

Edward Hill

Curriculum Vitae

December 2025

Address: Civic Health Innovation Labs (CHIL) & Institute of Population Health, University of Liverpool, Liverpool, UK.

Email: Edward.Hill@liverpool.ac.uk

Web: <https://edmhill.github.io/>

ORCID iD: 0000-0002-2992-2004

Nationality: British

Research Interests

Mathematical epidemiology | Infectious disease modelling | Public health | One health | Data science

Addressing interdisciplinary problems in epidemiology that involve the dynamics of behaviour. I have particular interests in public, veterinary and plant health policy, including zoonoses and the implementation of One Health approaches to disease management. My approach involves applying mathematical and computational methods, including the development of models, parameter inference and the evaluation of interventions via computational simulation.

Appointments

Sep 2024 -	Tenure Track Fellow in Health Protection Data Science , Civic Health Innovation Labs and Institute of Population Health, University of Liverpool.
Sep 2022 - Aug 2024	Warwick Zeeman Lecturer , Warwick Mathematics Institute, University of Warwick.
Jun 2017 - Sep 2022	Research Fellow , Zeeman Institute: SBIDER, University of Warwick.

Education

Sep 2013 - Aug 2017	PhD in Interdisciplinary Mathematics and Complexity Science. University of Warwick. Supervised by Dr. Thomas House and Dr. Michael Tildesley. Funded by EPSRC. Viva Date: June 2017. Postgraduate Certificate in Transferable Skills in Science. University of Warwick.
Sep 2012 - Sep 2013	MSc in Complexity Science, with Distinction. University of Warwick. Mini-project one: <i>Multi-host modelling of influenza A</i> . Mini-project two: <i>Social networks and health</i> . Funded by EPSRC.
Sep 2008 - June 2012	Master of Mathematics (MMath), with 1st class honours. University of Warwick. Final year project: <i>Optimal Vaccination</i> .

Grant Funding

Active grants

- Apr 2024 - Feb 2028 BBSRC. *Modelling to inform interventions during Highly Pathogenic Avian Influenza outbreaks in Great Britain*. Award: £838,305. Role: Co-Investigator (Co-I).
- Sep 2023 - Aug 2026 NIHR. *Mathematical and economic modelling for vaccination and immunisation evaluation (MEMVIE) 3*. Award: £900,000. Role: Co-I.

Previous grants

- Oct 2023 - Oct 2024 Bill & Melinda Gates Foundation. *Investigation of vaccination strategies to facilitate elimination of foot-and-mouth disease in India*. Award: £86,928. Role: Co-I.
- Oct 2022 - Oct 2023 Bill & Melinda Gates Foundation. *Investigation of vaccination strategies to facilitate elimination of foot-and-mouth disease in India*. Award: £180,029. Role: Co-I.
- Jan 2023 - Aug 2023 World Health Organization. *Modelling the impacts of current and variant adapted vaccines on VOC transmission dynamics*. Award: \$125,000. Role: Co-I.
- Jan 2023 - Mar 2023 NERC. *Quantifying the Impact of HPAI in the UK wild bird population*. Award: £19,968. Role: Co-Principal Investigator (PI).
- Sep 2022 - Mar 2023 BBSRC. *Furthering our understanding of the intercontinental transmission dynamics of avian influenza*. Award: £19,990. Role: PI.

Teaching

Awards

2024 *Fellowship of the Higher Education Academy*, Advance HE.
 Fellowships are awarded based on evidence of personal professional practice that meets the requirements of the Professional Standards Framework 2023, the standards framework for the higher education sector.

Lecturing

2025 - 2026 Delivered workshops on 'Health Policy: the role of evidence' to Year 3 students on the *MBChB medicine programme*, University of Liverpool.

2024 - 2025 Delivered interactive lectures for two MSc level modules *DASC505 Actionable Healthcare Data Analytics* & *IVES724 Understanding models and data*, University of Liverpool.

2023 - 2024 Module organiser and lecturer for *MA4E7 Population Dynamics: Ecology and Epidemiology*, University of Warwick.

2022 - 2024 Module co-organiser for *MA4K8 MA4K9 Projects*, University of Warwick. Core module for 4th year MMath students.

2017 - 2022 Lecturer/workshop assistant for taught module, *Mathematical Modelling*, delivered to postgraduate students in the Midland Integrative Biosciences Training Partnership doctoral training programme, University of Warwick. Delivered one lecture in a set of four workshop sessions. Discussed and aided students with workshop questions. Involved in marking the final assignment for the module..

PhD student supervision

The following students have passed their PhD:

2022 - 2026 Lead supervisor for Phoebe Asplin (MathSys CDT, University of Warwick).

2021 - 2025 Co-supervisor for Zak Ogi-Gittins (MathSys CDT, University of Warwick).

The following students are currently undertaking their PhD:

2024 - present Co-supervisor for Fateen Yasir (MathSys CDT, University of Warwick).

2024 - present Co-supervisor for Reanna Gregory (Institute for Global Pandemic Planning, University of Warwick).

2023 - present Co-supervisor for Elliot Vincent (MathSys CDT, University of Warwick).

2022 - present Lead supervisor for Rachel Seibel (MathSys CDT, University of Warwick).

Masters and undergraduate student supervision

I have supervised these projects at the University of Liverpool.

2025 Health Data Science MSc Dissertation project supervision (module code: DASC500). Student: Praise Ilechukwu.

I have supervised these projects at the University of Warwick.

2024 Supervision of two URSS (Undergraduate Research Support Scheme) projects at the University of Warwick. Project duration of eight weeks. Students: Alfie Ballinger, Scott Iyengar.

2023 - 2024 MMath Research project supervision (module code: MA4K9). Student: Andi Hani.

2023 Mathematics MSc Dissertation project supervision. Student: Alec Hodgson.

2022 - 2023 MMath Research project supervision (MA4K9). Student: Joe Brooks.

2022 Lead supervisor of two MSc Individual Research Projects (MA931). Students: Phoebe Asplin & Rachel Seibel.

2022 Academic co-leader for an MSc Research Study Group Project (MA932) in collaboration with the Department for Education.

2021 Lauren Adams, Masters in Public Health Professional Project (PC950).

2021 MSc Individual Research Project (MA931) co-supervision . Student: Zak Ogi-Gittins.

2021 Academic co-leader for an MSc Research Study Group Project (MA932) in collaboration with Public Health England.

2020 - 2021 Co-supervision of two MMath Research projects (MA4K9). Students: Panoraia Chortaria and Joel Kandiah.

Support classes

2015 - 2016 Teaching Assistant for 4th year undergraduate Mathematics module *Population Dynamics: Ecology and Epidemiology*, University of Warwick. Planned and ran support class sessions.

2011 - 2014 Supervisor for 1st year undergraduate Mathematics students, University of Warwick. Assigned groups of 4/5 students. Marked student assignments. Discussed assignments and other course material with the students.

Publications

Peer-reviewed journal articles

1. Prosser NS, Ferguson E, Kaler J, **Hill EM**, Tildesley MJ, Keeling MJ, Green MJ. (2025) Between-country differences in the psychosocial profiles of British cattle farmers. *Veterinary Record*. e5672. doi:10.1002/vetr.5672.
2. Sherratt K, Carnegie AC, Kucharski A, Cori A, Pearson CAB, **Hill EM**, Fearon E, Nightingale E, Arenas JV, Pi L, Davies N, van Elsland S, Funk S, Liu Y, Abbott S. (2025) Improving modelling for epidemic response: a progress update from a community of UK infectious disease modellers. *Interface Focus*, **15**(4): 20250007. doi:10.1098/rsfs.2025.0007.
3. Vincent EMR, **Hill EM**, Parnell S. (2025) Modelling the effectiveness of Integrated Pest Management strategies for the control of *Septoria tritici* blotch. *PLoS Computational Biology*, **21**(8): e1013352. <https://doi.org/10.1371/journal.pcbi.1013352>.
4. Higgins D, Looker J, Sunnucks R, Carruthers J, Finnie T, Keeling MJ, **Hill EM**. (2025) Introducing a framework for within-host dynamics and mutations modelling of H5N1 influenza infection in humans. *Journal of the Royal Society Interface*, **22**(228): 20240910. doi:10.1098/rsif.2024.0910.
5. Seibel RL, Tildesley MJ, **Hill EM**. (2025) Unifying human infectious disease models and real-time awareness of population- and subpopulation-level intervention effectiveness. *Royal Society Open Science*, **12**(6): 241964. doi:10.1098/rsos.241964.
6. Prosser NS, **Hill EM**, Gow L, Cavallaro M, Tildesley MJ, Keeling MJ, Kaler J, Ferguson E, Green MJ. (2025) Descriptive analysis of national bovine viral diarrhoea test data in England (2016-2023). *Veterinary Record*, **197**(6): 112135. e5325. doi:10.1002/vetr.5325.
7. Curran-Sebastian J, Dyson L, **Hill EM**, Pellis L, Hall I, House TA. (2025) Probability of Extinction and Peak Time for Multi-Type Epidemics with Application to Covid-19 Variants of Concern. *Journal of Theoretical Biology*, **608**: 112135. doi:10.1016/j.jtbi.2025.112135.
8. Ogi-Gittins I, Polonsky J, Keita M, Ahuka-Mundeke S, Hart WS, Plank MJ, Lambert B, **Hill EM**, Thompson RN. (2025) Real-time inference of the end of an outbreak: Temporally aggregated disease incidence data and under-reporting. *Infectious Disease Modelling*, **10**(3): 935-945. doi: 10.1016/j.idm.2025.03.009.
9. Ogi-Gittins I, Steyn N, Polonsky J, Hart WS, Keita M, Ahuka-Mundeke S, **Hill EM**, Thompson RN. (2025) Simulation-based inference of the time-dependent reproduction number from temporally aggregated and under-reported disease incidence time series data. *Philosophical Transactions of the Royal Society A*, **383**: 20240412. doi: 10.1098/rsta.2024.0412.
10. Keeling MJ, **Hill EM**, Petrou S, Tran PB, Png ME, Staniszewska S, Clark C, Hassel K, Stowe J, Andrews N. (2025) Cost-effectiveness of routine COVID-19 adult vaccination programmes in England. *Vaccine*, **54**: 126948. doi:10.1016/j.vaccine.2025.126948.
11. **Hill EM**, Ryan M, Haw D, Lynch MP, McCabe R, Milne AE, Turner MS, Vedhara K, Zeng F, Barons MJ, Nixon EJ, Parnell S, Bolton KJ. (2024). Integrating human behaviour and epidemiological modelling: unlocking the remaining challenges. *Mathematics in Medical and Life Sciences*, **1**(1): 2429479. doi: 10.1080/29937574.2024.2429479.
12. Bouros I, **Hill EM**, Keeling MJ, Moore S, Thompson RN. (2024) Prioritising older individuals for COVID-19 booster vaccination leads to optimal public health outcomes in a range of socio-economic settings. *PLoS Computational Biology*, **20**(8): e1012309. doi:10.1371/journal.pcbi.1012309.
13. Asplin P, Mancy R, Finnie T, Cumming F, Keeling MJ, **Hill EM**. (2024) Symptom propagation in respiratory pathogens of public health concern: a review of the evidence. *Journal of the Royal Society Interface*, **21**(216): 20240009. doi:10.1098/rsif.2024.0009.

14. Asplin P, Keeling MJ, Mancy R, **Hill EM**. (2024) Epidemiological and health economic implications of symptom propagation in respiratory pathogens: A mathematical modelling investigation. *PLoS Computational Biology*, **20**(5): e1012096. doi:10.1371/journal.pcbi.1012096.
15. Ogi-Gittins I, Hart W, Song J, Nash R, Polonsky J, Cori A, **Hill EM**, Thompson RN. (2024) A simulation-based approach for estimating the time-dependent reproduction number from temporally aggregated disease incidence time series data. *Epidemics*. **47**: 100773. doi: 10.1016/j.epidem.2024.100773.
16. Sherratt K, ..., **Hill EM**, ... *et al.* (2024) Improving modelling for epidemic responses: reflections from members of the UK infectious disease modelling community on their experiences during the COVID-19 pandemic. *Wellcome Open Research*, **9**: 12. doi:10.12688/wellcomeopenres.19601.1.
17. Althobaity YM, Alkhudaydi MH, **Hill EM**, Thompson RN, Tildesley MJ. (2024) The time between symptom onset and various clinical outcomes: a statistical analysis of MERS-CoV patients in Saudi Arabia. *Royal Society Open Science*, **11**(11): 240094. doi:10.1098/rsos.240094.
18. **Hill EM**[†], Prosser NS[†], Brown PE, Ferguson E, Green MJ, Kaler J, Keeling MJ, Tildesley MJ. (2023) Incorporating heterogeneity in farmer disease control behaviour into a livestock disease transmission model. *Preventive Veterinary Medicine*, **219**: 106019. doi:10.1016/j.prevetmed.2023.106019.
[†] denotes joint first authors.
19. **Hill EM**. (2023) Modelling the epidemiological implications for SARS-CoV-2 of Christmas household bubbles in England. *Journal of Theoretical Biology*, **557**: 111331. doi:10.1016/j.jtbi.2022.111331.
20. Keeling MJ, Moore S, Penman B, **Hill EM**. (2023) The impacts of SARS-CoV-2 vaccine dose separation and targeting on the COVID-19 epidemic in England. *Nature Communications*, **14**: 740. doi:10.1038/s41467-023-35943-0.
21. Chan YLE, Irvine MA, Prystajecy N, Sbihi H, Taylor M, Joffres Y, Schertzer A, Rose C, Dyson L, **Hill EM**, Tildesley MJ, Tyson JR, Hoang LMN, Galanis E. (2023) Emergence of SARS-CoV-2 Delta Variant and Effect of Nonpharmaceutical Interventions, British Columbia, Canada. *Emerging Infectious Diseases*, **29**(10): 1999–2007. doi:10.3201/eid2910.230055.
22. Guzman-Rincon LM, **Hill EM**, Thompson RN, Dyson L, Tildesley MJ, Keeling MJ. (2023) Bayesian estimation of real-time epidemic growth rates using Gaussian processes: local dynamics of SARS-CoV-2 in England. *Journal of the Royal Statistical Society Series C: Applied Statistics*, qlad056. doi:10.1093/jrssc/qlad056.
23. Eames KTD, Tang ML, **Hill EM**, Tildesley MJ, Read JM, Keeling MJ, Gog JR. (2023) Coughs, colds and “freshers’ flu” survey in the University of Cambridge, 2007–2008. *Epidemics*, **42**: 100659. doi:10.1016/j.epidem.2022.100659.
24. **Hill EM**, Prosser NS, Ferguson E, Kaler J, Green MJ, Keeling MJ, Tildesley MJ. (2022) Modelling livestock infectious disease control policy under differing social perspectives on vaccination behaviour. *PLoS Computational Biology*, **18**(7): e1010235. doi:10.1371/journal.pcbi.1010235.
25. Moore S, **Hill EM**, Dyson L, Tildesley MJ, Keeling MJ. (2022) Retrospectively modeling the effects of increased global vaccine sharing on the COVID-19 pandemic. *Nature Medicine*, **28**: 2416–2423. doi:10.1038/s41591-022-02064-y.
26. Prosser NS[†], **Hill EM**[†], Armstrong D, Gow L, Tildesley MJ, Keeling MJ, Kaler J, Ferguson E, Green MJ. (2022) Descriptive analysis of national bovine viral diarrhoea test data in England (2016–2020). *Veterinary Record*. **191**(5): e1854. doi:10.1002/vetr.1854.
[†] denotes joint first authors.

27. Keeling MJ, Dyson L, Tildesley MJ, **Hill EM**, Moore S. (2022) Comparison of the 2021 COVID-19 roadmap projections against public health data in England. *Nature Communications*, **13**: 4924. doi:10.1038/s41467-022-31991-0.
28. Tildesley MJ, Vassall A, Riley S, Jit M, Sandmann F, **Hill EM**, Thompson RN, Atkins BD, Edmunds J, Dyson L, Keeling MJ. (2022) Optimal health and economic impact of non-pharmaceutical intervention measures prior and post vaccination in England: a mathematical modelling study. *Royal Society Open Science*, **9**(8): 211746. doi:10.1098/rsos.211746.
29. Leng T, **Hill EM**, Keeling MJ, Tildesley MJ, Thompson RN. (2022) The effect of notification window length on the epidemiological impact of COVID-19 contact tracing mobile applications. *Communications Medicine*, **2**: 74. doi:10.1038/s43856-022-00143-2.
30. Leng T, **Hill EM**, Thompson RN, Tildesley MJ, Keeling MJ, Dyson L. (2022) Assessing the impact of lateral flow testing strategies on within-school SARS-CoV-2 transmission and absences: A modelling study. *PLoS Computational Biology*, **18**(5): e1010158. doi:10.1371/journal.pcbi.1010158.
31. Leng T, **Hill EM**, Holmes A, Southall E, Thompson RN, Tildesley MJ, Keeling MJ, Dyson L. (2022) Quantifying within-school SARS-CoV-2 transmission and the impact of lateral flow testing in secondary schools in England. *Nature Communications*, **13**: 1106. doi:10.1038/s41467-022-28731-9.
32. Prosser NS, Green MJ, Fergusson E, Tildesley MJ, **Hill EM**, Keeling MJ, Kaler J. (2022) Cattle farmer psychosocial profiles and their association with control strategies for bovine viral diarrhoea. *Journal of Dairy Science*, **105**(4): 3559–3573. doi:10.3168/jds.2021-21386.
33. Keeling MJ, Dyson L, Guyver-Fletcher G, Holmes A, Semple MG, ISARIC4C Investigators, Tildesley MJ, **Hill EM**. (2022) Fitting to the UK COVID-19 outbreak, short-term forecasts and estimating the reproductive number. *Statistical Methods in Medical Research*, **31**(9): 1716–1737. doi:10.1177/09622802211070257.
34. Dyson L[†], **Hill EM**[†], ... *et al.* (2021) Possible future waves of SARS-CoV-2 infection generated by variants of concern with a range of characteristics. *Nature Communications*, **12**: 5730. doi:10.1038/s41467-021-25915-7.
[†] denotes joint first authors.
35. **Hill EM**, Keeling MJ. (2021) Comparison between one and two dose SARS-CoV-2 vaccine prioritization for a fixed number of vaccine doses. *Journal of the Royal Society Interface*, **18**(182): 20210214. doi:10.1098/rsif.2021.0214.
36. Enright J[†], **Hill EM**[†], Stage HB, Bolton KJ, Nixon EJ, Fairbanks EM, Tang, ML Brooks-Pollock E, Dyson L, Budd CJ, Hoyle RB, Schewe L, Gog JR, Tildesley MJ. (2021) SARS-CoV-2 infection in UK university students: Lessons from September-December 2020 and modelling insights for future student return. *Royal Society Open Science*, **8**(8): 210310. doi:10.1098/rsos.210310.
[†] denotes joint first authors.
37. **Hill EM**, Atkins BD, Keeling MJ, Tildesley MJ, Dyson L. (2021) Modelling SARS-CoV-2 transmission in a UK university setting. *Epidemics*, **36**: 100476. doi:10.1016/j.epidem.2021.100476.
38. **Hill EM**,[†] Atkins BD[†], Keeling MJ, Dyson L, Tildesley MJ. (2021) A network modelling approach to assess non-pharmaceutical disease controls in a worker population: An application to SARS-CoV-2. *PLoS Computational Biology*, **17**(6): e1009058. doi:10.1371/journal.pcbi.1009058. [†] denotes joint first authors.
39. Gog JR, **Hill EM**, Danon L, Thompson RN. (2021) Vaccine escape in a heterogeneous population: insights for SARS-CoV-2 from a simple model. *Royal Society Open Science*, **8**(7): 210530. doi:10.1098/rsos.210530.
40. Keeling MJ, Guyver-Fletcher G, Holmes A, Dyson L, Tildesley MJ, **Hill EM**, Medley GF. (2021) Precautionary breaks: planned, limited duration circuit breaks to control the

- prevalence of SARS-CoV-2 and the burden of COVID-19 disease. *Epidemics*, **37**: 100526. doi:10.1016/j.epidem.2021.100526.
41. Southall ER, Holmes A, **Hill EM**, Atkins BD, Leng T, Thompson RN, Dyson L, Keeling MJ, Tildesley MJ. (2021) An analysis of school absences in England during the Covid-19 pandemic. *BMC Medicine*, **19**: 137. doi:10.1186/s12916-021-01990-x.
 42. Keeling MJ, Tildesley MJ, Atkins BD, Penman B, Southall E, Guyver-Fletcher G, Holmes A, McKimm H, Gorsich E, **Hill EM**, Dyson L. (2021) The impact of school reopening on the spread of COVID-19 in England. *Philosophical Transactions of the Royal Society B*, **376**(1829): 20200261. doi:10.1098/rstb.2020.0261.
 43. Thompson RN, **Hill EM**, Gog JR. (2021) SARS-CoV-2 incidence and vaccine escape. *Lancet Infectious Diseases*, **21**(7): 913–914. doi:10.1016/S1473-3099(21)00202-4.
 44. Moore S, **Hill EM**, Tildesley MJ, Dyson L, Keeling MJ. (2021) Vaccination and non-pharmaceutical interventions for COVID-19: a mathematical modelling study. *Lancet Infectious Diseases*, **21**(6): 793–802. doi:10.1016/S1473-3099(21)00143-2.
 45. Moore S, **Hill EM**, Dyson L, Tildesley MJ, Keeling MJ. (2021) Modelling optimal vaccination strategy for SARS-CoV-2 in the UK. *PLoS Computational Biology*, **17**(5): e1008849. doi:10.1371/journal.pcbi.1008849.
 46. Keeling MJ, **Hill EM**, Gorsich E, Penman B, Guyver-Fletcher G, Holmes A, Leng T, McKimm H, Tamborrino M, Dyson L, Tildesley MJ. (2021) Predictions of COVID-19 dynamics in the UK: short-term forecasting and analysis of potential exit strategies. *PLoS Computational Biology*, **17**(1): e1008619. doi:10.1371/journal.pcbi.1008619.
 47. Stanizewska S, **Hill EM**, Grant R, Grove P, Porter J, Shiri T, Tulip S, Whitehurst J, Wright C, Datta S, Petrou S and Keeling MJ. (2021) Developing a Framework for Public Involvement in Mathematical and Economic Modelling: Bringing New Dynamism to Vaccination Policy Recommendations. *Patient*, **14**(4): 435–445. doi:10.1007/s40271-020-00476-x.
 48. **Hill EM**, Petrou S, Forster H, de Lusignan S, Yonova I, Keeling MJ. (2020) Optimising age coverage of seasonal influenza vaccination in England: A mathematical and health economic evaluation. *PLoS Computational Biology*, **16**(10): e1008278. doi:10.1371/journal.pcbi.1008278.
 49. **Hill EM**, Petrou S, de Lusignan S, Yonova I and Keeling MJ. (2019) Seasonal influenza: Modelling approaches to capture immunity propagation. *PLoS Computational Biology*, **15**(10): e1007096. doi:10.1371/journal.pcbi.1007096.
 50. Buckingham-Jeffery E[†], **Hill EM**[†], Datta S, Dilger E, Courtenay O. (2019) Spatio-temporal modelling of *Leishmania infantum* infection among domestic dogs: a simulation study and sensitivity analysis applied to rural Brazil. *Parasites & Vectors*, **12**: 215. doi:10.1186/s13071-019-3430-y. [†] denotes joint first authors.
 51. **Hill EM**, House T, Dhingra MS, Kalpravidh W, Mozaria S, Muzaffar GO, Brum E, Yamage M, Kalam MA, Prosser DJ, Takekawa JY, Xiao X, Gilbert M and Tildesley MJ. (2018) The impact of surveillance and control on highly pathogenic avian influenza outbreaks in poultry in Dhaka division, Bangladesh. *PLoS Computational Biology*, **14**(9): e1006439. doi:10.1371/journal.pcbi.1006439.
 52. Eyre RW, House T, **Hill EM** and Griffiths FE. (2017) Spreading of components of mood in adolescent social networks. *Royal Society Open Science*, **4**(9): 170336. doi:10.1098/rsos.170336.
 53. **Hill EM**, House T, Dhingra MS, Kalpravidh W, Mozaria S, Muzaffar GO, Yamage M, Xiao X, Gilbert M and Tildesley MJ. (2017) Modelling H5N1 in Bangladesh across spatial scales: Model complexity and zoonotic transmission risk. *Epidemics*, **20C**: 37–55. doi:10.1016/j.epidem.2017.02.007.
 54. **Hill EM**, Tildesley MJ and House T. (2017) Evidence for history-dependence of influenza pandemic emergence. *Scientific Reports*, **7**: 43623. doi:10.1038/srep43623.

55. **Hill EM**, Griffiths FE and House T. (2015) Spreading of healthy mood in adolescent social networks. *Proceedings of the Royal Society B*, **282**(1813): 20151180. doi:10.1098/rspb.2015.1180.

Book chapters

1. **Hill EM** and House T. (2019) Modelling the Spread of Mood. In: *Mood: Interdisciplinary Perspectives, New Theories*. Breidenback B and Docherty T (eds.). Milton Park, Abingdon, Oxon: Routledge. pp. 87–108.

Preprints

1. Ilechukwu P, Hungerford D, French N, **Hill EM**. (2025) Inequalities in childhood pneumococcal conjugate vaccine uptake in England before and after the change from a 2+1 to 1+1 schedule: a longitudinal study. *medRxiv*. doi:10.64898/2025.12.05.25341691.
2. Hadley L, Miled SB, Clapham HE, Djaafara BA, Dyson L, Funk S, Gog JR, Heesterbeek H, **Hill EM**, Howerton E, Isham V, Kebir A, Keeling M, Kissler SM, Lessler J, Leung K, McBryde E, McCaw JM, Mercado CEG, Mollison D, Thumbi SM, Pan-ngum W, Pellis L, Prez-Reche FJ, Plank MJ, Thompson RN, Tran-Kiem C. (2025) The elusive ‘policy maker’. *OSF*. doi: 10.17605/OSF.IO/T3UJN.
3. Stolle L, Bolton JS, Steventon R, Gregory R, ..., **Hill EM**, ... , Thompson CP. (2025) Divergent antibody-mediated population immunity to H5, H7 and H9 subtype potential pandemic influenza viruses. *medRxiv*. doi:10.1101/2025.09.08.25335309.
4. Davis CN, **Hill EM**, Jewell CP, Rysava K, Thompson RN, Tildesley MJ. (2025) A modelling assessment for the impact of control measures on highly pathogenic avian influenza transmission in poultry in Great Britain. *bioRxiv*. doi:10.1101/2025.04.24.650264.
5. Ryan M, Hickson RI, **Hill EM**, House T, Isham V, Zhang D, Roberts MG. (2025) A Behaviour and Disease Model of Testing and Isolation. *arXiv*. doi:10.48550/arXiv.2504.02488.
6. **Hill EM**, Keeling MJ. (2022) Scenario modelling for diminished influenza seasons during 2020/2021 and 2021/2022 in England. *medRxiv*. doi:10.1101/2022.10.27.22281628.
7. Keeling MJ, Brooks-Pollock E, Challen RJ, Danon L, Dyson L, Gog JR, Guzman-Rincon L, **Hill EM**, Pellis LM, Read JM, Tildesley MJ. (2021) Short-term Projections based on Early Omicron Variant Dynamics in England. *medRxiv*. doi:10.1101/2021.12.30.21268307.
8. Keeling MJ, Thomas AC, **Hill EM**, Thompson RN, Dyson L, Tildesley MJ, Moore S. (2021) Waning, Boosting and a Path to Endemicity for SARS-CoV-2. *medRxiv*. doi:10.1101/2021.11.05.21265977.
9. Challen R, ..., **Hill EM**, ... *et al.* Early epidemiological signatures of novel SARS-CoV-2 variants: establishment of B.1.617.2 in England. *medRxiv*. doi:10.1101/2021.06.05.21258365.
10. Funk S, ... , **Hill EM**, ... *et al.* Short-term forecasts to inform the response to the Covid-19 epidemic in the UK. *medRxiv*. doi:10.1101/2020.11.11.20220962.

Other publications

1. Brooks-Pollock E, **Hill EM**, Campillo-Funollet E. (2022) Pandemics Special Issue Editorial *Mathematics Today*, **58**(5): 138–139. URL: <https://ima.org.uk/20322/pandemics-special-issue-editorial/>.
2. **Hill EM**, Tildesley MJ and House T. (2017) How predictable are flu pandemics? *Significance*, **14**(6): 30–35.

PhD thesis

- **Hill EM** (2017) *Mathematical modelling approaches for spreading processes : zoonotic influenza and social contagion*. PhD thesis, University of Warwick, UK.

Awards and prizes

Nov 2022	<p>Weldon Memorial Prize.</p> <p>Awarded to SPI-M-O (Scientific Pandemic Influenza Group on Modelling, Operational sub-group) for its noteworthy contributions to the development of mathematical methods applied to problems in Biology. Specifically, it recognises the epidemiological modelling conducted by SPI-M-O that supported the UKs policy response to the COVID-19 pandemic.</p>
Oct 2022	<p>SPI-M-O Award for Modelling and Data Support.</p> <p>Recognition for making an exceptional contribution, during the COVID-19 pandemic, to the work of SPI-M-O outside of my usual work activity.</p>
Apr 2022	<p>RAMP (Rapid Assistance for Modelling the Pandemic) Outreach Innovation Award (1000).</p> <p>Funding to form the SBIDER Podcast Hub and produce podcast episodes to share research findings from SBIDER with the public.</p>
Feb 2022	<p>RAMP Continuity funding: Early Career Researcher Knowledge Exchange Project Award (1000).</p> <p>Facilitation and organisation of Isaac Newton Institute for Mathematical Sciences workshop on “Behaviour and Policy During Pandemics: Models and Methods”.</p>
Nov 2021	<p>RAMP Continuity funding: Early Career Researcher Knowledge Exchange Project Award (2500).</p> <p>Facilitation and organisation of an Isaac Newton Institute for Mathematical Sciences workshop series on “Modelling Behaviour to Inform Policy for Pandemics”.</p>
Apr 2021	<p>Received a RAMP Early Career Investigator Award from the Royal Society.</p> <p>Recognition of early career researchers who have made exceptional contributions towards RAMP’s activities.</p>
Mar 2020	<p>University of Warwick 2020 Faculty Post-Doctoral Research prize (500).</p> <p>Awarded for the paper “Seasonal influenza: Modelling approaches to capture immunity propagation”.</p>
Nov 2018	<p>Bursary from the University of Warwick Public Engagement Fund (300).</p> <p>Co-applicant with other DataBeers Warwick organising team members.</p> <p>Support the running of a DataBeers Warwick meeting.</p>
Feb 2018	<p>ESMTB travel grant (€300).</p> <p>Support attendance at the European Conference on Mathematical and Theoretical Biology (ECMTB) 2018 conference.</p> <p>Held from 23rd-27th July, 2018 in Lisbon, Portugal.</p>
Aug 2014	<p>Accepted for participation in <i>The Helsinki Summer School on Mathematical Ecology and Evolution 2014: Dynamics of Infectious Diseases</i>.</p> <p>17th-24th August. Held in Turku, Finland. 40 participants.</p>
Sep 2012	<p>Engineering and Physical Sciences Research Council (EPSRC).</p> <p>Full funding for MSc and PhD studies.</p>

Conferences, Workshops and Talks

Session chair

- *Mathematical Epidemiology Contributed Talks Session 9* SMB 2021 (Society for Mathematical Biology 2021 Annual Meeting). Online conference, June 2021.
- *COVID-19 Contributed Talks III*. eSMB2020 (Society for Mathematical Biology 2020 Annual Meeting). Online conference, August 2020.
- *Diseases and Epidemics 1*. Conference on Complex Systems 2019. Nanyang Technological University, Singapore, October 2019.
- *Epidemiology: Part A*. 2018 Annual Meeting of the Society for Mathematical Biology & the Japanese Society for Mathematical Biology. Sydney, Australia, July 2018.

Invited Talks

- *Incorporating behaviour into infectious disease models: Challenges and Questions*. National Institute for Health Research (NIHR) Health Protection Research Unit in Emerging and Zoonotic Infections (HPRU-EZI) wrap up/launch meeting. Spaces at The Spine, Liverpool, United Kingdom, March 2025.
- *HPRU in Emerging and Zoonotic Infections (HPRU-EZI) & The Pandemic Institute*. University of Liverpool representative at a UK Epidemic Analytics and Modelling Event (organised by the London School of Hygiene and Tropical Medicine, Imperial College London and Epiverse). London, United Kingdom, February 2025.
- *Modelling symptom propagation in pathogens infecting via the respiratory tract*. Lancaster Epidemics Seminar Series. University of Lancaster, United Kingdom, December 2024.
- *Incorporating heterogeneity in farmer disease control behaviour into a livestock disease transmission model*. COVID crisis lab & Dondena centre: Workshop on Infectious Disease Modelling with Human Behaviour, Bocconi University, Milan, Italy, November 2024.
- *Epidemiological modelling with behavioural considerations and to inform policy making*. University of Oxford Mathematical Biology and Ecology seminar. University of Oxford, United Kingdom, May 2024.
- *RAMP Outreach Innovation Awards and the SBIDER Podcast Hub*. Newton Gateway to Mathematics - 10th Anniversary. Isaac Newton Institute, University of Cambridge, United Kingdom, November 2023. Talk recording URL: <https://youtu.be/rrPfZrwppbc?si=kGMPskBg5nEJqECL>
- *Incorporating heterogeneity in farmer disease control behaviour into a livestock disease transmission model*. North West Seminar of Mathematical Biology and Data Science. University of Liverpool, United Kingdom, November 2023.
- *Modelling the epidemiological implications for SARS-CoV-2 of Christmas household bubbles in England in December 2020*. University of Exeter Computer Science seminar. University of Exeter, United Kingdom, May 2023.
- *Incorporating heterogeneity in farmer disease control behaviour into a livestock disease transmission model*. JUNIPER consortium research meeting, University of Warwick, United Kingdom, March 2023.
- *Incorporating Behaviour into Models – Challenges and Questions*. Workshop on Recent Challenges in Mathematical Epidemiology. University of Nottingham, United Kingdom, September 2022.
- *Incorporating Behaviour into Models – Challenges and Questions*. Modelling to Support Resilience for Pandemics – Open Questions workshop. Miller Institute, Cambridge, United Kingdom, June 2022. Talk recording URL: <https://youtu.be/KikcUbk3Hp4>

- *Modelling potential impacts of SARS-CoV-2 variants of concern*. JUNIPER consortium virtual research meeting, May 2021. Talk recording URL: <https://youtu.be/yd8bKGHYzMI?t=2120>
- *Developing a Framework for Public Involvement in Mathematical and Economic Modelling: Bringing New Dynamism to Vaccination Policy Recommendations*. NIHR Statistics Group Career Development Section and the NIHR Methodology Incubator Statistics Workstream webinar “Applied Statisticians as Principal Investigators”, April 2021.
- *Predictions of COVID-19 dynamics in the UK: short-term forecasting, analysis of potential exit strategies and impact of contact networks*. Research and Teaching in statistical and data science seminar, University of Glasgow, September 2020.
- *Modelling SARS-CoV-2 transmission in a higher education setting: Application to the University of Warwick*. COVID 19 and Higher Education Space, Isaac Newton Institute (University of Cambridge) online workshop, July 2020.
- *Modelling seasonal influenza in England: Approaches to capture immunity propagation*. Infections@BDI Seminar, Big Data Institute, University of Oxford, July 2019.
- *Modelling influenza A (H5N1) in South and Southeast Asia*. Mathematical Biology for Understanding Emerging Infectious Diseases at the Human-Animal-Environment Interface: a “One Health” Approach. Banff International Research Station, Alberta, Canada, November 2016.

Contributed Talks

- *Incorporating heterogeneity in farmer disease control behaviour into a livestock disease transmission model*. EuFMD Open Session 2024. Alcal de Henares, Spain, October 2024.
- *Incorporating heterogeneity in farmer disease control behaviour into a livestock disease transmission model*. ECMTB 2024 (13th European Conference on Mathematical and Theoretical Biology). University of Castilla-La Mancha, Toledo, Spain, July 2024.
- *Incorporating heterogeneity in farmer disease control behaviour into a livestock disease transmission model*. KSMB-SMB 2024 (Joint Annual Meeting Korean Society for Mathematical Biology & Society for Mathematical Biology 2024). Konkuk University, Seoul, South Korea, July 2024.
- *Modelling the epidemiological implications for SARS-CoV-2 of Christmas household bubbles in England*. British Applied Mathematics Colloquium 2024. Newcastle, UK, April 2024.
- *Developing a Public Involvement Framework in Mathematical and Health Economic Modelling for Vaccination Policy Recommendations*. IDDconf 2023. Ambleside, UK, September 2023.
- *Modelling livestock infectious disease control policy under differing perspectives on vaccination behaviour*. EuFMD Open Session 2022. Marseille, France, October 2022. Talk recording URL: <https://www.youtube.com/watch?v=JCHCDw1hs0k&t=12979s>
- *Possible future waves of SARS-CoV-2 infection generated by variants of concern with a range of characteristics*. ECMTB 2022: 12th European Conference on Mathematical and Theoretical Biology/SMB 2022 (Society for Mathematical Biology 2022 Annual Meeting). Heidelberg, Germany, September 2022.
- *Enhancing modelling impact through collaboration: The case study of SARS-CoV-2 infection in UK university students*. Modelling the COVID-19 pandemic: achievements and lessons. The Royal Society, London, UK, June 2022. Talk recording URL: <https://youtu.be/3yMU-e38MGo?t=14362>
- *A comparison between one and two dose SARS-CoV-2 vaccine prioritisation in England for a fixed number of vaccine doses*. Epidemics⁸ - International Conference on Infectious Disease Dynamics. Online conference, December 2021.
- *A network modelling approach to assess non-pharmaceutical disease controls against SARS-CoV-2 in a worker population*. SMB 2021 (Society for Mathematical Biology 2021 Annual Meeting). Online conference, June 2021.

- *Predictions of COVID-19 dynamics in the UK: short-term forecasting, analysis of lockdown relaxation strategies and impact of reopening schools.* eSMB 2020 (Society for Mathematical Biology 2020 Annual Meeting). Online conference, August 2020.
- *Seasonal influenza: Modelling approaches to capture immunity propagation.* Conference on Complex Systems 2019. Nanyang Technological University, Singapore, October 2019.
- *Spatio-temporal modelling of visceral leishmaniasis among domestic dogs in rural Brazil.* IDDconf 2018. Ambleside, UK, September 2018.
- *Assessing intervention responses against H5N1 avian influenza outbreaks in Bangladesh.* ECMTB 2018: 11th European Conference on Mathematical and Theoretical Biology. Lisbon, Portugal, July 2018.
- *Evidence for history-dependence of influenza pandemic emergence.* 2018 Annual Meeting of the Society for Mathematical Biology & the Japanese Society for Mathematical Biology. Sydney, Australia, July 2018.
- *Assessing intervention responses against H5N1 avian influenza outbreaks in Bangladesh.* Mathematical Challenges from the Life Sciences. Coventry, UK, September 2017.
- *Modelling influenza A at the human-animal interface.* The 2016 Conference on Complex Systems. Amsterdam, The Netherlands, September 2016.
- *Modelling H5N1 influenza in Bangladesh across spatial scales: model complexity and zoonotic transmission risk.* Contagion16 Satellite Meeting. Amsterdam, The Netherlands, September 2016.
- *Spreading of healthy mood in adolescent friendship networks.* Stochastic models of the spread of disease and information on networks. Edinburgh, UK, July 2016.
- *Analysis of historic pandemic influenza outbreaks.* Student Conference on Complexity Science (SCCS) 2015. Granada, Spain, September 2015.
- *Modelling influenza at the human-animal interface.* Mathematical and Computational Epidemiology of Infectious Diseases (MathCompEpi) 2015. Erice, Italy, September 2015.

Posters

- *Incorporating heterogeneity in farmer disease control behaviour into a livestock disease transmission model.* Epidemics⁹ - International Conference on Infectious Disease Dynamics. Bologna, Italy, December 2023.
- *A network modelling approach to assess non-pharmaceutical disease controls against SARS-CoV-2 in a worker population.* Epidemics⁸ - International Conference on Infectious Disease Dynamics. Online conference, December 2021.
- *Modelling seasonal influenza in England: Approaches to capture immunity propagation.* Epidemics⁷ - International Conference on Infectious Disease Dynamics. Charleston, South Carolina, USA, December 2019.
- *Spatio-temporal modelling of Leishmania infantum infection among domestic dogs in rural Brazil.* Epidemics⁷ - International Conference on Infectious Disease Dynamics. Charleston, South Carolina, USA, December 2019.
- *Seasonal influenza in England: Modelling approaches to capture immunity propagation.* 2019 Annual Meeting of the Society for Mathematical Biology. Montreal, Canada, July 2019.
- *Assessing intervention responses against H5N1 avian influenza outbreaks in Bangladesh.* Epidemics⁶ - International Conference on Infectious Disease Dynamics. Sitges, Spain, December 2017.
- *Mathematical modelling of influenza A (H5N1) epidemics in Bangladesh.* ECMTB 2016: 10th European Conference on Mathematical and Theoretical Biology. Nottingham, UK, July 2016.
- *Spreading of healthy mood in adolescent social networks.* ECMTB 2016: 10th European Conference on Mathematical and Theoretical Biology. Nottingham, UK, July 2016.

- *Mathematical modelling of zoonotic influenza A applied to Bangladesh*. Epidemics⁵ - International Conference on Infectious Disease Dynamics. Clearwater Beach, Florida, USA, December 2015.
- *Modelling influenza at the human-animal interface*. Ecological and Molecular modelling of infections (EMOTIONS) 2014. Lyon, France, December 2014.

Scientific meeting organisation

- | | |
|------|--|
| 2024 | Lead organiser of the hybrid-run workshop <i>Mathematical modelling of behaviour to inform policy for societal challenges</i> .
10 June 2024, University of Warwick.
75 participants (in-person and online). |
| 2022 | Co-organiser of the online workshop <i>Behaviour and Policy During Pandemics: Models and Methods</i> .
22 February 2022, Isaac Newton Institute (INI) Newton Gateway to Mathematics.
30 attendees. |
| 2021 | Co-organiser of the online workshop <i>Modelling Behaviour to Inform Policy for Pandemics</i> .
01-02 November 2021, Isaac Newton Institute (INI) Newton Gateway to Mathematics.
40 attendees. |
| 2020 | Co-organiser of the online workshop <i>Mathematical modelling and COVID-19: How can modelling inform a response to the current COVID-19 resurgence?</i>
05-06 October 2020, International Centre for Mathematical Sciences.
40 attendees. |
| 2019 | Co-organiser of satellite session on <i>Challenges in Epidemiological Modelling</i> at the <i>Conference on Complex Systems 2019</i> .
In collaboration with two PhD colleagues from SBIDER and MathSys CDT, we solicited abstract submissions, compiled a programme with a run time of 210 minutes, and set up and maintained an event webpage. Engaged with 30 attendees. |
| 2016 | Co-organiser for <i>Centre for Complexity Science Annual Retreat 2016</i> .
03-06 May 2016, Ironbridge Coalport YHA. 60 attendees. |
| 2015 | Co-organiser for <i>Centre for Complexity Science Annual Retreat 2015</i> .
11-14 May 2015, YHA Wilderhope Manor. 60 attendees. |
| 2014 | Co-organiser for <i>Mathematical Challenges for Long Epidemic Time Series/Big Data and Google Flu workshop</i> .
15-17 December 2014, University of Warwick. 75 attendees. |

Service and Leadership

Editorial roles

- 2024 - Academic Editor: 'Epidemiology and Public Health' section, PLOS Computational Biology.
- 2024 - 2025 Guest Editor for the Mathematics in Medical and Life Sciences Journal. Special Issue on Behavioural Epidemiology.
Article collection webpage: https://www.tandfonline.com/journals/tmls20/collections/Behavioural_Epidemiology
- 2021 - 2024 Editorial Board member: Journal of Theoretical Biology.
- 2022 Guest editor: Mathematics Today (Pandemics Special Issue).

Reviewer roles

- Ongoing Reviewer for journals (listed alphabetically):
BMC Infectious Diseases,
BMC Public Health,
BMJ Open,
Communications Medicine,
Eurosurveillance,
Emerging Infectious Diseases,
Interface Focus,
International Journal of Environmental Research and Public Health,
International Journal of Infectious Diseases,
Journal of the Royal Society Interface,
Journal of Theoretical Biology,
Mathematics in Medical and Life Sciences,
Nature Communications,
Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,
Philosophical Transactions of the Royal Society B: Biological Sciences,
PLOS Computational Biology,
PLOS One,
Proceedings of the Royal Society B: Biological Sciences,
Royal Society Open Science,
Scientific Reports,
Theoretical Biology And Medical Modelling,
Tropical Medicine and Infectious Disease,
Virus Research,
Wellcome Open Research.
- Reviewer for scientific meetings (listed alphabetically):
NetSci-X 2020 subreviewer.

Committees and management teams

- 2025 - Standing member of the University of Liverpool Institute of Population Health Communication, Outreach, Engagement and Involvement Committee (ICOEIC). Representative as Departmental Lead for Communication and Engagement for the Department of Public Health, Policy and Systems.
- 2025 - Liverpool Centre for Mathematics in Healthcare management group member (representative from the Institute of Population Health).
Associated webpage: <https://www.liverpool.ac.uk/mathematical-sciences/research/centre-for-mathematics-in-healthcare/management-group/>.
- 2025 - Steering Group member for the NIHR Health Protection Research Unit in Emerging and Zoonotic Infection (HPRU-EZI).
- 2024 - JUNIPER partnership management board member.
Associated webpage: <https://maths.org/juniper/people>.
- 2024 - The Pandemic Institute Internal Scientific Advisory Panel (University of Liverpool representative).
Associated webpage: <https://www.thepandemicinstitute.org/people/internal-scientific-advisory-panel/>.
- 2024 UK Pandemic Sciences Network Management Board member.
- 2023 - 2024 University of Warwick Mathematics Institute Impact Committee .
Responsibility for engaging early career researchers.
- 2022 - 2024 University of Warwick Mathematics Institute Early Career Committee.
Responsibility for new starter induction documents.
- 2022 - 2024 University of Warwick MathSys CDT management team member.
Responsibilities include: PhD Advisory Committee member, assisting admissions interviews, contributing to the annual retreat.
- 2014 - 2016 Student-Staff Liaison Committee, student representative.

Grant application assessment roles

- 2025 Member of the UKRI College of Experts to assess proposals submitted to the funding call 'Interdisciplinary research proposals to tackle epidemic threats'.
Funding call URL: <https://www.ukri.org/opportunity/interdisciplinary-research-to-tackle-epidemic-threats/>

Advisory group participation

- | | |
|-------------|--|
| 2025 - | Deputy member of the Liverpool City Council Health Protection Board (as a representative of the Civic Health Innovation Labs from the University of Liverpool). The Health Protection Board is responsible for oversight of health protection arrangements in Liverpool and to provide assurance to the Health and Wellbeing Board that there are safe, effective, integrated arrangements and plans in place across the whole system to protect the health of the population and to promote reduction in inequalities in health protection. |
| 2020 - 2022 | Participant of the Scientific Pandemic Influenza Group on Modelling, Operational sub-group (SPI-M-O) for the Scientific Advisory Group for Emergencies (SAGE) in the UK responding to the COVID-19 pandemic. |

Society membership

- | | |
|----------------|--|
| 2016 - present | Member of the European Society for Mathematical and Theoretical Biology (ESMTB). |
| 2018 - 2024 | Member of the Society for Mathematical Biology (SMB). |

Programming Skills

- Proficient in Julia, MATLAB, R, C, LaTeX.
- Working knowledge of parallel computing.
- Use of git for version control and GitHub for open/reproducible science (GitHub username: EdMHill).

Public Engagement and Science Communication

- *Health Data Decoded podcast*. Co-creator and co-host of a podcast series for CHIL. Researchers and professional enabling staff from CHIL discuss their project roles and share their career journeys. Health Data Decoded is available on Spotify (<https://open.spotify.com/show/1kbSyvIQUeLCjsSAORw1xr>) and YouTube (<https://www.youtube.com/@HealthDataDecoded>).
- *Resonate Festival*. Interactive event to illustrate the importance of public and patient involvement in modelling and wider health research. Titled 'Scientists help policy-makers make public health decisions, but who helps the scientists?'. <https://www.resonatefestival.co.uk/events/ppi-and-policy>. (May 2024)
- *SBIDER Podcast Hub*. Co-creator and co-producer of podcast series for SBIDER, where researchers from SBIDER share their research, and discuss academic life and careers. Podcast series webpages: <https://sbiderpresents.podbean.com>; <https://sbidercareerspodcast.podbean.com>.
- *Coventry & Warwickshire Pint of Science*. Pint of Science brings researchers to local pubs to present their scientific discoveries. Volunteer at an event venue for the 2019 edition and Presenter for the 2022 edition.
- *University of Warwick Family Day*. Co-organiser of event in collaboration with colleagues from SBIDER and Warwick Medical School. Planned and ran a set of 'have a go' activities under the theme of 'Outbreak - Learning how diseases spread'. Engaged with 500-1,000 attendees (September 2019).
- *Co-organiser for DataBeers Warwick*. Public engagement event bringing together data experts from industry and academia at a level accessible to a wide audience in the West Midlands (2018, 2019).