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Counting children out: we are underestimating the health impacts of climate change without birth cohort studies

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Abstract

The majority of physical and mental health conditions have their origin during childhood. It is also well-established that children face unique vulnerability to environmental stressors. Climate change will make extreme heat, wildfires and flooding more frequent throughout Europe, and worsen biodiversity loss, with implications for children's health, wellbeing, and education. However, most studies of the health impact of climate change, and associated adaptation and mitigation policies, rely on all-age mortality as an outcome, masking child-specific and life-course impacts of one of the major global public health threats of our time. We argue for a combined-birth cohort approach to climate and child health research: leveraging recruited birth cohorts for mechanistic insights and administrative data-based birth cohorts for national-level analyses, including among smaller, vulnerable groups. Innovative uses of these complementary, longitudinal data resources enable robust, policy-relevant evidence relevant to pregnant women, children and across the life course. This will make climate change's full impact on pregnant women, children and adolescents visible, simultaneously addressing an urgent scientific need as well as intergenerational equity concerns.

Children's unique vulnerability to environmental threats

Medical innovations and public health interventions over the 20th and 21st centuries have led to reductions in deaths due to acute infections and injuries, resulting in large declines in infant and childhood mortality[1]. The global burden of disease simultaneously shifted to chronic conditions, including respiratory, inflammatory, cardiovascular, metabolic and mental health conditions[2]. These are caused by a complex interplay of genetics with the environmental[3], social[4] and commercial[5] determinants of health. A large majority of these chronic conditions have their origins in childhood, some even during pregnancy, as evidenced by a body of studies applying life course[6] or foetal origins of adult disease frameworks[7]. For example it is estimated that 50%[8,9] of adult mental health conditions start before the age of 15 years[10].

As these studies show, pregnancy and childhood are critical times of human development, encompassing organogenesis, adaptive immune system and gut microbiome development and maturation, lung growth and cognitive development. Exposure to environmental threats during pregnancy, infancy and childhood – such as extreme weather, air, soil and water pollution, or food contaminants[11,12] – cumulatively, or during sensitive or critical periods, impacts the risk of developing chronic conditions both during childhood and in future adulthood.

Children are far more vulnerable to external environmental stressors both in- and outdoors than adults – they have a faster breathing rate, breathe more air and consume more water and food per kilogram in weight, have higher levels of physical activity, spend more time outdoors, and exhibit behaviours (such as frequent hand to mouth touching) that expose them to higher levels of pollutants in the air, water and soils than adults[13,14]. Young children are also less able to thermoregulate than adults[15]. Pregnant women and their unborn children are particularly vulnerable to environmental threats; either directly as pollutants or chemicals cross the placenta, or indirectly via inducement of maternal inflammation which disrupts placental blood flow[16,17]. Children exposed to extreme heat during pregnancy are more likely to be born preterm or with low birthweight (with long-term consequences for health and development into later life)[18], also within temperate climate regions[19]. Later in childhood, adolescence represents another specifically vulnerable period, with rapid growth, brain development and hormonal changes during which exposure to environmental pollution or extreme weather could have long-term consequences for health, wellbeing, school outcomes and subsequent economic productivity in adulthood or later life[20,21].

Climate change and child health: a neglected research focus

Although we know the crucial importance of childhood for health across the life course, and children's particular vulnerability to environmental stressors, research on one of the most urgent public health issues of our time, climate change, tends to mostly ignore children.

Human-made climate change, driven by our failure to stop to burning fossil fuels, looks likely to increase global temperatures by 2100 by far more than the 1.5 degrees above pre-industrial levels agreed on in the 2015 Paris agreement[22]. This level of warming will result in severe heatwaves, rising sea levels, water shortages, wildfires, extreme precipitation and storms, coupled with declines in biodiversity[23]. As the adverse impacts from climate change will continue to intensify[24], those who are children now will face the largest cumulative health burden of climate change over their life course, as well as greater adaptation and mitigation costs in the future. Ebi and Paulson therefore identify climate change as an intergenerational equity problem[25].

A review of reviews showed that of the 94 systematic reviews identified, only 7 focused on children specifically[26]. This is partly due to many studies of health effects of climate change, all-age mortality as an outcome – this was the second most common outcome studied in the review of reviews, after infectious diseases. A review of the health co-benefits of net-zero interventions similarly focused on mortality outcomes only when comparing health co-benefits of these policies[27]. This focus is understandable, given that all-age, all-cause mortality data are easier to access, via the World Mortality Database for example, and arguably more easily comparable, than say hospital admissions or birth outcomes, across countries[28,29]. However, given that 87.8% of deaths globally and 99.1% of deaths in Europe were in adults aged 25 years and above in 2023 [30], this outcome will mask any specific health effects of climate change on children, such as impacts on perinatal health, educational outcomes, mental health and common childhood chronic conditions, including allergies, asthma and diabetes, which are very rarely fatal in children, and ignores the impact of extreme climate events during the life course.

Further, as others have pointed out[31,32], there have been no studies of the impact of climate change adaptation policies on child health[33]. This lack of evidence relevant to adaptation impacts on children matters: a further review of national adaptation policies on climate change showed that the majority (51%) of adaptation policy documents from 160 countries either completely excluded any domains relevant to children or only included one domain[34].

We urgently need to do better for children who, according to the World Health Organisation, will bear over 90% of the morbidity burden of climate change[35,36]. A recent scoping review indicated a

specific lack of longitudinal studies on how climate change will impact children, and particularly in low income settings[37]. Studies using data from birth cohort studies on children's environmental exposures, including extreme weather, pollution, and biodiversity loss and physical and mental health outcomes from before birth until adulthood allow us to consider climate change-related exposures (including extremes of temperature, wildfires, extreme precipitation, flooding) on not just mortality, but perinatal health indicators (birth weight, gestational age, Apgar scores etc), disease prevalence and incidence by age, biomarker profiles, health service use, educational outcomes and cognitive performance.

Two types of birth cohort studies and their complementarity for climate change and child health research

Recruited birth cohorts, where mothers and children (sometimes also fathers) have consented to take part by filling out questionnaires and having blood collected at different ages, hold deep phenotyping and biological sampling data, including genetic, metabolomic and epigenetic characterisation. This allows us to research biological mechanisms, gene-environment interactions and epigenetic risk, and use Mendelian randomisation for understanding causal relationships. A large number of these cohorts are available globally and have been successfully used for many years for research into environmental health impacts during the early life course, alone or as part of consortia. For example, recent studies showed that environmental factors can have an harmful but also beneficial effects on child health[38,39] and described the impact of different climate change scenarios on lung growth and delveopment[40]. For example, the EXPANSE project, which standardised models for 20 years of common air pollution exposure data across Europe[41], and the HELIX project[42], which measured, standardised and compared the maternal-child exposome across six countries, further enable internationally pooled or comparative studies of environmental child health research using multiple birth cohorts across Europe.

We believe recruited birth cohorts need to be complimented by national pregnancy or birth cohorts derived within routinely collected administrative datasets. Such national birth cohorts include whole-nation (or jurisdiction) population samples, which can be linked to up-to-date environmental exposure information via individuals' residential address histories, and insights into health service use (including primary and secondary care use, dispensed medicines, mental health referrals) and education outcomes (attendance, exam results, special educational needs provision). Unlike recruited birth cohorts, national administrative data birth cohorts do not tend to include detailed environmental or biosampling nor questionnaire data (due to the cost of

collecting these for whole populations), instead of relying on GIS-derived, Census or other administrative data for exposure definitions and outcomes measured via (health or other) service contacts. However, compared to recruited studies, national administrative datasets minimise selection bias and loss to follow up[43], and, in larger jurisdictions, provide sufficient power to examine associations between climate change and environmental pollution, and less common outcomes, including specific congenital anomalies[44]. Importantly, administrative data birth cohorts also include particularly vulnerable children, such as those in care, from migrant backgrounds or with complex and chronic conditions. This means they can be used to examine the impact of climate change or other environmental exposures on these groups, who are likely to be particularly susceptible to environmental risks[45], but are rarely sufficiently represented in recruited birth cohorts.

National administrative datasets studies have been used for multiple longitudinal studies into the impact of environmental conditions on child health in Denmark[46–48], Wales[49] and Western Australia[50] among other jurisdictions, however legal and administrative challenges in accessing and linking environmental data to health administrative data hamper or delay efforts to set up similar studies in other, larger countries[51], including England.

Making health impacts of climate change on children visible: combined analyses of recruited and administrative data birth cohorts

Recruited and administrative data-based birth cohorts are highly complementary sources for urgently needed, robust studies on the comprehensive impact of climate change-related exposures on health and development during pregnancy, infancy, and childhood. Both data sources can account for dynamic changes in climate-related exposures during vulnerable time windows and their cumulative effects across the life course.

However, recruited and administrative data birth cohort development can be more efficiently used for complementary analyses to address questions on climate impacts on child health. First, similar, parallel analyses can be carried out in both national administrative and recruited birth cohorts, in the same setting, and across different countries or areas, for triangulation and understanding of biological pathways. Second, linking recruited birth cohorts to longitudinal environmental exposure data and administrative data has already been implemented in several cohorts, including in Norway, Denmark, Sweden and the UK[52–56], thereby addressing some of the challenges raised within a recent review of integrating climate data with recruited cohort data[57].

Third, some jurisdictions, including Wales[58] and Denmark[59], allow recruited birth cohort studies to be embedded within national administrative datasets, permitting more detailed subset analyses within a national administrative data birth cohort. Associated development of methods, including imputation of variables present in recruited but not national administrative data cohorts, will enhance our ability to more robustly compare birth cohorts of different designs[60]. Fourth, harmonised and standardised assessment of environmental exposures and climate-relevant weather parameters is essential. These models should have high spatial and temporal resolution, covering the residential locations of the study participants from pregnancy through to the latest health data follow-up. While the modelling is computationally extensive, the feasibility of this has been demonstrated previously. For instance, within the pan-European EXPANSE project, 23 indicators for the environmental exposome have been derived in fine resolution[61]. Investments in connected trusted research environments such as the Data and Analytics Research Environments UK (DARE UK) programme should make it possible to link highly spatiotemporally resolved environmental data to national administrative databases over time, using efficient and secure federated architecture[62].

These analyses will allow us to move beyond the use of all-cause mortality in climate change and health studies, thereby making the full climate impact on health and education from pregnancy through childhood and into adulthood, now and in the future, visible for both policy makers and the public.

Contributors

MS and PH jointly came up with the idea for this personal view and drafted the manuscript together.

Ethics

This paper does not include any original data.

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Declaration of interests

MS is the principal investigator of the GINIplus and LISA cohorts (Germany) and PH is the principal investigator of the Kids' Environment and Health Cohort (UK).

Declaration of generative AI and AI-assisted technologies in the writing process

The authors used Microsoft Copilot, powered by GPT-5, to help derive a title and draft the summary. After using Copilot, the authors reviewed and rewrote the title and summary. AI technology was not used to draft the main text. The authors take full responsibility for the work presented.

References

1. Hardelid P, Dattani N, Gilbert R. Estimating the prevalence of chronic conditions in children who die in England, Scotland and Wales: a data linkage cohort study. BMJ Open. 2014 Aug;4(8):e005331. doi:10.1136/bmjopen-2014-005331

2. Jay MA, Herlitz L, Deighton J, Gilbert R, Blackburn R. Cumulative incidence of chronic health conditions recorded in hospital inpatient admissions from birth to age 16 in England. Int J Epidemiol. 2024 Aug 14;53(5):dyae138. doi:10.1093/ije/dyae138

3. Paltriguera L, Beamud F, Müller M, Pavlou P, Tertre L, Van den Bos S, et al. Environmental determinants of health, including those caused by climate change, publication for the Subcommittee on Public Health, Policy Department for Economic, Scientific and Quality of Life Policies, European Parliament, Luxembourg. 2024.

4. Gama E Colombo D. Closing the gap in a generation: health equity through action on the social determinants of health. Final report of the Commission on Social Determinants of Health. Rev Direito Sanitário. 2010 Feb 1;10(3):253. doi:10.11606/issn.2316-9044.v10i3p253-266

5. Gilmore AB, Fabbri A, Baum F, Bertscher A, Bondy K, Chang HJ, et al. Defining and conceptualising the commercial determinants of health. The Lancet. 2023 Apr 8;401(10383):1194–213. doi:10.1016/S0140-6736(23)00013-2 PubMed PMID: 36966782.

6. Ben-Shlomo Y. A life course approach to chronic disease epidemiology: conceptual models, empirical challenges and interdisciplinary perspectives. Int J Epidemiol. 2002 Apr 1;31(2):285–93. doi:10.1093/ije/31.2.285

7. Skogen JC, Øverland S. The fetal origins of adult disease: a narrative review of the epidemiological literature. JRSM Short Rep. 2012 Aug;3(8):1–7. doi:10.1258/shorts.2012.012048

8. Kessler RC, Berglund P, Demler O, Jin R, Merikangas KR, Walters EE. Lifetime prevalence and age-of-onset distributions of DSM-IV disorders in the National Comorbidity Survey Replication. Arch Gen Psychiatry. 2005 Jun;62(6):593–602. doi:10.1001/archpsyc.62.6.593 PubMed PMID: 15939837.

9. Copeland WE, Shanahan L, Costello EJ, Angold A. Childhood and adolescent psychiatric disorders as predictors of young adult disorders. Arch Gen Psychiatry. 2009 Jul;66(7):764–72. doi:10.1001/archgenpsychiatry.2009.85 PubMed PMID: 19581568; PubMed Central PMCID: PMC2891142.

10. Kessler RC, Berglund P, Demler O, Jin R, Merikangas KR, Walters EE. Lifetime Prevalence and Age-of-Onset Distributions of DSM-IV Disorders in the National Comorbidity Survey Replication. Arch Gen Psychiatry. 2005 Jun 1;62(6):593. doi:10.1001/archpsyc.62.6.593

11. Fuller R, Landrigan PJ, Balakrishnan K, Bathan G, Bose-O'Reilly S, Brauer M, et al. Pollution and health: a progress update. Lancet Planet Health. 2022 Jun;6(6):e535–47. doi:10.1016/S2542-5196(22)00090-0

12. Landrigan PJ, Dunlop S, Treskova M, Raps H, Symeonides C, Muncke J, et al. The Lancet Countdown on health and plastics. The Lancet. 2025 Sep;406(10507):1044–62. doi:10.1016/S0140-6736(25)01447-3

13. Etzel RA, Landrigan PJ. Children's Exquisite Vulnerability to Environmental Exposures. In: Landrigan PJ, Etzel RA, editors. Textbook of Children's Environmental Health [Internet]. Oxford University Press; 2013 [cited 2025 Dec 1]. p. 18–27. Available from: https://academic.oup.com/book/33130/chapter/284237415 doi:10.1093/med/9780199929573.003.0002

14. Brown M. Children's unique vulnerabilities to environmental hazards [Internet]. Available from: https://ceh.unicef.org/sites/default/files/2025-02/250210_AW_Fragile_Beginnings_Childhood_0.pdf

15. Smith CJ. Pediatric Thermoregulation: Considerations in the Face of Global Climate Change. Nutrients. 2019 Aug 26;11(9):2010. doi:10.3390/nu11092010 PubMed PMID: 31454933; PubMed Central PMCID: PMC6770410.

16. Korten I, Ramsey K, Latzin P. Air pollution during pregnancy and lung development in the child. Paediatr Respir Rev. 2017 Jan;21:38–46. doi:10.1016/j.prrv.2016.08.008 PubMed PMID: 27665510.

17. Brown M. Pregnant women and the developing fetuses' unique vulnerabilities to environmental hazards [Internet]. Available from: https://ceh.unicef.org/sites/default/files/2025-02/250210_AW_Fragile_Beginnings_Pregnant_Women.pdf

18. Chersich MF, Pham MD, Areal A, Haghighi MM, Manyuchi A, Swift CP, et al. Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths: systematic review and meta-analysis. BMJ. 2020 Nov 4;m3811. doi:10.1136/bmj.m3811

19. Yüzen D, Graf I, Tallarek AC, Hollwitz B, Wiessner C, Schleussner E, et al. Increased late preterm birth risk and altered uterine blood flow upon exposure to heat stress. eBioMedicine. 2023 Jul 1;93:104651. doi:10.1016/j.ebiom.2023.104651

20. Patton GC, Sawyer SM, Santelli JS, Ross DA, Afifi R, Allen NB, et al. Our future: a Lancet commission on adolescent health and wellbeing. The Lancet. 2016 Jun;387(10036):2423–78. doi:10.1016/S0140-6736(16)00579-1

21. Brown M. Adolescents' unique vulnerabilities to environmental hazards [Internet]. Available from: https://ceh.unicef.org/sites/default/files/2025-02/250210_Fragile_Beginnings_Adolescents%20%281%29.pdf

22. Gonzales-Zuñiga S, Heck S, Forner C, Hare B, Dacie S, Khan Z, et al. Little change in warming outlook for four years; new 2035 climate targets make no difference [Internet]. [cited 2026 Jan 8]. Available from: https://climateactiontracker.org/publications/warming-projections-global-update-2025/

23. United Nations. What Is Climate Change? [Internet]. [cited 2025 Dec 1]. Available from: https://www.un.org/en/climatechange/what-is-climate-change

24. Calvin K, Dasgupta D, Krinner G, Mukherji A, Thorne PW, Trisos C, et al. IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland. [Internet]. First. Intergovernmental Panel on Climate Change (IPCC); 2023 Jul [cited 2025 Dec 1]. Available from: https://www.ipcc.ch/report/ar6/syr/ doi:10.59327/IPCC/AR6-9789291691647

25. Ebi KL, Paulson JA. Climate Change and Children. Pediatr Clin North Am. 2007 Apr 1;Children's Health and the Environment: Part II54(2):213–26. doi:10.1016/j.pcl.2007.01.004

26. Rocque RJ, Beaudoin C, Ndjaboue R, Cameron L, Poirier-Bergeron L, Poulin-Rheault RA, et al. Health effects of climate change: an overview of systematic reviews. BMJ Open. 2021 Jun 1;11(6):e046333. doi:10.1136/bmjopen-2020-046333 PubMed PMID: 34108165.

27. Moutet L, Bernard P, Green R, Milner J, Haines A, Slama R, et al. The public health co-benefits of strategies consistent with net-zero emissions: a systematic review. Lancet Planet Health. 2025 Feb 1;9(2):e145–56. doi:10.1016/S2542-5196(24)00330-9 PubMed PMID: 39954682.

28. Joseph KS, Liu S, Rouleau J, Lisonkova S, Hutcheon JA, Sauve R, et al. Influence of definition based versus pragmatic birth registration on international comparisons of perinatal and infant mortality: population based retrospective study | The BMJ [Internet]. [cited 2026 Jan 8]. Available from: https://www.bmj.com/content/344/bmj.e746

29. Lut I, Lewis K, Wijlaars L, Gilbert R, Fitzpatrick T, Lu H, et al. Challenges of using asthma admission rates as a measure of primary care quality in children: An international comparison. J Health Serv Res Policy. 2021 Oct 1;26(4):251–62. doi:10.1177/13558196211012732

30. Our World in Data [Internet]. [cited 2026 Jan 8]. Number of deaths by age. Available from: https://ourworldindata.org/grapher/annual-deaths-by-age?time=2023

31. Scheelbeek PFD, Dangour AD, Jarmul S, Turner G, Sietsma AJ, Minx JC, et al. The effects on public health of climate change adaptation responses: a systematic review of evidence from low- and middle-income countries. Environ Res Lett ERL Web Site. 2021 Jul;16(7):073001. doi:10.1088/1748-9326/ac092c PubMed PMID: 34267795; PubMed Central PMCID: PMC8276060.

32. Mohamed M, Amin S, Lever E, Montini A, Machida K, Rajagopalan S, et al. Climate change and child wellbeing: a systematic evidence and gap map on impacts, mitigation, and adaptation. Lancet Planet Health. 2025 Apr 1;9(4):e337–46. doi:10.1016/S2542-5196(25)00061-0 PubMed PMID: 40252680.

33. Mohamed M, Amin S, Lever E, Montini A, Machida K, Rajagopalan S, et al. Climate change and child wellbeing: a systematic evidence and gap map on impacts, mitigation, and adaptation. Lancet Planet Health. 2025 Apr 1;9(4):e337–46. doi:10.1016/S2542-5196(25)00061-0 PubMed PMID: 40252680.

34. Zangerl KE, Hoernke K, Andreas M, Dalglish SL, Kelman I, Nilsson M, et al. Child health prioritisation in national adaptation policies on climate change: a policy document analysis across 160 countries. Lancet Child Adolesc Health. 2024 Jul;8(7):532–44. doi:10.1016/S2352-4642(24)00084-1

35. The coldest year of the rest of their lives: protecting children from the escalating impacts of heatwaves. New York: UNICEF; 2022.

36. Zhang Y, Bi P, Hiller JE. Climate change and disability-adjusted life years. J Environ Health. 2007 Oct;70(3):32–6. PubMed PMID: 17941401.

37. Helldén D, Andersson C, Nilsson M, Ebi KL, Friberg P, Alfvén T. Climate change and child health: a scoping review and an expanded conceptual framework. Lancet Planet Health. 2021 Mar 1;5(3):e164–75. doi:10.1016/S2542-5196(20)30274-6 PubMed PMID: 33713617.

38. Yu Z, Kress S, Blay N, Gregor P, Kukk HM, Leskien M, et al. External exposome and incident asthma across the life course in 14 European cohorts: a prospective analysis within the EXPANSE project. Lancet Reg Health Eur. 2025 Jul;54:101314. doi:10.1016/j.lanepe.2025.101314 PubMed PMID: 40672052; PubMed Central PMCID: PMC12266180.

39. Thiering E, Markevych I, Kress S, Astell-Burt T, Feng X, Altug H, et al. Gene-environment interaction in the association of residential greenness and 25(OH) vitamin D. Environ Pollut Barking Essex 1987. 2023 Jun 15;327:121519. doi:10.1016/j.envpol.2023.121519 PubMed PMID: 36990343.

40. Jeong A, Lovison G, Bussalleu A, Cirach M, Dadvand P, de Hoogh K, et al. Lung function-associated exposome profile in the era of climate change: Pooled analysis of 8 population-based European cohorts within the EXPANSE project. Environ Int. 2025 Feb;196:109269. doi:10.1016/j.envint.2025.109269 PubMed PMID: 39862723.

41. Shen Y, de Hoogh K, Schmitz O, Clinton N, Tuxen-Bettman K, Brandt J, et al. Europe-wide air pollution modeling from 2000 to 2019 using geographically weighted regression. Environ Int. 2022 Oct 1;168:107485. doi:10.1016/j.envint.2022.107485

42. Maitre L, Bustamante M, Hernández-Ferrer C, Thiel D, Lau CHE, Siskos AP, et al. Multi-omics signatures of the human early life exposome. Nat Commun. 2022 Nov 21;13(1):7024. doi:10.1038/s41467-022-34422-2

43. Olsen J. Register-based research: Some methodological considerations. Scand J Public Health. 2011 May;39(3):225–9. doi:10.1177/1403494811402719

44. Auger N, Fraser WD, Arbour L, Bilodeau-Bertrand M, Kosatsky T. Elevated ambient temperatures and risk of neural tube defects. Occup Environ Med. 2017 May;74(5):315–20. doi:10.1136/oemed-2016-103956

45. Arpin E, Gauffin K, Kerr M, Hjern A, Mashford-Pringle A, Barros A, et al. Climate Change and Child Health Inequality: A Review of Reviews. Int J Environ Res Public Health. 2021 Oct 17;18(20):10896. doi:10.3390/ijerph182010896 PubMed PMID: 34682662; PubMed Central PMCID: PMC8535343.

46. Pedersen M, Liu S, Zhang J, Jovanovic Andersen Z, Brandt J, Budtz-Jørgensen E, et al. Early-Life Exposure to Ambient Air Pollution from Multiple Sources and Asthma Incidence in Children: A Nationwide Birth Cohort Study from Denmark. Environ Health Perspect. 2023 May;131(5):57003. doi:10.1289/EHP11539 PubMed PMID: 37162236; PubMed Central PMCID: PMC10171081.

47. Pedersen M, Liu S, Andersen ZJ, Nybo AA, Brandt J, Budtz-Jørgensen E, et al. Birth Cohort Studies of Long-Term Exposure to Ambient Air Pollution in Early Life and Development of Asthma in Children and Adolescents from Denmark. Res Rep Health Eff Inst. 2024 Sep;2024(219):1–63. PubMed PMID: 39469971; PubMed Central PMCID: PMC11525942.

48. Engemann K, Pedersen CB, Arge L, Tsirogiannis C, Mortensen PB, Svenning JC. Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. Proc Natl Acad Sci. 2019 Mar 12;116(11):5188–93. doi:10.1073/pnas.1807504116

49. Davies J, Griffiths LJ, Pouliou T, Bailey R, Fry R, Lyons RA, et al. Cumulative residential greenness and childhood body mass index. Environ Epidemiol Phila Pa. 2025 Oct;9(5):e421. doi:10.1097/EE9.0000000000000421 PubMed PMID: 41019642; PubMed Central PMCID: PMC12466902.

50. Atalell KA, Pereira G, Duko B, Nyadanu SD, O'Donnell M, Tessema GA. Prenatal and early childhood exposure to biothermal stress and developmental vulnerability at school entry in Western Australia: a population-based cohort study. Environ Int. 2025 Aug 1;202:109642. doi:10.1016/j.envint.2025.109642

51. Sudlow C. The Sudlow Review [Internet]. [cited 2026 Jan 8]. Available from: https://www.hdruk.ac.uk/helping-with-health-data/the-sudlow-review/

52. UK LLC | UK Longitudinal Linkage Collaboration [Internet]. [cited 2026 Jan 8]. Available from: https://ukllc.ac.uk/

53. Danish National Birth Cohort [Internet]. [cited 2026 Jan 8]. Available from: https://www.dnbc.dk/

54. Norwegian Institute of Public Health [Internet]. 2025 [cited 2026 Jan 8]. Norwegian Mother, Father and Child Cohort Study (MoBa). Available from: https://www.fhi.no/en/ch/studies/moba/

55. Breathe Sweden [Internet]. [cited 2026 Jan 8]. Breathe Sweden. Available from: https://breathesweden.com/

56. COPSAC [Internet]. [cited 2026 Jan 8]. Childhood asthma - childhood asthma causes - childhood asthma symptoms. Available from: https://copsac.com/

57. Nissan H, Diggle PJ, Fronterre C. Combining climate and health data: challenges and opportunities for longitudinal population studies.

58. Pouliou T, Pedrick-Case R, Bailey R, Rawlings A, Mizen A, Davies J, et al. Neighbourhood walkability and body mass index in children: Evidence from the Millennium Cohort Study in Wales. J Transp Health. 2024 Sep 1;38:101855. doi:10.1016/j.jth.2024.101855

59. Pedersen M, Liu S, Andersen ZJ, Nybo Andersen AM, Brandt J, Budtz-Jørgensen E, et al. Birth Cohort Studies of Long-Term Exposure to Ambient Air Pollution in Early Life and Development of Asthma in Children and Adolescents from Denmark. Res Rep Health Eff Inst. 2024 Sep 1;2024:219. PubMed PMID: 39469971; PubMed Central PMCID: PMC11525942.

60. Silverwood RJ, Baranyi G, Calderwood L, De Stavola B, Ploubidis G, White I, et al. Adjusting for confounding in population administrative data when confounders are only measured in a

linked cohort [Internet]. SocArXiv; 2025 [cited 2026 Jan 8]. Available from: https://osf.io/preprints/socarxiv/7ec6b_v2/ doi:10.31235/osf.io/7ec6b_v2

61. de Hoogh K, Hoek G, Flückiger B, Bussalleu A, Vienneau D, Jeong A, et al. A Europe-wide characterization of the external exposome: A spatio-temporal analysis. Environ Int. 2025 Jun 1;200:109542. doi:10.1016/j.envint.2025.109542

62. DARE UK [Internet]. 2026. DARE UK. Available from: https://dareuk.org.uk/