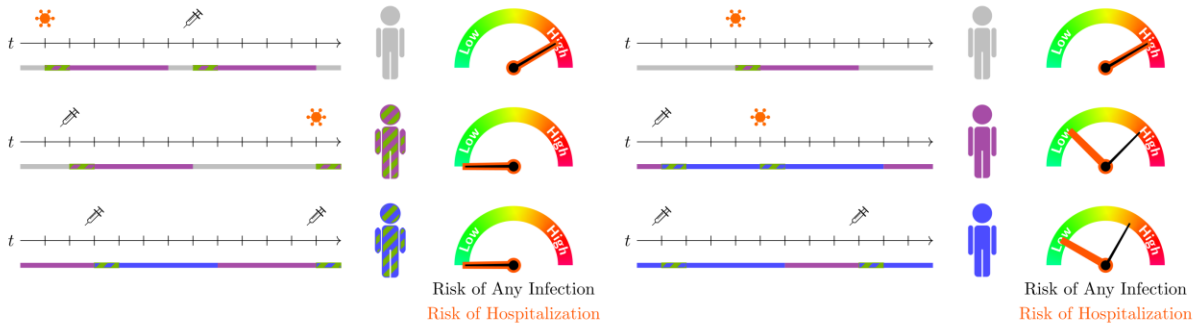
HELMHOLTZ LOKI Pandemics

Adapt to heterogeneous immunity landscape and waning immunity

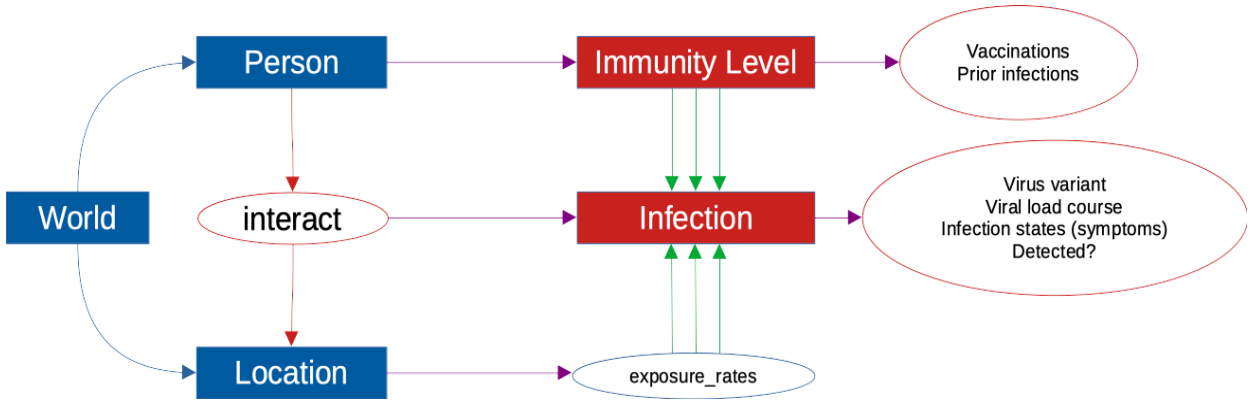


Lange et al (Infection, 2024)





Zunker (PLOS Comp, 2024)



Kerkmann (2024)

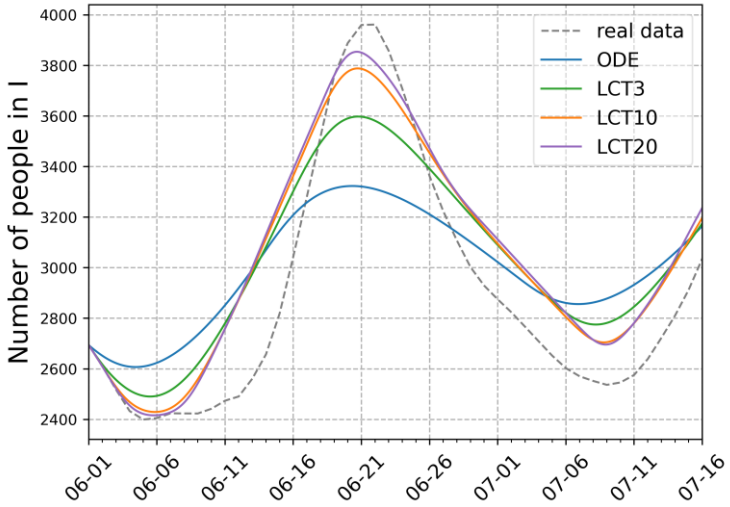
Metapop (2024)

ABM (2024)

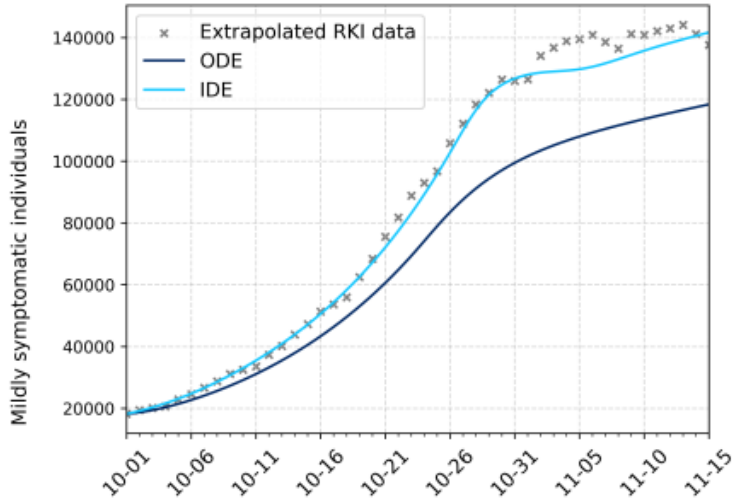
Better models for change points and improved parameters

HELMHOLTZ LOKI Pandemics

Develop more suitable models for change points (nonpharmaceutical interventions/NPIs)



L. Plötzke, A. Wendler, R. Schmieding, M. J. Kühn *Revisiting the Linear Chain Trick in epidemiological models: Implications of underlying assumptions for numerical solutions. Mathematics and Computers in Simulation 239, pp. 823-844 (2026)*

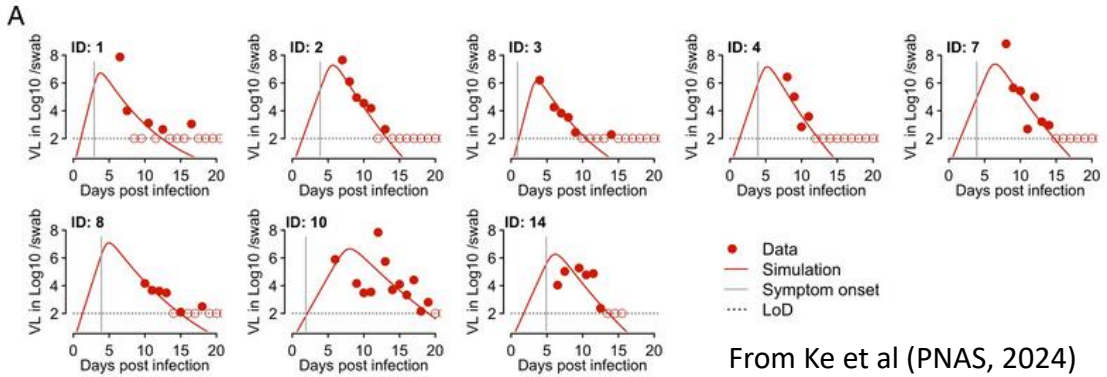


A. Wendler, L. Plötzke, H. Tritzschak, M. J. Kühn *A nonstandard numerical scheme for a novel SECIR integro-differential equation-based model allowing nonexponentially distributed stay times. Applied Mathematics and Computation 509, 129636 (2026)*

Chain Trick (2024)

IDE (2024)

Findings (parameters) improve models: Direct benefit from research community



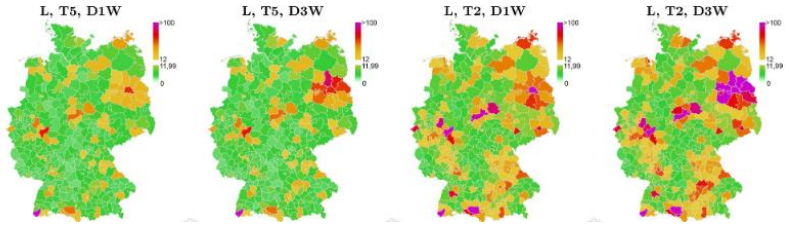
From Ke et al (PNAS, 2024)

Summary

Science and transfer for sustainable pandemic preparedness

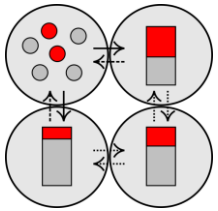
Localized

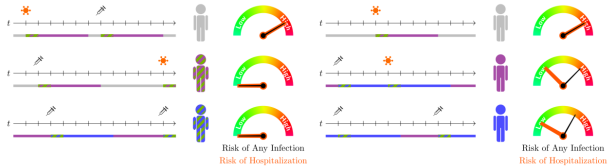
→ enables suitable control



Modeling expertise

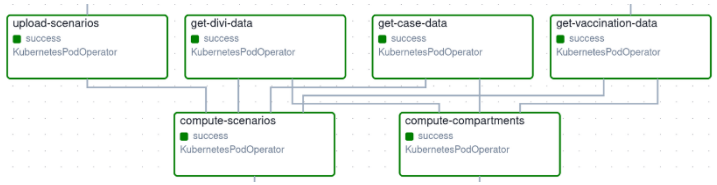
→ Large variety of models to deploy and compare





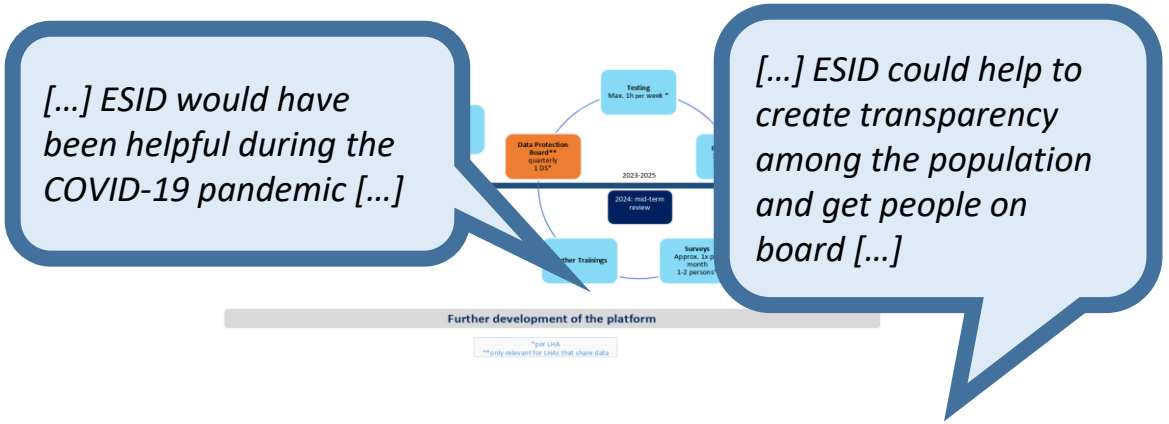
Automatized & scalable

→ no delays, swift reactions



User-centered

→ developed according to needs



National and international cooperation

→ Using and creating synergies

HELMHOLTZ LOKI Pandemics

Backup slides

Filters (age and gender)

(scenario) Cards with case numbers

Infection prevention and infection control/ outbreak management

Pandemic management:
- → Better planning of resources
- → Increase call for vaccination
- → Recommendations for hospitals, care facilities or outpatient care
- → Risk assessment (and testing) concepts for vulnerable areas and facilities
- → Evidence-based introduction of NPI's

Surveillance and monitoring

→ Early recognition of infection dynamics

Parameters

Crisis management
- → Better planning of resources
- → Optimization for crisis communication
- → Information/ recommendations to citizens

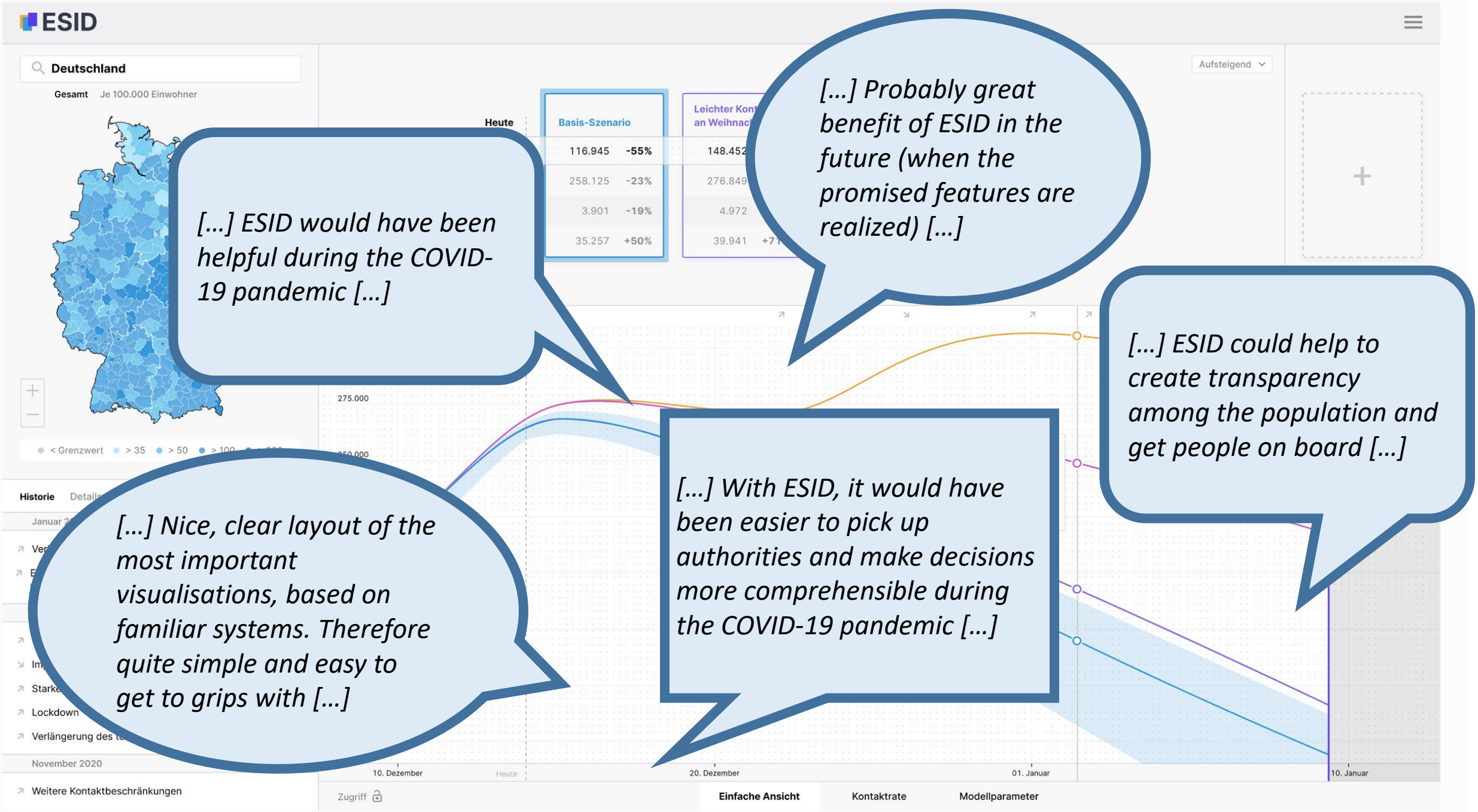
Export function

County/district based choropleth map

Supraregional outbreak management

→ Early recognition of infection dynamics (also in other counties)

Line chart comparing the scenarios


ESID
Deutschland
Gesamt
Je 100.000 Einwohner
Heute
Basis-Szenario
116.945 -55%
258.125 -23%
3.901 -19%
35.257 +50%
Aufsteigend
275.000
Historie
Januar 2
November 2020
Lockdown
Weitere Kontaktbeschränkungen
10. Dezember
Heute
20. Dezember
01. Januar
10. Januar
Zugriff
Einfache Ansicht
Kontaktrate
Modellparameter
[…] ESID would have been helpful during the COVID-19 pandemic […]
[…] Probably great benefit of ESID in the future (when the promised features are realized) […]
[…] ESID could help to create transparency among the population and get people on board […]
[…] With ESID, it would have been easier to pick up authorities and make decisions more comprehensible during the COVID-19 pandemic […]
[…] Nice, clear layout of the most important visualisations, based on familiar systems. Therefore quite simple and easy to get to grips with […]