Contents

Application summary

Application title
Tracking the impacts of climate change on maternal and child health: the Global Heat Attribution Project (GHAP)

Grant reference	309105/Z/24/Z
Lead applicant name	Prof Cathal Dominic Walsh
Scheme name	Attriverse: Developing Digital Solutions for Health Impact Attribution
Round	Attriverse Call

Proposed duration of funding (months)
36

Proposed start date	01 August 2024

Name of administering organisation If your application is successful, this is the organisation that will be responsible for administering the award.
Trinity College Dublin

Lead applicant's address at administering organisation If your application is successful, we will use this address in your award letter.	
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Research subject area
Data Sciences, Tools and Technology

Proposal summary

Proposal summary
Detection and attribution studies isolate health impacts specific to climate change, spotlighting the growing health, and socio-economic consequences of climate inaction, providing a baseline for long-term monitoring, and marking a step-change in climate change communication. The three-year GHAP project focuses on measuring heat impacts on maternal and child health by linking climate data with around 45 million birth records from Africa, Europe and Latin America, and upscaling data harmonisation workflows and analysis platforms. Additional data will be sourced throughout. We will develop a suite of software solutions for streamlining attribution analyses. We will use statistical approaches, such as trend-to-trend and event attribution analyses, as well as novel machine learning methodology to quantify impacts of increasing temperatures. Following an indicator-validation protocol, we will select 2-4 indicators to inform sub-national service planning, national resource allocations and global priority setting. We aim to mainstream indicators into global monitoring systems, including the Lancet Countdown. Lastly, we will model effectiveness of adaptation projects, and integrated adaptation and emissions reduction indicators. This project marks a fundamental shift in climate change action through its transdisciplinarity, unprecedented geographical coverage and analytical pipelines with actionable outputs from causal inference to policy modelling. CHANCE and GHINN mechanisms facilitate research-to-policy shifts.

Objective and aims

The overall objective is to transform measurement approaches in the field of climate change and health, and translate that into policy and programmatic change from sub-national to global-level.

Through the lens of heat impacts on maternal and child health, GHAP aims to:

1. Upscale databases with climate and health data from across Africa, Europe and Latin America, underpinned by long-term federated data analysis platforms
2. Quantify impacts of anthropogenic climate change on health, supported by a suite of software solutions
3. Mainstream indicators for tracking climate change impacts and adaptation responses within sub-national, national and global monitoring systems

Background

<u>Once the health sector brings its full weight to bear on the climate crisis, we may begin to see real progress</u>[1]. More rigorous evidence of *where, to whom, to what extent* and *how* climate change is affecting human health is key to unlocking the health sector's potential contribution. Robust data is a constant feature of all successful responses to public health threats, from the 19th century London cholera outbreaks to the HIV and COVID-19 pandemics. Moreover, quantifying the health harms of climate change will lay bare the health trade-offs of a fossil-fuelled economy.

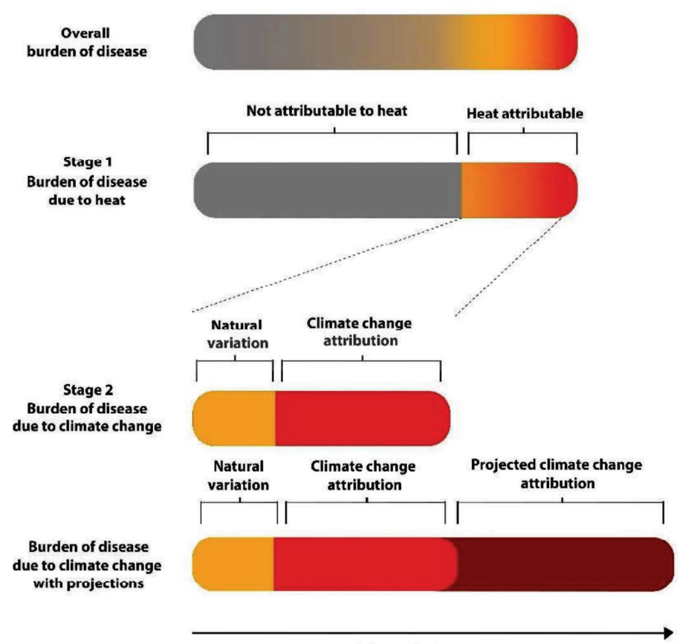

Figure 1: Health impact attribution and projections

<u>Detection and attribution studies are statistical means of detecting changes in the climate system and attributing associated health impacts to anthropogenic and natural forcings</u>[2]. *Throughout this proposal we refer to climate change from anthropogenic causes, not other forcings*. Traditional heat-impact studies conflate adverse outcomes from natural variations in climate with those from anthropogenic climate change. Those studies are mostly *post-hoc*, stand-alone, methodologically diverse, opportunistic analyses of trends in health outcomes, making it challenging to interpret findings and draw overall conclusions. We offer something quite-different, transformative: geographically-representative, systematically curated, annually-repeated, large-scale, high-quality data, and joined-up and methodologically standardised analyses of actual harms of climate change. Going even further, we take important steps towards producing ''quasi-real-time'' measures of climate change impacts on maternal and child health[3].

International multi-site, multi-continent analyses of heat-related mortality have had major policy impacts[4]. Similar analyses with ''morbidity'' outcomes may be even more impactful, given their more-direct relevance for programming and resource allocation.

There are major gaps in impact attribution science and many applications remain under-utilised. The Attriverse systematic review, involving co-applicant Chersich, located only 13 health impact attribution studies[2], one by Birch/Chersich/Marsham[5]. Many studies used only *published* estimates of exposure-response functions. This approach has multiple drawbacks, including: methodological diversity, challenges in exploring statistical heterogeneity, poor study quality, with considerable risks of bias, especially publication bias. These factors markedly constrain analytical potential and interpretation. We use empirical data, obviating many such limitations.

We study the direct impacts of heat, a major, yet under-appreciated, public health threat. The need for more robust, easily-understood evidence becomes more apparent as each warm season sets new temperature records, heatwaves expand in frequency, intensity, duration and spatial extent, and more parts of the world become ''unworkable'' and even ''unlivable''. The potential for ''mass mortality heatwaves'', where temperatures exceed thermoregulatory thresholds in areas with little adaption capacity, is very real[6].

The rationale for studying pregnant women and children is compelling given their marked vulnerability to climate change[7] and life-long sequelae for affected children[8], who played no part in creating this crisis. The consortium has done novel quantitative and qualitative work in landmark studies on heat impacts in pregnancy[5, 9-11] and systematically reviewed around 200 studies (updated 06/2023)[12, 13]. Most notably, around 80 studies linked heat exposure with preterm birth (Figure-2), but also 25 other pregnancy outcomes[12]. Another complementary review is underway(Raffetti) and we previously systematically reviewed heat impacts on children[9]. Importantly, maternal and child health programmes form the cornerstone of most national and global health monitoring and evaluation (M&E) systems, producing amongst the highest quality, most "real-time" data available. Integrating new indicators within these programmes may be far-and-away more feasible than with alternative populations. The relative strength of maternal and child services globally means that future national programmes on climate change and health ***(the ultimate goal of our work)*** may be initiaited within these services, as occurred with HIV, immunizations and nutritional services, for example[7].

GHAP will work with the key global policy and M&E leaders. Both the WHO/WMO and Lancet Countdown teams have co-written the proposal and have committed to support the work, including through hosting GHAP staff working on specific outputs. WHO/WMO is mandated to guide global and national M&E systems, including assisting countries to incorporate new priority indicators, such as those developed here. Additionally, in GHAP, we leverage almost 10 years of Lancet Countdown's advances in analytical methods and indicator development[14]. "Attribution-type" indicators - the GHAP study goal - are a core priority for the Countdown[15].

The project coalesces unique sets of expertise and extensive preliminary data from world-leading teams of researchers into one coherent whole, together providing robust foundations and scaffolds for transformative, legacy outputs.

Below we describe the proposal preparation, and the rationale and planned activities across four stages, running concurrently (Additional File: Figure-5).

Proposal preparation: co-production and engagement

The research questions and proposal were co-designed with wide-ranging stakeholders, responding to the needs and interests of at-risk populations, policymakers and researchers. We engaged CHANCE Network members (impact-attribution webinar); a Community Advisory Board in Tshwane, South Africa; a civil-society group; post-graduate students; Directors of South African MRC units; policymakers in National Indicator Workshops in pilot countries (South Africa and Zimbabwe), and researchers through international conference oral, poster and panel presentations[16-18].

Stage-1: Upscaling of long-term, federated data analysis platforms

1.1 Justification

End-to-end workflows provide foundations and scaffolds for analyses (Digital-Solution 1), underpinned by a progressively-refined suite of software packages (Additional File Figure-5). Reproducibility and benefit sharing, including through pro-active code and data sharing, is fundamental to the integrity, credibility and value of our work.

1.2 Planned activities

1.2.1 Data ecosystem

The consortium's data science ecosystem, constructed by the HE^{2}AT Center (a data science project within the Data Science for Health Discovery and Innovation in Africa [DS-I Africa] Initiative, which interlinks closely with the Wellcome Trust), allows us to leverage technical experts in legal and ethical frameworks (e.g., cross-border data transfer and privacy legislation), data security safeguard protocols, codebooks, workflows, and considerable geospatially-linked health and environmental data (Additional-file: Table-1).

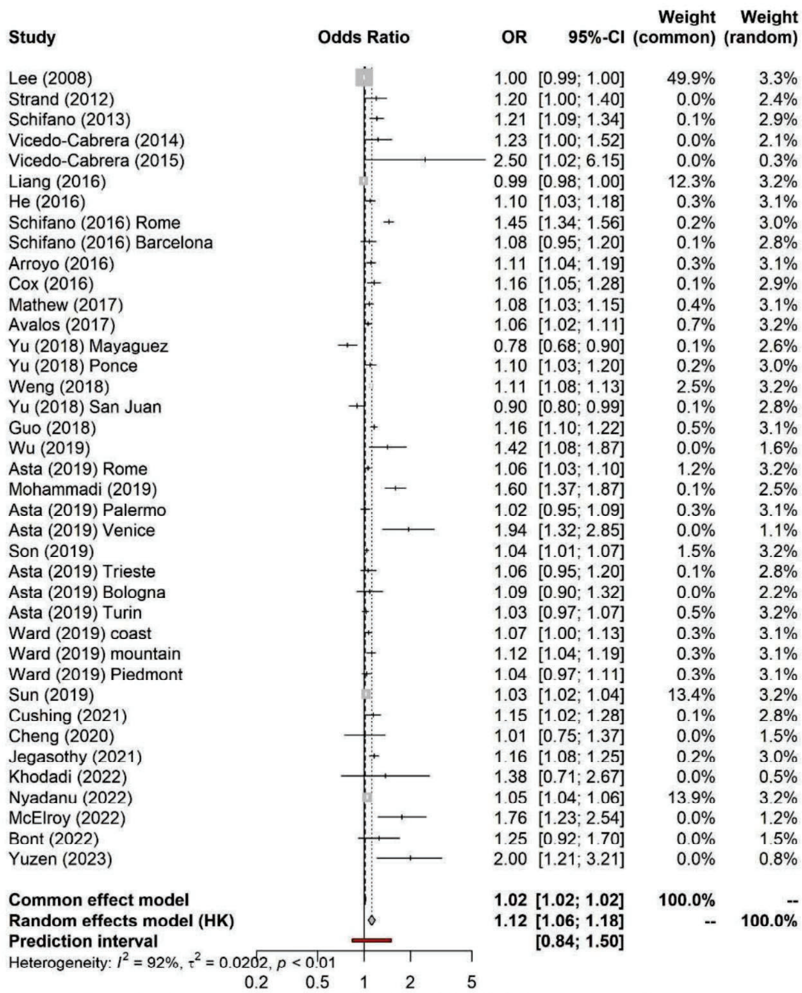

Figure 2: Impacts of heat exposure on preterm birth: forest plot and meta-analysis from a systematic review (Wits partner)

1.2.2 Climate and other exposure data

There exists a plethora of climate data products. The validity and applicability of each (e.g., daily temperature time series) varies by source (e.g., weather stations, satellite sensors) and geography (e.g., urban, rural, mountainous). Model-based climate data (e.g., scenario simulations) also require careful consideration of realism, particularly for event-attribution studies. Evaluation of climate datasets, both observed and modelled, form a core component of analysis workflows.

Temperature anomaly methods provide a common metric for standardised analyses across databases, allowing for variation in minimum 'mortality' temperatures[19] and daily maximum values, night-time heat intensity and diurnal variation, for example, and also measures accounting for humidity, such as the wet bulb globe temperature diurnal variation[20]. In heatwave analyses, we employ classic definitions (e.g., TMean ≥95th centile for ≥3 days), but explore alternatives, including those pioneered by Shumake-Guillemot, which capture heat intensity, such as variation in daily heat exposures.

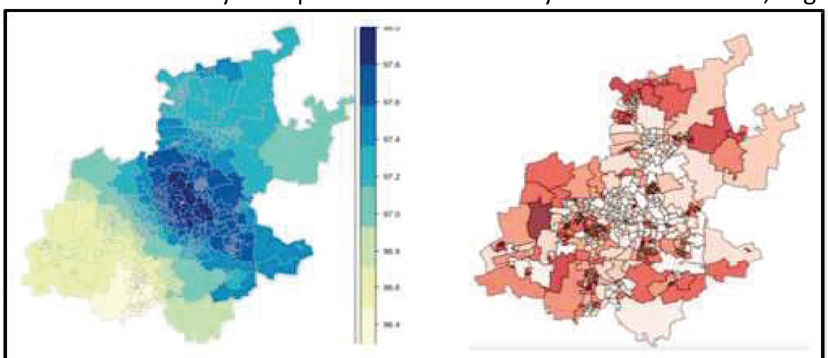

Figure 2: Geographically Weighted Principal Component Analysis (GW-PCA) highlighting areas of vulnerability within the Johannesburg/Gauteng region, represented by the Heat Vulnerability Index map.

Harmonization with other environmental and socio-economic hazards leverages our HE^2AT Center (IBM, University of Cape Town) and World Bank collaborations[21], to construct high-resolution geospatial vulnerability mapping of these exposures[22, 23].

1.2.3 Health outcome data sources

We draw on already curated data in the EU HIGH Horizons project[24], which covers large regions of Greece, Italy, Kenya, South Africa and Sweden[25], and the NIH HE^2AT Center, which includes data from around 200 maternal and child longitudinal cohorts or trials across sub-Saharan Africa[26]. The GHAP study adds large African databases, including the Western Cape Provincial Health database (longitudinal unique identifiers; Boulle)[27] and private-sector health insurance in South Africa (3.3 million members; Roman).

We have developed links with data holders from 17 countries (>45 million births; Additional file: Table 1), many are GAHP partners. We will continue seeking additional databases from the three selected continents. Given available resources, we elected to secure high coverage of these continents, rather than extending beyond these.

We have secured interest for collaboration from groups analysing climate and health data within DHIS2[28], leveraging multiple synergies. The European Association of Perinatal Medicine will establish a Special Interest Group to pool birth data across Europe (Schleussner, Heimann). WHO PAHO will contribute a large database in Latin America[29], and facilitate linkages with other data holders in their region.

Our federated-data approach makes it highly efficient to continuously and securely upscale databases.

1.2.4 Data harmonisation and traditional heat-health analyses

We will use the HE^2AT Center's methodologies and tools[30], including a common codebook of variables using existing ontologies. We will ingest metadata from diverse sources, utilising a semi-automated data harmonisation platform to provide transformation scripts to execute locally. Harmonised data will then be enhanced with climate and socioeconomic data, and accessed through a protected federated-relational database. As data are pseudonymised[31], we adopt GDPR-standard technical and organizational measures to ensure non-attribution to an identifiable individual[32]. We will establish protocols for sharing health outcome data within and outside the consortium, especially through privacy-preserving federated learning, cloud integration, or novel ''black box'' applications.

Synthetic data generation techniques (e.g. VAMBN-FT, CTGAN, and diffusion) and federated machine learning techniques (e.g., random and causal forest approaches) for causal inference will be explored and validated[33]. Summary data and traditional statistical methods will complement this exploratory work.

Using time series analyses (e.g., Distributed Lag Non-linear Modelling)[34], we generate exposure-response functions for different combinations of heat-health outcomes. We examine pre-specified outcomes (e.g., preterm birth and stillbirths rates during heatwaves) and exploratory outcomes, aiming to document: 1) overall size and shape of heat-outcome relationships; 2) individual and *composite outcomes*; 3) whether impacts are mediated through, for example, temperature threshold effects or cumulative exposure; 4) lag effects; 5) high-risk groups, 6) whether differences over time, space or population group might be attributed to adaptive interventions; and 7) putative causal pathways involving direct and indirect causal mediators, including air pollution.

Stage-2: Perform impact attribution analyses

2.1 Justification

Impact attribution research offers a degree of scientific rigour currently missing in climate change-relevant impact assessments, with unique, truly-transformative potential. Given the field's newness, the development of a suite of flexible-integrated analytical software packages is critical for accelerating method diffusion.

2.2 Planned activities

2.2.1 Overview

We adopt a step-wise, iterative approach to analyses, remaining sufficiently agile to progressively incorporate new methods, data types and sources, while remaining guided by an overarching framework and standardised protocol[35]. This approach follows a guide that Chersich and others developed on health-impact attribution in Attriverse work commissioned by the Wellcome Trust[2].

The HIGH Horizons and HE^2AT Center projects already include preliminary attribution impact work[18].

We will develop a suite of software packages for alternative methodological approaches to impact attribution, extending other open software for automating steps (Digital-Solution 2)[34]. Though our work is predominantly applied, we will contribute to methodological advancement by, for example, contrasting findings of alternative analytical approaches, as done previously[36].

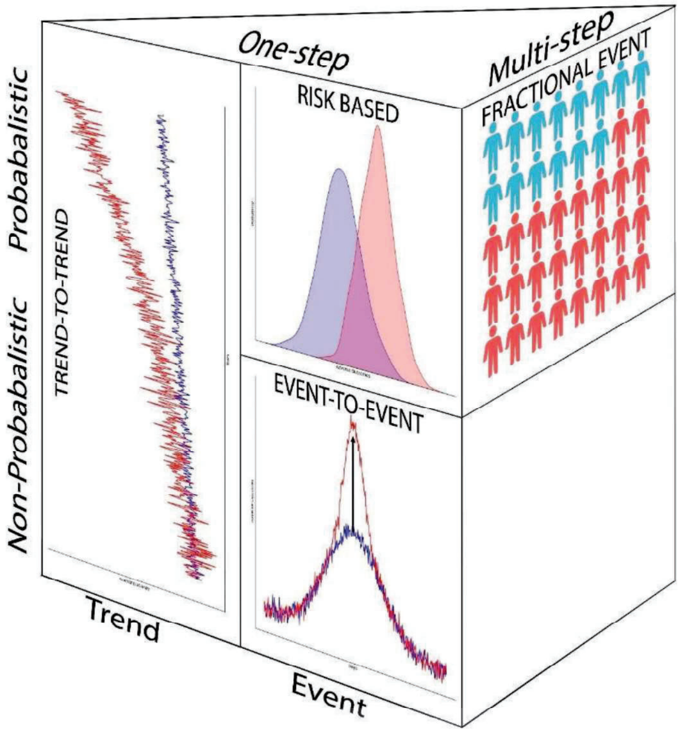

Figure 4: Three main approaches to end-to-end health impact attribution research

2.2.2 Analytical approaches

In end-to-end analyses, we draw on the exposure-response functions generated in empirical analyses in Stage 1, supplemented by exposure-response functions from published studies identified in two ongoing systematic reviews[12](Raffetti).

We then apply these functions to factual and counterfactual model simulations through established statistical approaches[2, 37]. We will use the Detection and Attribution Model Intercomparison Project[38] ensemble of model simulations, which are simulations for the historical period performed once as a control, including all natural and anthropogenic greenhouse gas emissions, and then as an experiment, without anthropogenic forcings. We use outputs, such as daily Tmean and Tmax, in health impact models to quantify historical health impacts due to climate change, as we did previously[5]. Differences between the two simulations quantify the anthropogenic component of climate change signals.

We will principally use probabilistic approaches to assess the frequency of a comparable event, and the relative risk between these two scenarios through risk-based, fractional event and trend-to-trend impact attribution (Figure-4)[24]. We draw on complex modelling work of Walsh[39, 40] and adapt methods used by Vicedo-Cabrera and others[2, 37].

Event-based analyses are more challenging than trend attribution, though evolving methods, especially from the World Weather Attribution project provide learning platforms for the GHAP project[3].

Non-probabilistic approaches take the existence of a heatwave for granted (rather than considering probability) and use, for example, climate models that produce the weather scenario of interest, showing how an event would have differed with and without anthropogenic forcings. In work led by Jack, we will use 'Storylines approaches, a form of prospective event simulation, to explore driving factors involved and the plausibility of these, using ensemble boosting of weather forecast models[41]. These modelling experiments necessitate substantial computing power, such as from the high-performance computing at Trinity College and NIH STRIDES.

2.2.1 **D**ata science approaches

We will employ machine learning approaches using ensemble methodologies (bagging, boosting and stacking to improve accuracy) to predict complex climate change attribution utilising our federated data ecosystem to interrogate exposure-response functions that may be modified by adaptations that are inadequately captured in traditional statistical analyses. Ensuring model interpretability is paramount to maintaining stakeholder trust and deriving actionable insights. Rigorous validation and generalization techniques, including cross-validation, will ascertain the models' robustness and applicability across varied data sources and settings.

2.2.3 Analyses of adaptation**/mitigation** potential

We explore alternative adaptation/mitigation scenarios. Firstly, we use actual adaptation outcomes from research (including projects involving Machingura/Chersich)[42-44] and the development sector. Secondly, where our empirical analyses identify variation in minimum mortality temperatures over time or geolocation, we will assess evidence for plausible explanations for these changes. Lastly, we estimate cases averted with alternative hypothetical adaptation (varying effectiveness, coverage and plausible ranges of uncertainty) and mitigation scenarios[45]. This extends our experience with CARBOMICA, a machine learning resource allocation tool[46].

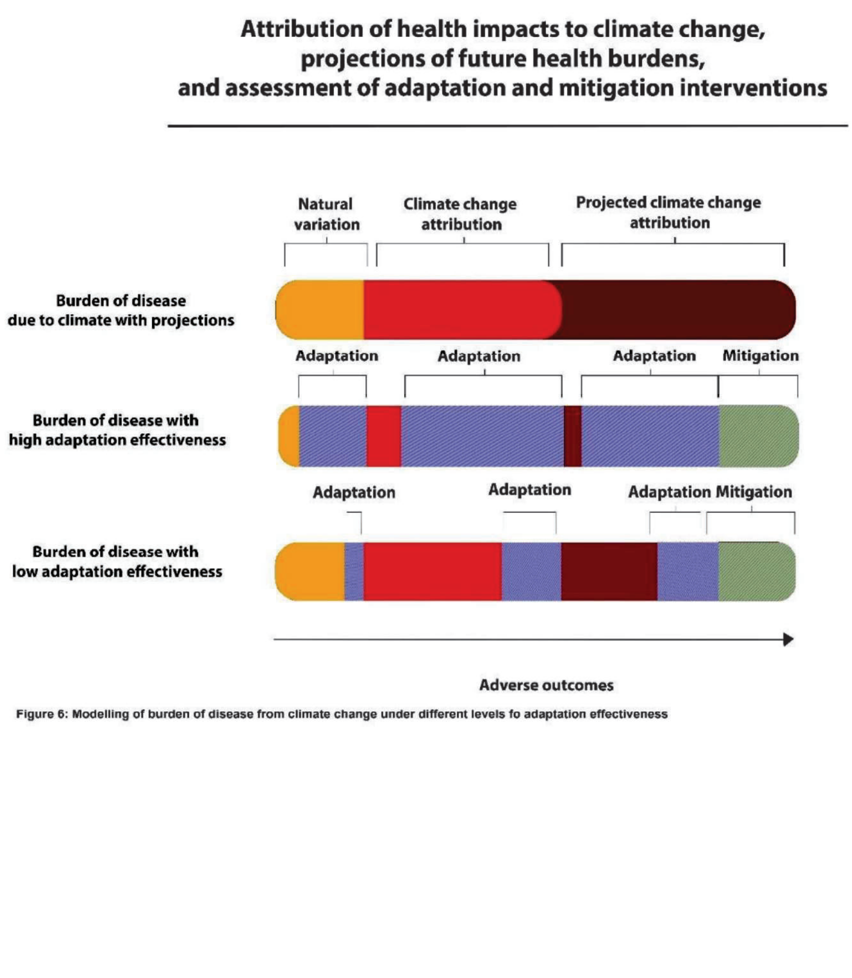

Figure 6: Modelling of burden of disease from climate change under different levels fo adaptation effectiveness

2.2.4 Projections

Using outputs of above analyses, future health outcomes will be estimated under different climate scenarios using the CMIP6 ensemble climate projections, while allowing for varying degrees of adaptation within and between the populations.

Stage-3: Co-produce "second-generation" indicators for tracking climate change impacts, adaptation progress and overall health sector performance

3.1 Justification

Robust indicators will make explicit the benefits, costs and policy trade-offs involved in allocating resources between different disease priorities and settings, and provide evidence needed to optimise these trade-offs.

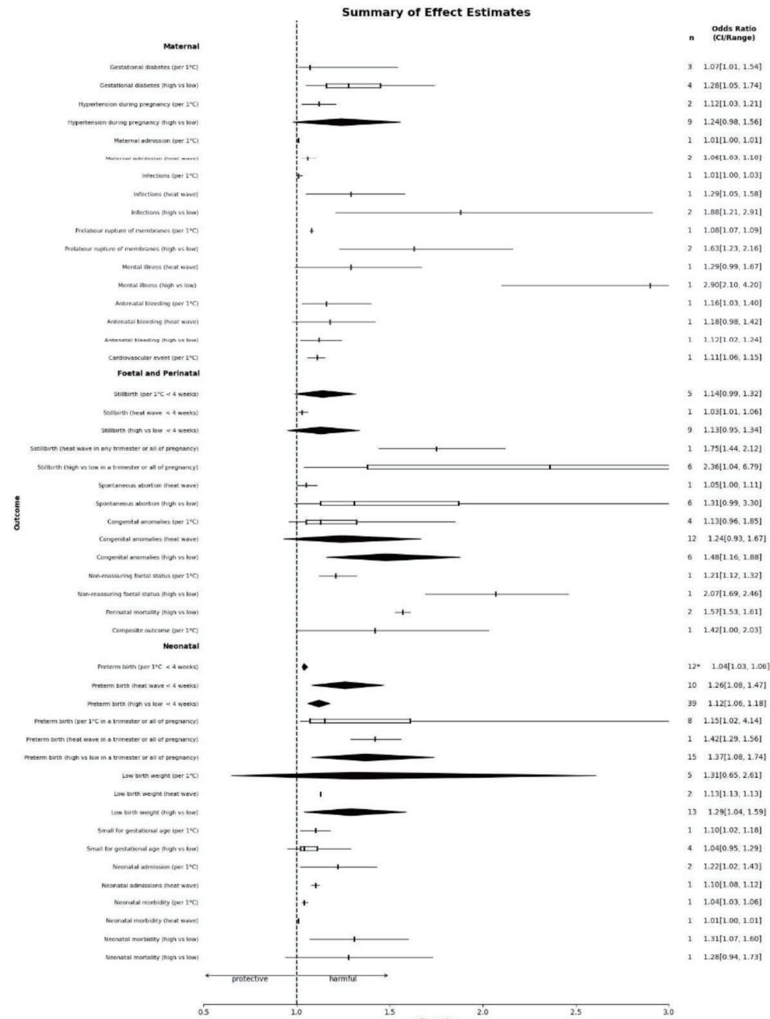

Figure 7: Effects of heat exposure on maternal and child health outcomes: meta-analyses of systematic review (Wits partner)

3.2 Planned activities

3.2.1 Selection of candidate indicators

Our work extends a HIGH Horizons collaboration with WHO to select ''first-generation'' heat-health indicators (e.g., number of heat-related preterm births in District X)[24], and draws on the HIGH Horizons Expert Group (n=8-10), lessons and tools. We also leverage years of indicator-development work in the Lancet Countdown. In the first Expert Meeting, we will define indicator selection criteria (including the Countdown's criteria)[14], such as exposure-response effect size, power to track changes and detect inequities[24, 25], public health significance of condition(s) and feasibility of sustained data collection. The group then selects 12-15 candidate indicators, different combinations of: health outcome(s), heat-exposure metric(s), target population(s), and geospatial-temporal units (Figure-7). Composite health outcomes (e.g., total heat-related preterm births plus pre-eclampsia plus stillbirths per 10,000 live births) increase event number, and better reflect overall public health implications of climate change.

In exploratory research, we will develop indicators that explicitly integrate adaptation effectiveness and emissions reductions. This could be used, for example, to estimate adverse pregnancy outcomes resulting from new fossil fuel projects, for example[47].

3.2.2 Indicator co-production in pilot countries

Indicators will be refined in co-production workshops and key informant interviews in pilot-study countries (South Africa and Zimbabwe), and through the European Special Interest Group (Schleussner).

3.2.3 Indicator selection and implementation

The second Expert Meeting involves reviewing results of analyses in Stage-2 for each of the 12-15 candidate indicator, together with the pilot-study outcomes. Following a decision-making protocol, the group will rank each indicator against the selection criteria and select 2-3 final core indicators, for incorporation within the WHO/UNFPA/UNICEF/WMO publication on priority indicators on heat impact on maternal newborn and child health. Indicators will undergo Lancet Countdown's indicator assessment processes, and – if approved – be incorporated within the Countdown's reporting systems. We will support mainstreaming of selected indicators into M&E systems, where possible, and translation of indicators into time-bound targets

Stage-4: Translation and co-production

4.1 Justification

Given that the field of health-impact attribution is new, engagement needs to focus on clarifying real-world relevance of outputs for stakeholders and for the broader climate change agenda.

4.2 Planned target groups and activities

4.2.1 Stakeholder mapping

In focused mapping exercises, we will identify potential users of attribution evidence among national and international policymakers, DHIS2 staff[28], IHME[48], environmental lawyers, media and civil society.

4.2.2 Structured dialogues

We will hold structured dialogues about use cases with stakeholders identified. Dialogues (n=10/group/ year) will occur throughout, allowing us to iteratively tailor study activities to respond to stakeholder input and ensure ongoing relevance of the work.

Discussions focus on exploring how health-impact attribution findings might be packaged to optimise their use in policy documents and climate-financing proposals. At Expert Meetings, conferences, and civil society and media interactions, the study team and stakeholders will co-produce a translation of statistical outputs into accessible messaging.

4.2.3 Engagement with legal fraternity

Stevenson and van Asselt will facilitate workshops (n=2) with environmental lawyers. We will pro-actively make our findings available for litigation proceedings, and Loss and Damage claims.

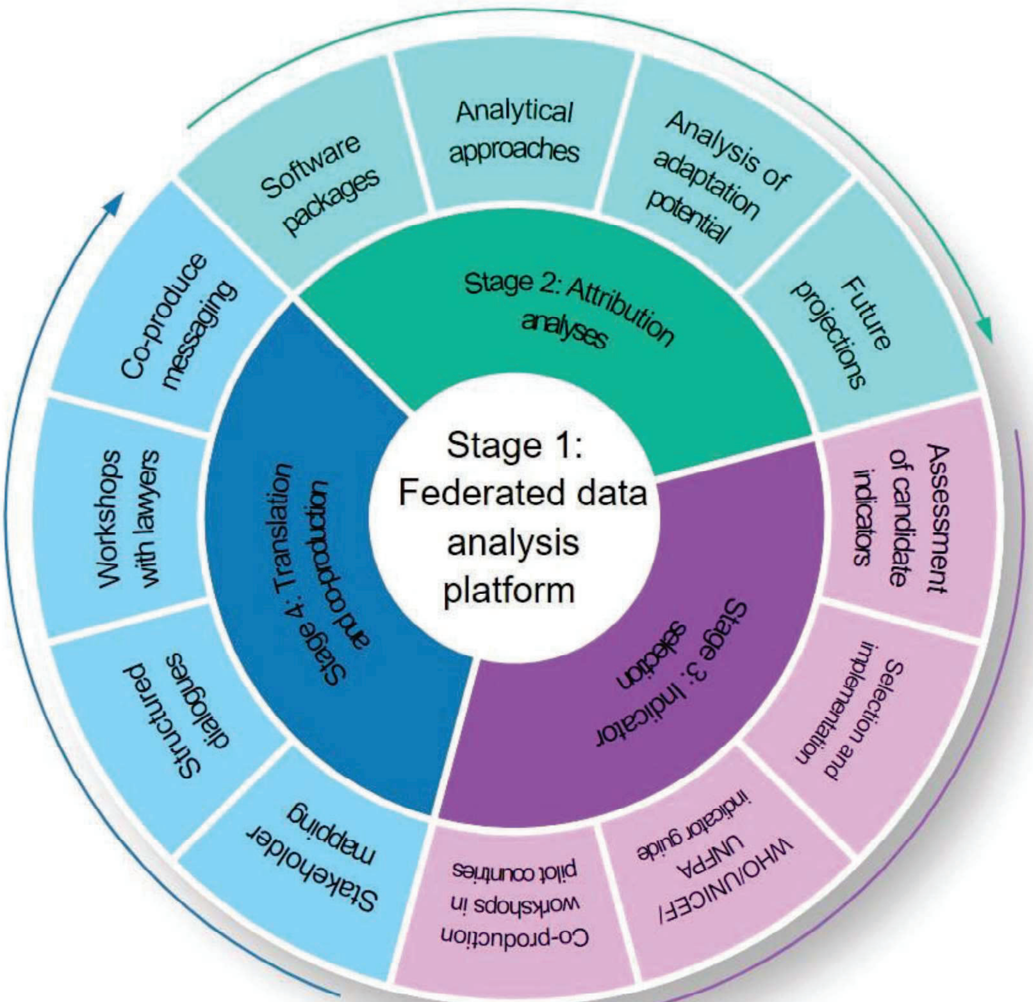

Figure 8: Overall project contribution

Overall project contribution

The study makes five principal contributions. Foremost, our multi-country and -continent analyses capture the evolving nature of climate change risks for pregnant women and children, highlighting areas for more intensively-resourced, targeted responses. Secondly, our Digital Solutions facilitate an acceleration in impact attribution research and move us closer towards quasi-real-time attribution[3]. Thirdly, we set ''attribution indicators'' firmly at the forefront of national and global M&E systems, using these to drive resourcing and programmatic priorities[15]. Fourthly, our work advancing methods for evaluating numbers of cases averted by alternative adaptation and mitigation options will help optimise resource-allocation decisions. Lastly, we provide concrete causal evidence on climate change morbidities to help demonstrate legal causality and support litigation against governments and private actors, and Loss and Damage funds.

Lastly, we will monitor and limit the projects' carbon emissions using the AKU tool applied in several ongoing studies[49]. We aim to offset all emissions to target net-zero.

Figure 5: Conceptual framework of study showing four stages, interrelations and activities

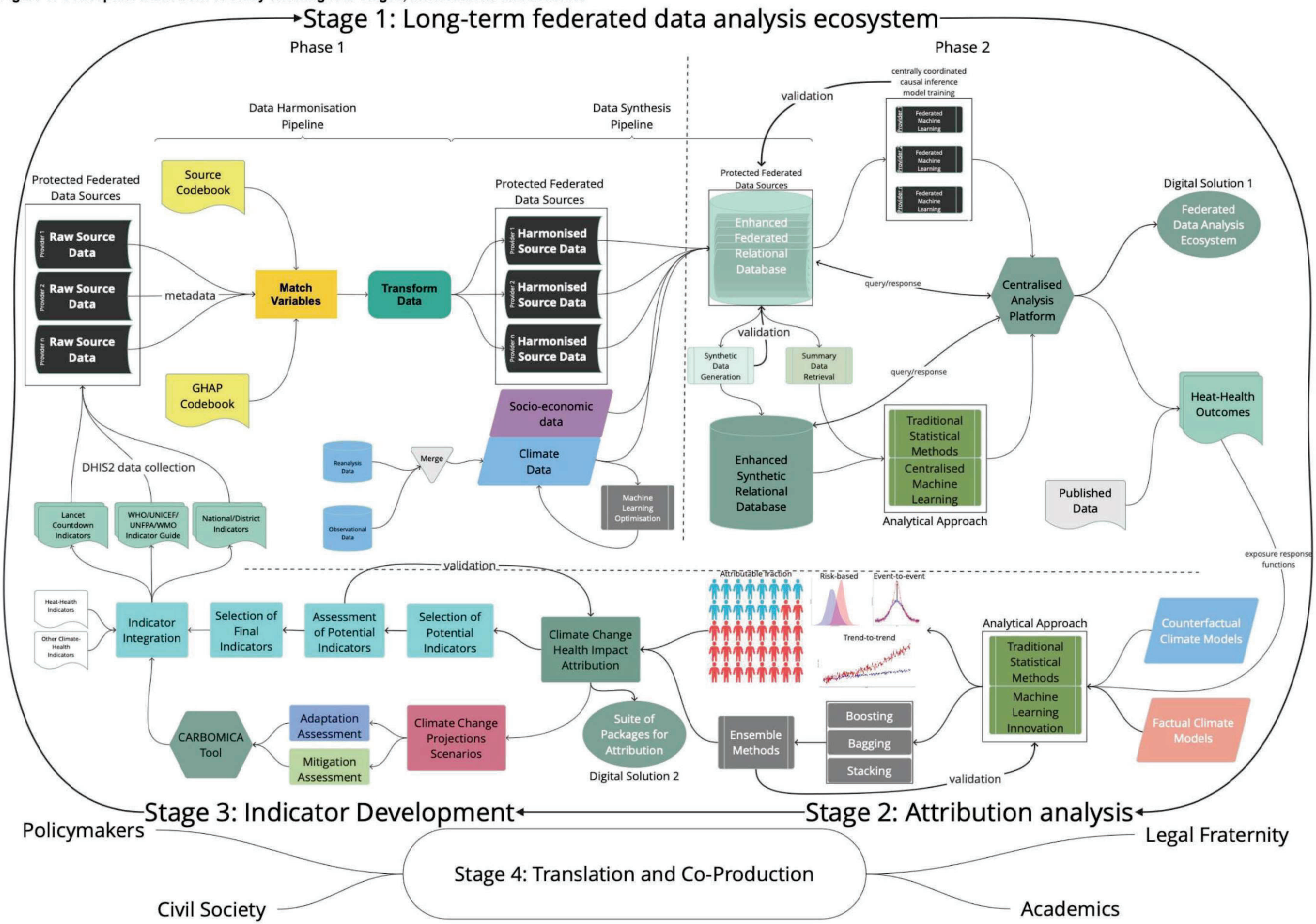

Table 1: Description of databases in the HE^{2}AT Center, HIGH Horizons and for inclusion in the GHAP project

Project	Location	Region or city	Data provider	Time period	N births
Existing already-harmonised data					
HIGH Horizons (EU Horizons)	Italy	Lazio (Rome and surrounds)	Regional health authority	2001-2023	856,000
	Greece	Whole country	Hellenic Statistical Authority	1999-2021	2,316700
	[#]Sweden	Whole country	Swedish Pregnancy Register	2014-2018	561,000
	South Africa	Soweto, Johannesburg	VIDA Research Unit	2016-2023	220 000
	Kenya	Mombasa, Coast Province	AGA Khan Hospital Network	2017 - 2023	4,000
NIH HE^{2}AT Center	Sub-Saharan Africa	All countries (+/-200 studies)	Principal Investigators of cohorts or trials	2000-2023	2,000,000
Additional upscaled data in GHAP study					
GHAP Project	[e]South Africa	Whole country	Private sector health insurance	2009 onwards	910,000
	[e]South Africa	Western Cape	Public sector population registry	2015 onwards	770,000
	[e]Bolivia	Sentinel sites	Perinatal Information System	2018-2023	13,000
	[e]Ecuador	Sentinel sites	Perinatal Information System	2022-2023	6,000
	[e]Guatemala	Sentinel sites	Perinatal Information System	2018-2023	17,000
	[e]Honduras	Sentinel sites	Perinatal Information System	2019-2023	64,000
	[e]Rep Dominicana	Sentinel sites	Perinatal Information System	2018-2023	23,000
	[e]Uruguay	Whole country	Public sector	2009-2023	600,000
	[+]Belgium	Whole country	Public sector	1998-2020	2,836,000
	[+]Cyprus	Whole country	Public sector	2014-2019	56,000
	[+]Greece	Whole country	Public sector	1999-2019	2,139,000
	[+]Lithuania	Whole country	Public sector	2001-2020	574,000
	[+]Romania	Whole country	Public sector	1994-2020	5,871,000
	[+]Spain	Whole country	Public sector	1980-2018	16,947,000
	[e]Germany	German perinatal database	Public sector	2001 onwards	800,000
	[#, e]Sweden	Whole country	Birth and National Patient register	1973-2021	5,750,000
	[$]Italy	Lombardy region	Population-based birth register	2012-2023	800,000
	[$]England	Whole country	Hospital episode statistics	2019-2022	1,200,000
TOTAL					**45,340,000**

[e]Data holders have agreed to data sharing. [$]Data providers have been contacted and expressed interested in participating. [+]Studies within the EARLY-ADAPT (European Research Council project under the European Union's Horizon 2020). Permissions for data sharing will be sought from the Consortium Home - EARLY ADAPT (early-adapt.eu). [#]Overlap in some of these data. Covariates include maternal age, marital status, education, migrant status, gravidity and parity, and maternal chronic illness in most studies. Longitudinal data (cohorts, trials, population cohort registers, or health insurance data) have comprehensive repeated measures of health outcomes and covariates

Gannt Chart: activities and deliverables

	Project year	1												2													3										
	Item / Project months*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
	Study management																																				
0.1	Documentation of all reports and financial matters																																				
0.2	Follow up of milestones																																				
0.3	Development of administrative SOPs (e.g., publication plan and data sharing policy)																																				
0.4	Development of Data Management Plan (D0.1)																																				
0.5	Monitoring project quality and risk analysis																																				
0.6	Sign consortium agreement; sub-contracts																																				
0.7	Formalization of Scientific Advisory Committee, Steerco																																				
0.8	Annual and final reporting																																				
	Stage-1: Upscaled long-term federated data analysis platform																																				
1.0	Finalize generic Stage-1 study protocol (D1.1)																																				
1.1	Ethical and regulatory approvals																																				
1.2	Acquisition of health outcome data																																				
1.3	Long-term generalisable federated data harmonisation platform (D1.2)																																				
1.4	Federated harmonised relational database (D1.3)																																				
1.5	Heat-health data analysis platform (D1.4)																																				
1.6	Digital-Solution 1: Federated data harmonization, storage and analysis platform (D1.2 + D1.3 + D1.4)																																				
1.7	Traditional time-series and machine learning analysis of new data acquired for GHAP																																				
	Stage-2: Perform health impact attribution analyses																																				
2.1	Finalize generic Stage-2 study protocol (D2.1)																																				
2.2	Ethical and regulatory approvals																																				
2.3	Factual and counterfactual climate models datasets prepared																																				
2.4	Development of impact attribution code and software frameworks																																				
2.5	Impact attribution analyses with exposure-response functions from published data (D2.1)																																				
2.6	Impact attribution analyses with exposure-response functions from empirical analysis (D2.2)																																				
2.7	Impact attribution analyses of 12-15 exposure-outcome pairs (candidate indicators)																																				
2.8	Digital-Solution 2: Suite of software packages for attribution analysis (D2.3)																																				
	Stage-3: Co-produce ''second-generation'' indicators																																				
3.1	Selection of candidate indicators in Expert Group meeting 1 (D3.1)																																				
3.2	Indicator co-production workshops in South Africa and Zimbabwe (D3.1)																																				
3.3	Selection of final indicators in Expert Group meeting 2 (D3.2)																																				
3.4	Finalized WHO/UNFPA/UNICEF/WMO document on indicators																																				
3.5	Incorporate indicators into Lancet Countdown reports, if relevant																																				
	Stage-4: Engagement and co-production																																				
4.1	Stakeholder mapping and report (D4.1)																																				
4.2	Structure dialogues and key informant interviews																																				
4.3	Workshop with environmental lawyers (D4.1)																																				
4.4	Co-produced communication tools and materials																																				
4.5	Dissemination of overall project findings																																				

D Deliverable

The proposal

The proposal

Any attachments uploaded will be included at the end of this pdf

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Does your proposal involve human participants or human biological material?
No - does not involve human participants and/or human biological material

Does your proposal involve a clinical trial?	

Confirm that the trial will be registered on one of the following:

- International Standard Randomised Controlled Trial Number Register (ISRCTN)
- ClinicalTrials.gov
- another register listed on the WHO International Clinical Trials Registry Platform (ICTRP).

Is the proposed clinical trial covered by The Medicines for Human Use (Clinical Trials) Regulations in the UK?	

Describe the oversight arrangements for the clinical trial (e.g. membership of Trial Steering Committee, Data Monitoring Board etc.)

Are you applying with coapplicants?	Yes

Team composition and management

Taken together, GHAP coalesces unique sets of expertise from world-leading teams of researchers to form one coherent whole. We are ideally placed to tackle the complexities of impact-attribution research, given our networks of data holders, existing workflow platforms, and experience with classic heat-health impact studies. Moreover, we will work closely with global leads in climate change monitoring: Lancet Countdown (Romanello) and WHO/WMO Climate and Health Office (Shumake-Guillemot). Bringing these groups together with the WHO Maternal, Newborn and Child health team (Portela) is critical for implementing the the GHAP cross-domain indicators.
Many partners are long-term collaborators, including on landmark studies on heat and pregnancy (CHAMNHA, HE2AT Center, HIGH-Horizons, HAPI and Bio-HEAT). The team is diverse in race and gender, with a notable global South focus. Each climate, network organisation, legal and statistical lead has a Northern or Southern counterpart to facilitate meaningful cross-fertilisation and equity.
TCD (Walsh, Chersich) is responsible for overall project leadership, development of data management and analysis plans, Digital Solution deliverables, data security oversight, standardisation of activities, and reporting. Walsh, the overall lead statistician, has led decades of related analyses. Climate scientists Birch and Marsham (Leeds University) and Jack (Climate Systems Analysis Group, University of Cape Town), have highly complementary expertise. Jack has specific expertise in attribution analyses.
Data holders, spread across Africa, the EU and Latin America, play wide-ranging roles, from data sharing to full data analysis (Quantum, South Africa - Roman; Western Cape Provincial Health, South Africa - Boulle; University of Karolinska, Sweden - Raffetti; Human Technopole, Italy - Zuccolo; and Friedrich Schiller Universität, Germany – Jena University Hospital, Schleussner, Heimann).
All partners, as a collective, are responsible for indicator development, selection and promoting the mainstreaming of indicators into district, national and global monitoring systems.
Local teams in South Africa (Chersich, Brink, Section27; Stevenson) and Zimbabwe (CeSSHAR; Machingura) lead engagement with key national stakeholders around indicator selection and implementation. Brimicombe (statistician) and Otto (societal impacts of climate change) cement links with the EU HIGH Horizons project.
The Executive Committee, comprised of the lead applicant (Walsh) and co-applicants (Birch, Boulle and Chersich), will meet fortnightly or *ad hoc* to review activities, including coordination, management, communication, implementation and output management and sharing. The Steering Committee, consisting of all partners, meets monthly. They will conduct annual risk-analyses to anticipate major shifts and take pre-emptive actions. Annual workshops review progress, share findings, advance analysis methodology and plan (Year 1: TCD, Dublin, Ireland, Year 2: UCR, Cape Town, South Africa, and Year 3: WHO, Geneva, Switzerland).
The Scientific Advisory Board meets annually to provide overall technical oversight, consists of Marleen Temmerman, among the world's leading maternal health experts (Aga Khan University, Kenya); George Thurston, a globally-acclaimed air pollution impact measurement expert (New York University); Harro van Asselt, a Professor of Climate Law (University of Cambridge); Christopher Trisos, an attribution and impact assessment expert (Africa Climate Development Institute, University of Cape Town); Vincent Nkundi (University Botswana, CHANCE Network lead), and Gueladio Cisse, a leading climate change and health expert (University of Basel).

Outputs management and sharing

Provide an outputs management plan
1. What outputs will your research generate? GHAP will generate multiple, large, parallel and integrated datasets on climate, environment and health, modelling software and computational tools that will be of value to climate change researchers, health researchers and other stakeholders. This includes individual participant level data gathered across multiple sites and meta-data extracts from the federated secure environment. Research outputs include publications, expert group meeting reports, and conference presentations, as well as mainstream and social media outputs. 2. What metadata and documentation will accompany the outputs? Metadata include data dictionaries and data descriptors technical information (e.g., file formats), coding instruments will be created and made available through the World Data Center for Climate (WDCC) as described below. These are searchable, and persistent digital object identifiers (DOIs) facilitate dissemination and access. 3. When will these outputs be made available? We will adhere to the Wellcome Trust policies on data sharing. Access to granular data, and outputs from federated analyses will be coordinated through TCD project manager, who will work to process data-sharing requests as quickly as possible. 4. Where will you make these outputs available? All software will be released open source, deposited at open-access third party repositories including Github and CRAN. The data sources will be archived in the WDCC platform within one year of project completion. This facility enables long-term archiving and open access of data to other researchers. Research outputs will be presented at conferences, community and policymaker meetings, and through media, optimised in the GHAP Stage 4 activities. 5. How will these outputs be discovered and accessed by the research community? As highlighted above, the WDCC provides a discipline-specific platform for discovery and data access. The High-Performance Computing Centre at TCD will maintain access to granular data, where possible. The work and these sources will be highlighted in research presentations and publications, and through the use of DOIs which facilitate discovery and use. 6. Are there possible restrictions to data sharing or embargo reasons? Sharing is to the fullest extent possible. Most data holders have privacy restrictions in place, especially around sensitive health data. For this reason, a workflow (Additional File Figure 1) has been designed to facilitate federated processing. Anonymised and synthetic data extracts from this environment and the meta-data will be fully shared according to GDPR regulations, or applicable regulations in Africa and Latin America. 7. How will data and metadata be stored, backed up and preserved? As highlighted above, the WDCC will act as a primary platform for archive and access. More granular data will be stored and accessible on request for at least five years at TCD through the High-Performance Computing Centre, which provides a local backup (RAID and off site) and archive for their systems. 8. What resources will be dedicated to ensuring all data is FAIR? Data-management is a specific element of the budget, including the role of data steward/manager in ensuring the Data Management Plan is updated regularly and maintenance of FAIR principles.

Select the approach you will use to maximise the impact of your significant research outputs to improve health and benefit the wider research community.
Make research outputs available for access and re-use

Collaborations

Are any collaborations essential for this proposal?	Yes

List any key collaborators (name and organisation) and provide a very brief outline of their role in the proposed research.		
Name	**Organisation**	**Outline of role in proposed research (50 words maximum)**
Tamlyn Roman	Quantium Health, South Africa	Data science analyst of private sector health insurance data in South Africa.
Fortunate Machingura	Centre for Sexual Health and HIV AIDS Research (CeSHHAR), Zimbabwe	Coordination of Zimbabwe country case study for indicator selection, key informant interviews, and related engagement and co-production activities.
Anayda Portela	Department of Maternal, Newborn, Child, Adolescent Health and Ageing, World Health Organization, Switzerland	To coordinate the Expert Group meeting in Year 3 on final indicator selection. Assist with making synergistic links between the GHAP and HIGH Horizons projects. Link with the WHO/WMO office on the indicator development work, critical given the cross-domain nature of these measures. Coordinate the WHO/UNFPA/UNICEF/WMO publication on priority indicators. Link with other maternal and child leads in WHO regional offices to facilitate data sharing.
Emma Kalk	Centre for Infectious Disease Epidemiology and Research, School of Public Health and Family Medicine, University of Cape Town, South Africa	Clinical and methodological oversight of analysis of health outcome data in the Western Cape Provincial Health Data Center database. Link with provincial monitoring and evaluation leads.
Mary-Ann Davies	Centre for Infectious Disease Epidemiology and Research, School of Public Health and Family Medicine, University of Cape Town, South Africa	Epidemiology oversight of analyses using the Western Cape Provincial Health Data Center database.
Sasha Stevenson	Section 27, Non-Governmental Organization, South Africa	Provide expert inputs on legal issues in climate litigation; co-facilitate a workshop with environmental law practitioners, help make the study findings available for litigation proceedings and Loss and Damage claims; and review findings and the communication thereof for relevant civil society and legal practitioners.
John Marsham	Met Office Joint Chair at the University of Leeds,	Climate scientist and modeler. Input on climate datasets, both observed and

List any key collaborators (name and organisation) and provide a very brief outline of their role in the proposed research.		
Name	**Organisation**	**Outline of role in proposed research (50 words maximum)**
	United Kingdom	modelled, and streamlining these into the analysis workflows and overall evaluation framework.
Chris Jack	Climate Systems Analysis Group, University of Cape Town, South Africa	Climate Scientist and attribution analysis expert. Providing technical inputs on Storyline approaches to health impact attribution.
Noel McCarthy	Department of Population Health Medicine, Public Health & Primary Care, Trinity College Dublin	Public health and policy technical role, with links to the Ireland and EU health system
Marina Romanello	University College London, Executive Director Lancet Countdown on Health and Climate Change, United Kingdom	Selection and development of indicators with links to mainstream indicators into global monitoring frameworks. Incorporation of the selected indicators in different regional reports, or global report, depending on results of the formal Lancet Countdown indicator assessment process. Link with the WHO/WMO office, in particular to co-supervise the GHAP staff seconded to that office for advancing specific study deliverables.
Nicholas Brink	Faculty of Health Sciences, University of the Witwatersrand, South Africa	To coordinate the Expert Group meeting in Year 3 on final indicator selection. Assist with making synergistic links between the GHAP and HIGH Horizons projects. Link with the WHO/WMO office on the indicator development work, critical given the cross-domain nature of these measures. Coordinate the WHO/UNFPA/UNICEF/WMO publication on priority indicators
Ekkehard Schleußner, Yvonne Heimann	Director, Department of Obstetric Medicine, University of Jena, Germany	Coordination of activities on heat impacts in pregnancy with the European Association of Perinatal Medicine. This includes sharing of data from site in Germany, as well as in other countries of the EU.

I confirm that the collaborators named above have agreed to be involved, as described, in the proposed research and are willing for their details to be included as part of this application.
Yes