Climate Compatible Growth Programmed Research Strategy 2025-2028

October 2025

Summary

Many communities in Low- and Lower-Middle Income Countries (LICs and LMICs) still lack equitable access to basic services, including healthcare, education, clean air and water, energy, and transport. At the same time, these countries face severe financial, economic, environmental, and social pressures. There is long way to go before the Sustainable Development Goals for 2030 are met. These countries are also already on the front line of the global climate change crisis and are particularly vulnerable to its impacts. A new model of development is therefore required that provides the services needed and opportunities for growth, whilst being resilient to climate change.

Phase 2 of the Climate Compatible Growth (CCG) Programmed Research effort aims to deliver novel, long-term research that focuses on putting this new model of development into practice. Building on CCG phase 1, this research focuses on how energy and transport needs can be met through low-carbon, climate-resilient investment, underpinned by inclusive and equitable economic growth, and resourced by equitably sourced and governed critical minerals.

Through an integrated, interdisciplinary, and collaborative approach, the CCG research programme provides deep understandings of the drivers and barriers to climate compatible growth; co-creates[1] models, tools, and data sets to inform decision-makers; and works with country partners and international stakeholders to apply and transfer these knowledge products effectively. By working closely with government, research centres and other partners in specific countries, the programme builds local capacity to continue and carry out research independently. Additionally, the participatory approach of the programme enables local researchers, policymakers, and other actors to inform research priorities, ensuring outcomes are relevant to the local stakeholders and context.

This document sets out the CCG Programmed Research strategy for the Phase 2 period from 2025 to 2028. It identifies and justifies research focus areas, domain-specific research communities and the primary cross-cutting research themes that will be pursued over this period. It also sets out how the research effort will be organised and delivered, and how impact will be pursued, including via integration within the overall CCG programme.[2]

The intention of this Programmed Research Strategy is to provide a framework within which specific projects will be co-created and delivered in partnership with local and international stakeholders going forwards. (Note that CCG's Country Partnerships and International Partnerships produce and induce significant volumes of research independently to meet their respective strategies – as described later – in this strategy, unless otherwise stated 'research' refers to the Programmed Research component of the programme.)

[1] The term "co-create" is core to the CCG research approach. It refers to a process where local stakeholders are engaged in research from the outset, develop capacity to deliver and use the research, and ultimately own the research outputs and can deliver related outcomes beyond the life of the CCG programme.

[2] The overall CCG programme contains three elements; Programmed Research, International Partnership (IP) and Country Partnerships (CP). This strategy relates to Programmed Research, and references IP and CP organisation and strategy. The reader should refer to IP and CP strategies for further details of these efforts.

Contents

Glossary

ADB	Asian Development Bank
Catalyst Facility	A CCG International Partnerships initiative to support global south individuals to become future leaders in CCG research areas
CCG	Climate Compatible Growth
CDF	Constituency Development Fund of Zambia
CLEWS	Climate, Land-use, Energy and Water Systems open-source modelling framework
CP	The CCG Country Partnerships team
CM	Critical Minerals
D2D	Data-to-Deal
DMDU	Decision Making under Deep Uncertainty
EF	The CCG Engagement Fund, a flexible fund to support partnerships
EIMET	Exploring Innovative Modelling approaches to Energy Transitions in LMICs
EMP	Energy Modelling Platform, a training school for energy modelling and related methods
FRF	The CCG Flexible Research Fund, a flexible fund to support CCG-aligned research by external partners
GESI	Gender Equality and Social Inclusion
GIS	Geographical Information Systems
HIEO	High Impact Economic Opportunity
IP	The CCG International Partnerships team
JETP	Just Energy Transition Partnership
LMIC	Lower-Middle Income Country
LIC	Low Income Country
LTS	Long-Term Strategy
MatDP	Material Demand Projections
MDB	Multilateral Development Bank
NDC	Nationally Determined Contribution
OnStove	OnStove is an open-source clean cooking modelling framework
OnSSET	OnSSET is an open-source spatial electrification modelling framework
OSeMobility	OSeMobility is a proposed open-source transport modelling framework
OSeMOSYS	OSeMOSYS is an open-source energy systems modelling framework
PEU	The CCG Political Economy Unit
PyPSA	PyPSA is an open-source energy systems modelling framework
RDM	Robust Decision Making
RQ	Research Question
SDG	Sustainable Development Goal
SIG	Special Interest Group. An in-country group of stakeholders with an interest in a specified topic. SIGs are supported by CCG Country Partnerships
SPF	The CCG Southern Partners Fund, a flexible fund to enable global south researchers to collaborate with the CCG programme
TDCI	Transport Data Commons Initiative
ToC	Theory of Change
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

1.1 Context

It is widely recognised that urgent global action is needed to mitigate and adapt to climate change [1]. In this context, low income and lower-middle income countries (LICs and LMICs) continue to face a series of challenges, prioritising much-needed sustainable development while navigating climate change mitigation, impacts and adaptation. Many communities in these countries lack access to basic services, and at the same time are disproportionately vulnerable to climate change impacts, with limited economic resources and underdeveloped infrastructure hindering adaptation. At the same time demographic and economic growth are increasing energy and transport demand, often with an associated pipeline of emissions [2], alongside exacerbated inequality as economic growth fails to reach the poorest groups in society [3]. LICs and LMICs are working towards solutions to these challenges, with the aim of achieving inclusive and equitable climate compatible growth.

There is an array of intersecting issues to overcome in achieving this. Central among these is the need to build a resilient and sustainable energy and transport infrastructure that can support service provision and underpin growth, including aiding pursuit of economic opportunities such as development of critical minerals and green hydrogen supply chains. Barriers to this are multifaceted, including insufficient planning capability, perceived or actual financial risks, underdeveloped evidence to support financing decisions, insufficient technical knowledge for implementing emerging policies, new regulation and market structures, status quo political and economic interests, high national debt hampering public spending [4], and insufficient institutional capacity to coordinate on multisectoral issues like climate change [5]. Moreover, it is recognised that LICs and LMICs are a heterogeneous group, each facing different challenges. These differences significantly influence opportunities going forward and highlight that locally owned context-specific evidence is crucial to understand starting points, objectives, and potential future just transition and adaptation pathways [6].

Many LICs and LMICs have declared their commitment to transition towards a low-carbon future, recognising opportunities to avoid lock-in to carbon-intensive infrastructure and to build sustainable and resilient energy and transport systems. Many have also recognized that energy and transport transitions bring economic opportunities such as material demand for low-carbon infrastructure, batteries and electric components, technical innovation in supply chains, green hydrogen and ammonia demand, the need for climate-resilient food production, and new productive ecosystems related to clean energy, with a background of significant renewable energy potential [7]. To realise such opportunities, considerable investment is needed. According to the International Energy Agency (IEA), capital investment in clean energy in developing economies, excluding China, needs to increase by approximately 6.5 times by 2035 relative to 2023 [1].

To unlock the required financing and effectively direct its investment, countries need capabilities and knowledge, as well as a conducive environment. A crucial element of this is coherent quantitative and qualitative assessment frameworks, and related high-quality data, to support the local creation of pathways and policies for resilient energy and transport system development, and the local pursuit of high impact economic opportunities aligned with plausible sustainable futures. There are concerns both in the wider research community and policy domain that current assessment frameworks often do not adequately reflect country contexts [6], fail to consider political context [8], are not undertaken or 'owned' by institutions in region [9, 10], focus on climate rather than development priorities [11], or are too reliant on approaches forged in developed regions [12]. Moreover, the impacts of investment pathways and opportunities on socio-economic distributional impacts, Gender Equality and Social Inclusion (GESI), and access to basic services are underrepresented in existing evidence [13].

1.2 Research Objective

The objective of CCG Programmed Research is to deliver world-leading research that generates knowledge products on resilient energy, transport, and critical minerals systems that can foster climate compatible, equitable and inclusive growth in LICs and LMICs. Ultimately this is to enable improved climate compatible growth for developing countries in Africa, Asia and other regions through breakthrough increases in the level of investment – or reorganisation of spend patterns – in infrastructure, services and policy. These accelerate economic growth and decelerate GHG-emissions per unit of growth.

We aim to provide a high-quality evidence base on what works and what does not work regarding low carbon growth initiatives in local contexts, and to co-create, collaboratively apply, and foster lasting capacity in the next generation of quantitative and qualitative approaches that can support decision-making on local, national, and international strategies and policies for energy, transport and critical minerals related sustainable development.

Noting the need for context-relevant and locally owned knowledge, CCG Programmed Research recognises that this research objective can only be achieved if efforts are informed by and embedded in local and regional realities. As such, our research is delivered in collaboration with country partners – for example government and research institutions - and with context-relevant international partners. Our research questions are informed by the stated needs of governments, researchers, development partners and other stakeholders in a set of partner countries[3], alongside international partners, and drawing on the expertise of the CCG research team. This enables local and regional context to inform priorities as the research progresses, and results in knowledge products that are tailored to the local or regional situation. In practice, this collaboration and process of embedding knowledge products is achieved via Programmed Research working with the CCG Country Partnerships (CP) team and the CCG International Partnerships (IP) team, and with local and regional stakeholders, throughout project lifecycles.

Drawing on the research context presented above, our research focuses on areas where there are stated demands and needs for knowledge and capability, as follows:

1) Stakeholder-owned, context-relevant, and fit-for-purpose energy, transport and critical minerals system design and analysis methods and their application, enhanced by new or improved supporting data.
2) Enhanced ability to identify and plan engagement with high impact economic opportunities, including relating to critical minerals and green hydrogen supply chains, and moving away from extractive practices towards a more just transition.
3) Enhanced ability to assess the resilience to climate change impacts and mitigation potential of energy, transport and critical minerals system investments.
4) Guidance on related policies, financing approaches, and new business models that can help unlock and align investments and entrepreneurship with climate compatible outcomes.

Delivery of all the above is undertaken in a context where the political economy of investment pathways and guidance is understood, equity and inclusion outcomes are assessed and improved,[4] governance and institutional capacity is strengthened, and partners are engaged to ensure relevance, uptake and application of outputs.

[3] As of February 2025, CCG partner countries are Ghana, Kenya, India, Laos, Malawi, Nepal, Vietnam, and Zambia
[4] Informed by CCGs Political Economy Unit (PEU) and Gender Equality and Social Inclusion (GESI) strategy.

Finally, our objective includes embedding local and regional research capacity to apply the knowledge developed in the long term, with capability persisting after the CCG programme is complete. This includes fostering the skills necessary to design and deliver new knowledge products related to our research objective and supporting the next generation of research leaders in partner organisations.

1.3 CCG Research from Phase 1 to Phase 2

As CCG research progresses from phase 1 to phase 2, focus areas are being adjusted to serve emerging country and regional demands, and research organisation is being adjusted to better facilitate internal and external collaboration on research efforts. In Phase 1, research activities were shaped by the FCDO (Foreign, Commonwealth and Development Office) Business Case, itself informed by the expertise and insights of the CCG team. The research was structured into three main workstreams, each with its own sub-workstreams:

1. **System Design**, with a sub-workstream Geographical Information System modelling.
2. **Sector Interactions** (e.g. energy-land-water, infrastructure-energy).
3. **Economics and Policy**, with sub-workstreams Policies and Pathways for Climate Compatible Growth, Decarbonising Transport, and Investment Pipelines.

Moving to phase 2, CCG research activity aims to build on successful phase 1 efforts with (a) restructuring the workstreams to provide greater clarity on the research focus areas, and (b) alteration to incorporate new research areas as identified as in-demand from country and regional partners, namely Critical Minerals, Data-to-Deal (D2D), and Green Hydrogen related research. These changes remain anchored in the updated FCDO Business Case, but are now more directly informed by lessons learned and impact achieved during Phase 1. At the same time, core areas of research from Phase 1 will continue, particularly in energy and transport system planning and policy, governance and equity issues surrounding energy transition and adaptation, and economics and finance.

Phase 2 CCG will also adopt a more structured process of project creation and management, providing greater opportunity for collaboration among CCG researchers, and tighter integration across CCG as a whole, incorporating Country Partnerships and International Partnerships teams.

1.4 Research Principles

Following the approach in CCG phase 1 research, CCG Programmed Research in phase 2 is developed and implemented with five key principles in mind:

1. **Interdisciplinarity:** research on societal challenges facing LICs and LMICs cannot be carried out from a single disciplinary perspective, especially on just transition issues. CCG's research programme therefore combines engineering, natural science, and social science expertise.
2. **Collaboration:** Partners in LICs and LMICs are core to the localisation of research. Collaboration with partner countries and coordination with international partners enables CCG research to be more effective and relevant to local needs with a direct pathway to impact. An important avenue for achieving this is CCG Country Partnerships and International Partnerships, which complement our activity under this Research Strategy.
3. **Responsiveness:** Policy and investment agendas for energy, transport and critical minerals can change rapidly. Whilst the core themes of CCG research are necessarily long-term, they are also sufficiently broad to respond to a rapidly changing landscape.
4. **Balance:** Making state-of-the art contributions to knowledge whilst remaining relevant to decision-makers requires a balance of priorities. CCG research priorities are informed by

partner collaborations, enabling us to build on the latest research advances whilst maintaining alignment with local needs.

5. **Transparency:** Informing real-world decision making requires research to go beyond traditional avenues for publication. The CCG programme has a particular focus on making methods, models, tools and data transparent, accessible to a wide range of researchers and decision-makers by adhering to open-access principles. Where knowledge products are published, results should be reproducible by third parties using freely available resources where possible.

2 Research Organisation & Project Workflow

2.1 Research Organisation

CCG Programmed Research is organized into **Research Communities,** each representing an interdisciplinary community of knowledge. Expertise from one or more Research Communities is brought together in **Research Projects** to tackle research questions aligned with a set of collaborative research priority areas, known as **Cross-Cutting Themes**. This framework is shown in Figure 1, with each element described below.

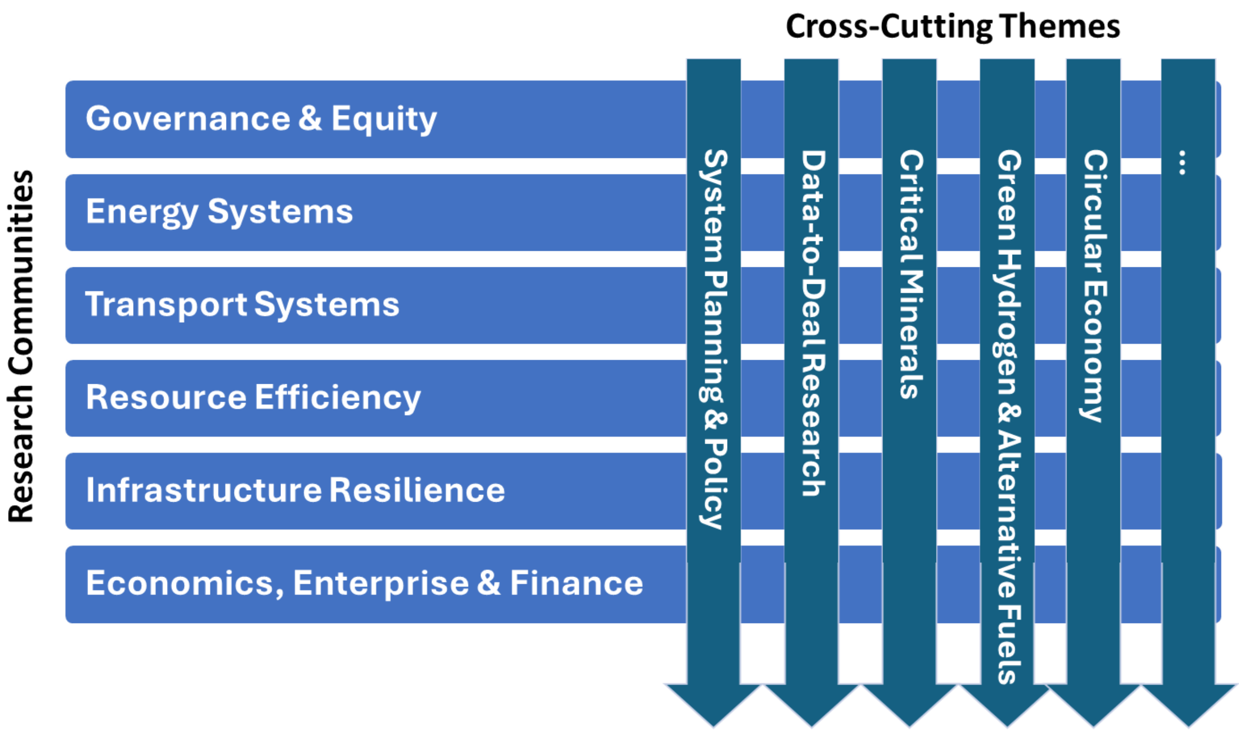

Figure 1:CCG Programmed Research organisation. Horizontal "Research Communities" represent domain-specific communities of expertise. "Cross-Cutting Themes" bring together the Research Communities to tackle key questions surrounding climate compatible growth in LICs and LMICs.

Research Communities are the domain-specific groupings of expertise in CCG Programmed Research, within which researchers are conversant with granular research challenges and work to create and improve knowledge products addressing these challenges. While Research Communities frequently cross classical disciplinary boundaries, they represent communities of knowledge with established approaches and collaborations. Each Research Community is described in detail in Section 4, and Research Community academic leads at the time of writing are identified in Appendix A.

Multidisciplinary approaches are essential to answer CCG research questions. To this end, **Cross-Cutting Themes** are defined to represent the priority research areas that bring together the Research Communities to tackle the most topical and urgent opportunities and challenges relating to climate compatible growth in LICs and LMICs. Cross-Cutting Themes frame the priority research areas and necessitate collaboration between Research Communities. For example, it is likely that projects aligned with the Critical Minerals Cross-Cutting Theme require input from Governance & Equity and Resource Efficiency Research Communities at a minimum to answer some topical research questions.

Research Projects are the delivery mechanism for research effort within this framework. Each Research Project brings together one or more Research Communities collaborating on a defined research effort, usually aligned with a specified Cross-Cutting Theme. The Research Project creation process provides flexibility to tailor the research questions from this strategy to local or regional context. The Research Project workflow is detailed in section 2.2.

2.2 Research Project Workflow

To promote localised demand-led research activity, and to advance broader academic community knowledge, CCG Programmed Research adopts a Research Project workflow that (a) underpins long-term comprehensive research and thought leadership, while (b) collaborating with and taking on board localised research priorities and including effort to foster long-term local capacity. As CCG moves from Phase 1 to Phase 2, some research activities will continue, whereas some new projects will be initiated. The workflow of new Research Projects is shown in Figure 2.

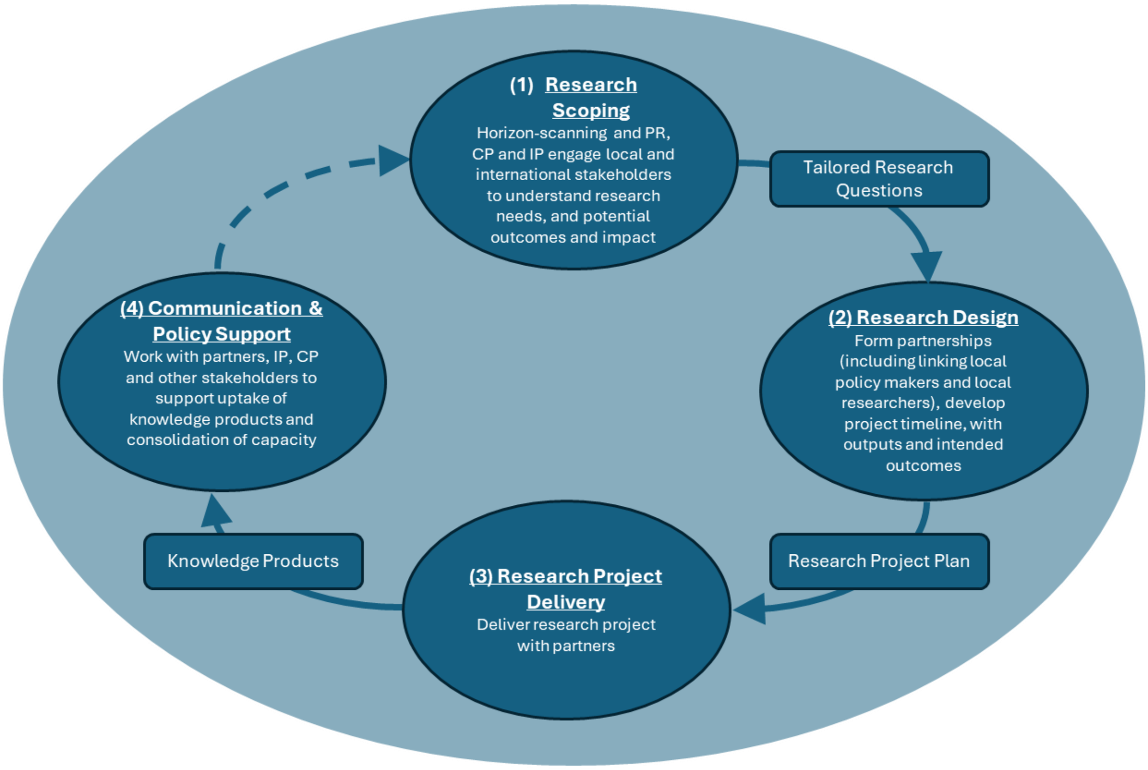

Figure 2: CCG Programmed Research workflow. Through collaborative scoping, tailored research questions are developed with partners within the guidelines of the research questions presented in this strategy (see Appendix B).

As per CCG Phase 1, Research Projects within CCG Phase 2 can start at any time within a financial year and can proceed for any length of time within the overall envisaged program term (i.e. until 2030).

2.2.1 Research Project Origination & Shaping

In Figure 2, (1) Research Scoping and (2) Research Design relate to project origination and project shaping. Programmed Research supports project origination via several routes, examples of which are described below, followed by a project shaping approach that ensures research remains aligned with CCG's research objectives from a programmatic point of view.

Most projects are originated through a combination of the following routes:

1. **Stakeholder-driven (requested):** Local, regional, or international stakeholder requests for research.
2. **Stakeholder-driven (identified)**: Topics generated from researcher interactions with local, regional or international stakeholders.
3. **Research continuation**: Previous or ongoing context-relevant projects that have identified research gaps.
4. **Foresight & strategic scanning**: Horizon scanning agile projects or literature review.
5. **Strategies**: In-country strategy or international-partnerships strategy.
6. **Investigator-identified**: Investigator ideation based on experience, research team capabilities, data needs/availability, etc.

Project origination is usually supported by CCG Country Partnerships (CP) and International Partnerships (IP) teams. For example:

Country Partnership activities can lead to local requests for research (1) or facilitate researcher-stakeholder interaction (2), including:

- scoping and political economy studies,
- in-country annual workshops,
- establishment and operation of Special Interest Groups,
- shaping via CP-developed country strategies (5).

Similarly, **International Partnerships** may support project origination via:

- Facilitating activities related to communication and uptake of knowledge products and other outputs, where discussion on research gaps is supported,
- Feedback on needs for educational material and tools (e.g. via IP's Open Learn collection and Energy Modelling Platform training where appropriate),
- Establishing future research leaders in the global south (e.g. via IP's Catalyst Facility) who then collaboratively generate project ideas with PR, and
- Establishing institutions to house and promote capability going forwards (e.g. via deployment of the Engagement Fund to create centres) which in turn help refine project ideas.

Once a set of possible projects have been identified, they are reviewed to shaped using a **programmatic approach**. Projects proceed based on their strategic fit, with the understanding that each project is shaped as a function of the full portfolio—ensuring alignment while allowing space for novel contributions. It is important to note that project budgets are allocated by research unit prior to project shaping.

1. Programmed Research Leads (PRL) meetings are used to discuss project ideas, explore opportunities for collaboration, consolidate projects where beneficial and align projects where complementary.

2. A programmatic approach to programme project shaping is then pursued, where project proposals are assessed by the Research Directorate to ensure that:
    - they are aligned with the Research Strategy (contribution to programme-level objectives)
    - most projects are originated from local, and regional contexts
    - cross-RC collaboration has been considered and pursued where appropriate
    - the GESI objectives of CCG, as outlined in the GESI strategy, have been considered, evaluated and pursued where appropriate,
    - potential outcomes and impact that are relevant to the CCG ToC have been identified
    - space has been created for blue-sky thinking, where innovative or exploratory ideas are encouraged and asses on their potential to contributing long-term strategic goals—even if not immediately aligned with the current portfolio priorities.
3. Where any issues arise from this review, Investigators are given opportunity to revise projects to address these.
4. Additionally, information provided in the Annual Consortium Review feeds back into project shaping. ACR comments are considered in PRL meetings, and where appropriate may be used to refine project shaping and/or redirect projects that are underway.

Following project shaping, a Research Project Plan is submitted that includes the following information at inception:

Element	Description
Title:	*Short title*
Investigator/s:	*Names of academic leads*
Research Community/s:	*List of Research Communities contributing*
Cross-Cutting Theme:	*Name of Cross-Cutting Theme*
Strategy Research Question/s:	*Identification of Research Strategy RQs addressed by the project (numbers only)*
Project Origination Route:	*Drop-down list as per 1-6 above, and including an "Other, please specify" category. More than 1 route can be selected where a combination where used.*
External Collaborators:	*List of local, regional and other project contributors*
Start date:	*Start date*
End date:	*End date*
Synopsis:	*<200-word summary of context, research gap, and approach/methodology. Specific tailored research question to be addressed by the project*
Intended Outputs and their Timing	*List of deliverables (and their timing) that are the responsibility of funded CCG research units, including LogFrame category*
Anticipated Outcomes	*List of possible outcomes, including LogFrame category*
Gender Equality and Social Inclusion (GESI) considerations	*Description of how the project takes into consideration marginalised and vulnerable groups such as women/girls, refugees, the elderly, etc*
TRAC Activity engagement, if yes, state which and contributions	*Transversal Activities (TRACs) are actively managed joined up efforts across CCG's three legs of PR, IP and CP.*
Is this jointly organised with IP or CP, if so note counterpart and point (s) of strategy intersection	*IP, CP and PR have distinct strategies overlaps and joined up workplans are prioritised where they increase impact.*

Table 1: Information captured at Research Project inception

2.2.2 Research Project Delivery and Uptake

From Figure 2, during (3) Research Project Delivery, progress is tracked against the Research Project Plan, via quarterly reporting from Research Communities to the CCG Central Directorate. Research stays grounded in local or regional context throughout the delivery phase via ongoing interaction with the local collaborators, and alignment of outputs with developments regarding the evidence base required, for example as observed through local policy document needs, or through local knowledge gaps observed by the Programmed Research, IP or CP teams, or local/regional stakeholders. Finally, knowledge generated is fed back to the broader local, regional or wider academic community via (4) Communication and Policy Support, to enable the delivery of outcomes and impact to beneficiaries, once again in collaboration with IP, CP and local/regional stakeholders.

2.3 Research Responsiveness

The Programmed Research strategy incorporates both formal and informal mechanisms to allow for adjustments to research direction as demands and new knowledge emerge. The localised and demand-led nature of research is a distinct feature of CCG strategy, alongside an imperative to build capacity with partners, and to contribute to state-of-the-art research knowledge products. Balancing these aims, CCG Programmed Research incorporates several flexibility mechanisms:

1) **Localisation of research questions:** Development of this research strategy has adopted two complimentary approaches to localisation of research questions. Firstly, research questions identified herein are based on partner interactions within CCG phase 1, where research projects have been developed and delivered in collaboration with local and international partners, leading to identification of further research questions. Secondly, research questions identified here are intentionally broad to create space to fine tune research direction in response to emerging needs, identified by stakeholders, Country Partnerships, International Partnerships or by CCG Programmed Researchers. These tailored research questions result from collaborative research scoping, see Figure 2 and Table 1.
2) **Flexibility regarding research prioritisation:** Following the CCG phase 1 research approach, in phase 2 Programmed Research adopts a flexible approach where ongoing Research Projects may be delayed or slowed to free resources to focus on emerging high priority research needs. While this flexibility is expected to only make small alterations to Research Project plans, it is an important element of overall responsiveness, acknowledging that original project timelines and outputs maybe altered to accommodate opportunities that arise.
3) **Agile/Responsive funding:** The further mechanism of responsiveness is via application for additional funding for specific responsive projects. CCG Central Directorate periodically opens calls for proposals, typically for horizon scanning projects that seek to define the key research questions to be addressed by a field. Programmed Research strategy envisages using this resource to define research priorities going forward, and then deliver on these using the responsiveness mechanisms described above. The outputs of these projects may result in alterations to research focus over the programme period.
4) **Leveraged funding:** CCG Programmed Research units will also achieve responsiveness to demands and emerging research directions through creation of new projects that are funded externally. New projects, potentially leveraged with CCG research effort, can address adjacent research questions aligned with the CCG Theory of Change.
5) **Alignment of flexible funding research priorities:** CCG operates a range of flexible funding mechanisms to enable new partners to contribute to research. These are the Flexible Research Fund (FRF), including a directed component, Southern Partners Fund (SPF), and Engagement

Fund (EF). Modalities of these funding streams will continue to be aligned with CCG Programmed Research, with increasing coordination integrate these efforts more closely, and ensure that commissioned research contributes to CCG's theory of change.

3 Research Communities

The following sub-sections describe the research context, priorities, research questions and methodologies of each Research Community for the CCG phase 2 (2025 – 2028) period. Detailed descriptions of associated research questions are included in Appendix B: Detailed Research Questions. As localisation of research agendas is central to CCG, the Programmed Research workflow (see section 2.22.2) tailors the research questions presented here address demands as the programme progresses.

3.1 Governance & Equity

Context

LICs and LMICs are facing significant and immediate risks from climate change due to low resilience and adaptive capacity. The need to transition towards a low carbon future is now widely recognised, yet efforts to realise the benefits of clean energy and transport infrastructure to all are met with many challenges. These include perceived or actual political, regulatory, economic, financial, technical, social, and administrative barriers, alongside insufficient institutional capacity, especially for the coordination of multisectoral issues [5].

Despite these challenges, many LICs and LMICs are committed to transitioning toward a low-carbon future. There is an expressed desire within partner countries to build sustainable infrastructure that avoids reliance on carbon-intensive technologies. But these countries are in a diverse range of situations, and the paths to low-carbon transitions vary widely among them, influenced by (for example) differences in economic development, resource endowments, and institutional capacities.

Furthermore, achieving climate compatible growth requires shifting resources between competing economic sectors and political constituencies, which can create political and institutional challenges [14], often against a backdrop of structural economic deficiencies and high levels of debt distress that constrain development potential [4, 15]. Understanding these contextual factors is crucial as LICs and LMICs strive to lift millions out of poverty while simultaneously providing access to modern energy and reducing emissions.

Research Priorities

The Governance & Equity Research Community examines the political economy, governance, and policy challenges faced by LICs and LMICs in pursuing inclusive, equitable and climate-compatible growth. It builds on research and partnerships established in Phase 1 which elicited the need for greater localised and context-specific solutions. In Phase 2 the Community will have a deeper focus on equity informed by the gender equality and social inclusion (GESI) and political economy unit (PEU) strategies, which have been developed by the Community leads. Critically, our research responds to partner demand and is case study driven. This means we are able to drive impact by working with a range of stakeholders critical for change and by accounting for their specific and diverse needs. Built upon equitable partnerships with country stakeholders, this research examines power dynamics and decision-making processes that influence low-carbon transitions, with a focus on institutional frameworks, economic interests, and local decision making. As an example of improving decision-making through more strategic infrastructure placement, we explore high-income economic opportunities (HIEOs)—such as mining, green hydrogen, and data centers—and their potential to enhance distributional outcomes, strengthen local resilience, and drive area-based economic development. This approach integrates both essential energy infrastructure and the energy-intensive activities that anchor these systems, while actively considering diverse local interests.

By evaluating diverse perspectives on future sustainable energy and transport systems, the research focuses on supporting the local development of effective strategies and policies across governance levels (subnational, national, global). The approach aims to strengthen community resilience by understanding and accounting for local needs, climate impacts and the context in which they occur thus addressing climate impacts and anchoring decision-making in local realities. This necessarily encompasses incorporation of GESI considerations, the evaluation of which will be undertaken by the GESI Unit. It also explores governance frameworks to ensure fair outcomes for marginalized communities, analyses competing stakeholder interests to facilitate coalition-building, and assesses how power dynamics shape knowledge interpretation in policy development. Additionally, it takes a justice-centered approach considering the whole energy system, with a view to identifying equitable policies for both present and future generations.

This Community is primarily embedded in countries and works in partnership with CP; it also adopts a global, transboundary perspective to understand the broader context in which transitions occur. Lastly, as an integral step to all investigations, the research aims to balance national infrastructure development with local community needs, highlighting how economic opportunities can enhance resilience and address social disparities. This comprehensive research agenda aims to foster inclusive, just, and sustainable low-carbon transitions by integrating diverse perspectives and stakeholder partnerships. It supports infrastructure decision-making grounded in local realities to maximise positive impacts.

To deliver this ambitious agenda, our research is categorised into three thematic areas:

1. Affordable, equitable and sustainable energy access and planning
2. Energy-enabled resilience and adaptation
3. Supporting an ecosystem for inclusive green growth.

Methodologies

We deploy a broad set of social research methods, depending on the research question(s) being addressed. These include case study analysis, stakeholder mapping, policy and economic analysis, scenario approaches, and other social research methods (i.e. interviews, surveys, focus group discussions, stakeholder mapping, workshops, visioning and other participatory research methods). We are committed to ensuring a wide range of stakeholders (e.g. academics, experts, policymakers, local communities etc) are included in methodologies, both as collaborators and study participants.

We have also developed a political economy framework to guide our research and practice, which draws on existing theories and conceptual frameworks e.g. on political economy, multi-level, and polycentric governance. Such approaches embrace complexity, and so are fundamental to provide deep and contextualised understandings of the topics we are working on, enabling us to think politically, and to provide workable and equitable solutions.

Method	RQs	Details	Potential Collaboration
Political economy analysis	1.1, 1.2, 1.7	Analyses governance, power dynamics, and economic structures affecting climate-compatible and equitable transitions. Helps identify political and economic interests of stakeholders.	All
Case study analysis	1.1, 1.2, 1.3	In-depth examination of specific contexts to understand transitions to climate-compatible energy and transport systems.	All
Stakeholder mapping	1.2, 1.4, 1.7	Identifies and analyses key actors in climate and energy transitions, their interests, and influence in decision-making.	All
Policy analysis	1.1, 1.4	Examines policies, policy instruments and institutional changes influencing energy and transport transitions.	All
Scenario approaches	1.3, 1.4, 1.5	Explores potential future pathways and trade-offs in energy and transport systems.	Energy Systems, Transport Systems
Participatory/social research methods (e.g., interviews, surveys, focus groups)	1.1, 1.5, 1.6, 1.7	We assess community needs by collecting both qualitative and quantitative data on local perspectives, opportunities, barriers, and impacts using methods like User-Perceived Value (UPV) and Social Return on Investment (SROI). UPV captures what communities value through visual prompts and narrative responses, while SROI quantifies social, environmental, and economic outcomes by assigning financial proxies to stakeholder-identified benefits. Stakeholders are actively engaged to co-produce knowledge and solutions for equitable energy transitions.	Transport systems, Energy systems
Spatial techno-economic modelling (GeoX framework)	1.3, 1.4, 1.5	Uses hexagon-based spatial analysis to optimize energy systems for specific sites and industries. It integrates land cover data, spatial features, and climate data to identify suitable renewable energy sites and model optimal system designs in PyPSA. Key applications include GeoH2 for green hydrogen, GeoNH3 for green ammonia, and GeoCu for copper processing.	Energy systems
Risk assessment	1.1, 1.2, 1.4, 1.6	We model spatially explicit costs of HIEOs under different economic scenarios to assess trade competitiveness and cost of capital impacts. We do this for green H2 and NH3, as well as mining. Additionally, we apply a resource curse risk framework to evaluate neocolonial risks, using stakeholder interviews and policy reviews. This helps identify potential risks and benefits of energy export strategies for developing countries.	Economics, enterprise and finance
Data governance analysis	1.7	Examines sustainable data infrastructure needs in developing country contexts.	All

Table 2: Methods used to answer Governance & Equity research questions

Research Questions

RQ1.1. How can transitions to climate-compatible and equitable energy and transport systems be governed to ensure no one is left behind, and what are the political economy challenges? *[Justice, Political Economy and Governance]*

RQ 1.2. How do the political and economic interests of stakeholders shape the formation and effectiveness of coalitions for climate-compatible and equitable transitions, and how does this influence the use of knowledge, data, and evidence in decision-making? *[Political Economy]*

RQ1.3. What are the visions (hopes, dreams and aspirations) of and pathways to climate-compatible and equitable energy and transport systems, and what synergies or trade-offs exist between national macroeconomic goals and local community development needs? *[Visions and Pathways]*

RQ 1.4. What strategies, policies, institutional changes, and timelines are required to develop climate-compatible and equitable energy and transport systems, and how can cross-sectoral collaboration ensure alignment between national priorities, social equity, and climate impacts? *[Policy and Institutions]*

RQ1.5. How can soft and hard infrastructure be developed to meet both top-down national macro-economic and policy goals, and local bottom-up community development needs, and where are the synergies and trade-offs in decision-making? *[Place-Based Impacts]*

RQ1.6. How can local community development needs be captured and accounted for in decision-making to increase community resilience, reduce existing vulnerabilities and minimise negative impacts of transitions? *[Community Resilience and Justice]*

RQ1.7. What are the key design attributes of a sustainable data infrastructure architecture for developing country contexts? *[Data Governance]*

3.2 Energy Systems

Context

To meet sustainable development goals, a reliable and functioning energy system is a fundamental building block, providing affordable energy services that meet economic and social needs today and in the future [13]. The rapid growth in the demand for energy in LICs and LMICs, driven by economic growth and increasing populations, means that robust and adaptive planning is crucial. Planning an energy system is, however, challenging. It is a process that often must deal with a fast-changing economy, shifts in societal trends, and that balances political priorities, notably around access and affordability, equity, resilience and security, and sustainability. It may also cover multiple sectors, including power generation, transportation, households, agriculture, and industry, all of which have different actors with a stake in the decision-making process. Finally, the system may have critical linkages to and dependencies on wider resource systems, including water and land. These linkages are affected by climate change.

Energy models have emerged as effective tools for providing decision support to this complex planning challenge [9, 16]. If applied appropriately, they can provide a useful quantitative framework for analysing trade-offs between policy priorities, notably across and between different parts of the system and wider biophysical systems. This is often done using scenario-based approaches that allow for exploration of different energy systems pathways, given an uncertain future. However, questions have been raised about whether model and scenario-based approaches are providing effective decision support. For example, there are concerns that analyses do not adequately reflect country contexts [6], fail to consider the political context [8], are made in silo [17], are not undertaken or ‘owned’ by institutions in region [10], focus on climate rather than development priorities [11], and are based on modelling approaches forged in developed region contexts [18].

Research Priorities

The Energy Systems Research Community focuses on co-creating and improving energy system planning tools and approaches to effectively address the unique challenges faced by LICs and LMICs in their energy transitions. A significant aspect of this effort involves integrating socio-political factors such as GESI into modelling frameworks, which is essential for aligning energy planning with context-specific development priorities. Moreover, improving the assessment of transition risks and decision-making under uncertainty is crucial, as poor policy choices can result from inadequate incorporation of uncertainty in planning processes. Traditional scenario-based approaches often fall short in capturing the full scope of uncertainty, necessitating the development of more sophisticated methods, such as Robust Decision Making (RDM), to better equip decision-makers.

Additionally, there is a pressing need to represent the spatial dimensions of energy demand, infrastructure, and governance levels within energy models. Energy demand levels vary geographically, and need to be better understood to ensure adequate and affordable supply, including infrastructure, notably for analysis of energy access. Utilizing high-resolution data sets to analyse service demands and resource availability can further enhance planning efforts and allow for a more nuanced understanding of socio-economic factors influencing energy transitions. A key focus is on how this understanding of spatial energy demand (and fast growth in LMICs) impacts on decision making around electricity system capacity and infrastructure, including types of system (centralised versus decentralised), need for flexibility, reliability and resilience of the system, and balancing affordability and utility economic sustainability.

Governance levels can also be represented spatially in order to assess policies for specific parts of the country; for example, a current project is representing counties in the national Kenya model to improve representation of subnational energy planning efforts. Current modelling approaches frequently overlook such critical spatial dimensions, which can be important for investment decisions and effective policy formulation.

Energy systems also need to reflect key dependencies with other systems such as land and water, competition with other productive activities for resources, and adequately reflect multi-sector priorities to support decision making. Failure to do so may lead to lack of system resilience, especially under climate extremes (e.g. the energy crisis arising from the prolonged drought in Zambia and impacts on electricity generation).

Collaborative projects undertaken by the Energy Systems Research Community will prioritise the importance of co-creating modelling approaches with local stakeholders to ensure relevance and applicability. This includes the development of country-driven modelling approaches using CCG modelling tools, but also where possible, new innovative modelling led by local partners. Overall, the research effort aims to foster equitable and sustainable energy systems by addressing the specific needs of LICs and LMICs while leveraging technological innovations, system thinking, new methods grounded in AI and machine learning, and open science practices.

Methodologies

The methods used to answer research questions energy system research questions are outlined Table 3 below, with the research questions set out in the section that follows.

Method	RQs	Details	Potential collaboration
Whole system energy models (OSeMOSYS), power systems capacity expansion and system operation models (OSeMOSYS & FlexTool)	2.1	These models of focus in Phase 1 will continue to be used and developed for energy sector analysis – but further complemented in phase 2 by more spatially resolved approaches (as described below). The focus of development will be in improving the use of models by use of systems mapping, improved incorporation of GESI, and political economy analysis (PEA), and a longer-term focus over Phase 2 on the potential use of socio-technical approaches, such as System Dynamics. Such considerations are being shaped by the ongoing EIMET (Exploring Innovative Modelling approaches to Energy Transitions in LMICs) project, led by UCL.	Equity and Governance (GESI & Futures); PEA; Economics, Enterprise and Finance; Transport (for whole systems)
Robust Decision Making (RDM) and other Decision Making Under Deep Uncertainty (DMDU) approaches	2.2	These approaches will be used to better capture uncertainty in system planning and enhance participatory approaches in modelling. The focus will be on RDM but may also consider other approaches used in other parts of the programme such as Info-Gap and Global Sensitivity Analysis. This will help establish CCG as a centre of excellence for uncertainty and risk assessment in LMICs.	Infrastructure Resilience; International Partnerships (Jairo Quiros)
Multi-scale modelling of energy systems	2.3	Firstly, these modelling methods will allow us to address different planning governance levels. This is currently being done using OSeMOSYS and other models to explore county level planning in Kenya and Benin. Models such as OnSSET and PyPSA will also be considered for more spatially disaggregated planning questions.	Equity and Governance (spatial modelling); Infrastructure Resilience
Spatial demand assessment	2.3, 2.4	A range of quantitative methods, including fitting statistical models and machine learning approaches, are combined with Geographical Information Systems software (e.g. QGIS) to estimate parameters relevant for energy systems modelling at desired spatial scales. This notably includes energy demand estimation across different infrastructure e.g. buildings, and communities.	Infrastructure Resilience; Resource Efficiency, Transport Systems
Climate Land Energy Water (CLEWS)	2.5	CLEWS enables scenario planning related to the nexus between the land use, energy supply and water supply sectors ensuring that policy is informed by evidence on how decisions in one sector affect the others. . KTH, UCL, UNDESA and the CCG country partnerships of Zambia and Lao PDR have designed a program for developing a CLEWs	Equity and Governance (particularly relating to land-energy); Infrastructure Resilience

		ecosystem in the two countries, including development of new methods, model applications and capacity strengthening. The development of models and applications is dictated by needs emerging from the country strategies, and expands on work started in WS3 with OSeMOSYS. Much of it relies on increasing the spatial and temporal resolution of the analyses.	
OnStove for spatial analysis of clean cooking, OnSSET for spatial analysis of electrification pathways	2.1-2.6	OnStove and OnSSET will be applied and improved to include considerations of affordability and climate resilience. Broadly the focus is on investigating how Geographic Information Systems (GIS) can be used for integrated planning of electricity and clean cooking access. Methodological advancements will be made to include considerations on economic possibilities (affordability) and for assessing strategies to enhance the resilience of interventions aimed at improving electricity and clean cooking access in the face of climate extremes. Identify vulnerabilities, development of adaptation measures, and integration of resilience considerations into planning frameworks to ensure the long-term sustainability and effectiveness of access initiatives.	Equity and Governance (particularly relating to land-energy); Infrastructure Resilience

Table 3: Methods used to answer Energy Systems research questions

Research Questions

RQ2.1. How can energy system planning tools and approaches better represent the energy transition opportunities and challenges faced by LIC and LMIC countries, and be shaped by local expertise?

RQ2.2. How can the assessment of transition risks and the robustness of decision-making under uncertainty be enhanced to improve planning and better support investment?

RQ2.3. What approaches can be developed to better represent location-specific determinants of energy infrastructure investment, as well as multi-level governance systems in energy models?

RQ2.4. How can highly resolved data sets for demand, infrastructure, resource availability, industrial production, etc, be used, combined and interpreted for use in energy system planning? RQ2.5. What energy system modelling approaches and spatiotemporal scales of analysis can help identify technological innovations that mitigate conflicts over the use of scarce resources under uncertain climate change?

RQ2.5. How can energy access planning be coordinated with planning in other spheres such as climate, economy and other resources, and how can the use of AI techniques support such coordination?

RQ2.6. How and to what extent can open science practices and open educational resources achieve positive development outcomes relating to energy and transport in CCG partner countries?

3.3 Transport Systems

Context

Transport systems are complementary and essential to sustainable economic development, as transport services and infrastructures enable people to access fundamental goods and services including food, healthcare, education and economic opportunities by reducing costs and removing displacement barriers [19]. However, access to transport services is not equitably distributed amongst populations: marginalised groups including women and girls [20], people on low income [21] and disabled people [22] are disproportionately likely to lack access to such fundamental amenities. Transport systems are exposed to the impacts of climate change, and disruption of these lifelines in extreme events also has a disproportionate impact on poorer people [23].

Aside from being unequal, current transport systems are highly polluting to human environments. Transport accounts for 23% of global energy-related CO_2 emissions and, of this, 70% comes from road vehicles. Transport emissions are growing more rapidly in LICs and LMICs than in Europe or North America, and this trend is likely to continue in coming decades [24]. Many African and Asian LICs and LMICs with little fossil fuel reserves but plentiful renewable energy resources risk being locked-in to high-emitting technologies that depend on imported fossil fuels and therefore missing economic opportunities and making it difficult to transition away from fossil fuels in the future [25]. Rising emissions are not limited to CO_2 and other greenhouse gases, as transport is also a major source of local air pollutants such as particulate matter of various sizes (PM_{10}, $PM_{2.5}$) and nitrogen oxides (NOx) which have direct respiratory, cardiovascular and fertility impacts, including lung cancer, stroke, stillbirths and infant death [26, 27].

CCG in transport means supporting the development of sustainable, affordable and inclusive transport systems for equitable access to basic goods and services in a manner that ensures meeting economy-wide emissions and climate resilience targets. With a view to this overarching goal, CCG's Transport Systems Research Community provides and co-creates research, knowledge and public goods to support investment and the development of local capacity to enable LICs and LMICs to advance resilient, low-carbon transport infrastructures and services enabling clean, safe, efficient and equitable access to goods and services for all. The Transport Systems Research Community works primarily at two levels:

- On the macro level, we co-create analytical support tools with LIC and LMIC researchers and decision-makers to build pathways to just, clean, safe, low-carbon and climate resilient mobility futures. This involves the production of novel datasets, scenario making resources for imagining sustainable and equitable futures, the development of context-appropriate modelling frameworks and the delivery of analytical support to assist policymakers and financiers at national and international levels in building robust policy and investment pipelines. We also work with international-level stakeholders, notably a partnership with the Asian Development Bank, which we will expand to other multilateral development banks (MDBs), in scaling up these approaches to achieve impact across a wider network of LICs and LMICs than just the CCG partner countries.
- On the micro level, we work with LIC and LMIC researchers, practitioners and governments on localised contexts, including land use, walking and cycling, popular transport), air pollution, public transport infrastructure, sustainable EV infrastructure, and the day-to-day experienced mobilities of marginalised groups through an intersectional approach of gender, age, race, social class and abilities, among others. The work will build on latest research carried out under the High-Volume Transport Programme (HVT). Given the escalating climate crisis, we will also

consider how adaptive capacity and climate resilience can be enhanced as an integral part of our all our research activity.

Research Priorities

The overarching goal of the Transport Systems Research Community for 2030 is to leave a legacy of greater capacity in the development of low-carbon and climate-resilient transport systems that enable clean, safe, and equitable access for all. In achieving this vision, our work focuses on the following research priorities:

- The development of open transport data platforms and data infrastructures to improve the quality and availability of the transport data landscape for transport and energy system models [28] and equity analysis, notably through involvement in, and co-funding of, the Transport Data Commons Initiative (TDCI) with 30+ international organisations.
- The development of detailed representations of the transport system in whole energy system models to support LICs' and LMICs' long-term development goals, thus building on the D2D approach.
- With relation to the above point, the application of socio-technical approaches (e.g. [29, 30]) in developing transport system models, thus allowing for more detailed representation of transport-energy system phenomena (compared to centralised optimisation models often used in energy systems analysis) and the co-creation of future scenarios with local stakeholders. Specifically, this involves the development of OSeMobility, the open-source mobility model. The first open-source transport-energy model specifically designed around open-source data in LIC and LMIC contexts, OSeMobility will combine a socio-technical approach to modelling transport demand with a choice-based vehicle stock model, allowing stakeholders to explore the quantitative impacts of credible transport scenarios, including energy, emissions, and a range of co-benefits such as reduced air pollution, fatalities and reduced fuel import bills. It will be rooted in open-source data, including OpenStreetMap, to enable rapid development of new models with a modular approach to suit varying levels of data availability. OSeMobility will therefore provide a link between land use and spatial planning and the transport/energy system, providing transport stakeholders with familiar "levers" in scenario development for the rest of the D2D workflow. This will enhance the level of detail afforded to transport in whole energy-system models and allowing stakeholders to link spatial and temporal analyses in evaluating transport-energy system futures. The development of OSeMobility will be supported by engagement with a steering group (ongoing), which will include members of the TDCI (above) and the International Transport Energy Modelling (ITEM) project (including Sonia Yeh, Paul Kishimoto and Pierpaolo Cazzola.
- The development of decision support tools, effectively communicating the results of CCG co-developed transport models to provide evidence that supports policy and investment towards equitable and GESI-transformative climate-compatible transport transitions in LICs and LMICs. The latest research and tools by HVT on climate, gender and inclusive transport will be considered in future work
- The delivery of these decision support tools at scale, including working with MDBs – notably the Asian Development Bank (ADB), with whom FCDO has established a memorandum of understanding to accelerate deployment of CCG tools in advancing low-carbon transport pathways in Asia and the Pacific. The objective of the partnership is to facilitate ADB's Developing Member Countries (DMCs) to move from data to deal, i.e. translating high-quality data and modelling efforts into evidence-based policy development and well-substantiated investment strategies, piloting and further adjusting the Data-to-Deal approach initially

developed by CCG with partners in Latin America. The CCG-ADB partnership aims to reach its objectives by establishing key partnerships among IFIs and development agencies active in the region, thus maximizing its impact on the ground. The project aims to focus on four DMCs in the region, where separate aspects of the D2D approach are piloted, but also developing a regional approach through capacity building and knowledge sharing (e.g. integrating transport in the CCG summer schools), paving the way for scaling up the approach in other DMCs in the region.
Further, the development of investment strategies that result in investable pipelines will be an especially relevant step of the D2D approach for International Finance Institutions, and this is why the project aims to assess using the D2D approach in the background to directly support the development of investment strategies, e.g. of existing (or updated) NDCs.

- The development of training content and delivery to support capacity building in the development of clean, safe, equitable, low-carbon and climate-resilient transport systems in LICs and LMICs. It is planned to build in the transport sector in future summer schools hosted by CCG.

To analyse questions of climate resilience of transport networks, and interventions to equitably enhance resilience, this Research Community will work in tandem with the Infrastructure Resilience Research Community, which is developing spatial models of transport flows to identify hotspots of climate exposure and prioritize resilience interventions.

Methodologies

The methods used to answer research questions RQ3.1-RQ3.7 are outlined in Table 4. See the following section for research questions.

Method	**RQs**	**Details**	**Potential collaboration**
Scenario development through deliberative workshops	3.5, 3.6, 3.7	• Conducting the development of scenarios from within and by local users that are relevant to policy planning and to expanding imaginations of possibilities, risks, and opportunities. • Based on scenario narratives, inform plausible transport pathways and modelling leavers that provide insights relevant for informing robust policy decisions in climate change resilience, inclusivity, economic development, energy access and security, and wider economic and geopolitical impacts.	D2D; Critical minerals; GESI; Energy systems; finance; political economy
Travel & vehicle choice survey design	3.2	• Co-design of surveys and other data collection methods to be applied in CCG partner countries • Productization of survey to improve visibility of outputs and make sure it can be easily adopted by partner countries • Development of capacity in partner countries to build and use similar surveys	GESI; Economics and Finance

Stakeholder mapping, interviews and qualitative analysis	3.4, 3.5, 3.6, 3.7	• Co-development of stakeholder maps for transport systems (and adjacent sectors) in CCG partner countries • Production of stakeholder interviews and qualitative analysis to inform scenario development and air pollution analysis • Mining (through interviews) of data regarding place attachment, thus feeding into workshops linking land use and transport systems, and contributing to understanding of people's reasons for travelling/not travelling	Critical minerals; GESI; Energy systems; finance; political economy
Database curation and software architecture development	3.1, 3.2, 3.3	• Support the development of architectures to support FAIR open data principles in CCG products & public goods through the Transport Data Commons Initiative (TDCI)	Data platform, D2D
Mathematical model development (several sub-methods)	3.2, 3.3	• Co-development of context-appropriate modelling frameworks to support pathway development in CCG partner countries • Development of open-source software with communities of practice to allow training (integration with Energy Modelling Platform)	Data platform; GESI; Energy systems; finance; D2D; Critical minerals
Development of toolkits (several context-specific sub-methods)	3.2, 3.3, 3.4, 3.5, 3.6, 3.7	• Co-development, with stakeholders in partner countries, of toolkits for evaluating cross-sectoral impacts of transport-energy transitions (e.g. fuels, air pollution, access, emissions, critical minerals, electricity infrastructure) • Co-development of tools to assess the appropriateness of different financing mechanisms to support investments in transport-energy transitions.	GESI, Economy and finance; Energy systems; D2D; Critical minerals

Table 4: Methods used to answer Transport Systems research questions

Research Questions

RQ3.1. How can open data and tools be leveraged to i) enable better reporting, monitoring, and analysing and ii) support better policy in transport systems in LICs and LMICs, and how can platforms and infrastructures to support those data and tools best be developed?

RQ3.2. How do passenger travel demand and e-mobility adoption vary between population groups in LICs and LMICs, and how can approaches to gather data on those issues be tailored to suit localised contexts?

RQ3.3. How can the transport sector be represented effectively in whole energy system models, guided by user-led future scenario development and the tenets of open-source data and stakeholder inclusion, and how can the resulting representations be used to co-develop quantitative analyses that supports the development of policy and investment resulting in equitable, low-carbon and climate-resilient transport system pathways?

RQ3.4 How can the distribution and effects of air pollution be integrated into the development of pathways for equitable, low-carbon and climate-resilient transport systems in ways that capture the differentiated health impacts among marginalised groups?

RQ3.5. How can equitable, low-carbon and climate-resilient transport system pathways, co-developed with local stakeholders, user-led scenarios, and supported by CCG's modelling offer, be integrated to support a wider and cross-sectional understanding of SDGs, including the development of GESI-transformative transport policies and investments?

RQ3.6 What are the cross-sectoral impacts of the transport-energy pathways discussed in RQ3.3 and RQ3.5, including electricity demand growth, air pollution reduction, social inclusion, climate infrastructure resilience, critical minerals, taxation revenues from fuel sales, fuel import bills and job creation?

RQ3.7 What are the most effective and locally appropriate financing mechanisms to support investments to promote pathways to equitable, low-carbon and climate-resilient transport systems in LICs and LMICs, including public-private partnerships? (Note that this RQ will be addressed in collaboration with ADB.)

3.4 Resource Efficiency

Context

A future zero-carbon-world will require all countries, including LICs and LMICs, to transform energy and transport systems away from fossil fuel extraction and combustion to more complex material-based technologies which extract or store energy from nature and make it available to users [31]. These technologies include most of the low-carbon infrastructure, such as wind turbines, solar panels, and batteries. They require greater quantities of complex combinations of materials [32] and long supply chains. Sourcing and producing these critical minerals (CMs) has potential detrimental impacts on the GHG emissions targets [33] and their long and complex supply chains may threaten the ability to reliably secure supplies [34]. Additionally, there are significant geopolitical vulnerabilities in CM supply chains. All these impacts remain largely unexplored in energy, transport, and CMs modelling efforts.

Many LICs and LMICs countries in Asia and Africa have historically been involved in the raw material extraction of CMs, largely to meet demand for products in high income countries [35]. As demand for low-carbon technologies grows and drives increased demand for bulk materials and CMs, LICs and LMICs are seeking opportunities to extract more value by expanding their operations downstream of mining in the supply chain. The stages of refining CMs and component/product manufacture have traditionally involved greater added value. If this increased participation in the value chain is handled appropriately, it could enable development and economic growth in LICs and LMICs, while creating the conditions necessary for a global low-carbon industrial revolution. Many bulk and CM materials are prone to supply risks, [36-38] and many countries have classified lists of materials deemed to be critical. However, there is little consensus about how to define materials as being critical or formal risk modelling of value chains in the literature. Rigorous evidence can be provided by further modelling and analysis of the physical resources and capacities, technical and economic expertise, and the environmental and social implications, while also considering the equity (GESI) and political economy (PEU) implications. This is essential to identify and prioritise the most promising interventions for LICs and LMICs to extract more value from CMs, while supporting sustainable and inclusive development.

Research Priorities

The Resource Efficiency Research Community will focus on: a) the assessment of **material requirements** for future energy and transport systems; b) the assessment of **material criticality**; c) the evaluation of opportunities for **material circularity**. The first area is centred around the development of MatDP (Material demand projections) [39] through to an open-source software offering, while the second area focuses on development of two new models on (1) CM supply and (2) CM value chains. These software products, when combined, anticipate the bulk and CMs required to build-out electricity and transport systems in LICs and LMICs countries under different future scenarios, and inform how these countries can extract more value from CM value chains, remove constraints where they exist, and respond to disruption risks. In the immediate future, MatDP will be linked with CCG and other energy and transport models, and training materials and case studies will be developed.

In the third research area we assess the potential for moving to more circular use of materials, particularly in LICs and LMICs, by creating dynamic stock and flow models of materials. Material recycling, waste recovery, reuse and material efficiency can play a role in alleviating future material supply constraints and reducing environmental impacts, including GHG emissions. However, the dynamics of material supply, demand and its accumulation in service enable different circularity opportunities at different times. For this reason, circularity opportunities should be deployed with the timing and location that allow them to deliver meaningful positive impacts. We will develop new modelling approaches to explore circularity opportunities and to reveal the timing and location that would allow them to deliver the maximum possible impacts. These approaches will help to identify the required interventions to remove or relieve future material supply constraints. The quantitative modelling will be applied in LICs and LMICs to support the development of national circularity strategies and policies.

Methodologies

The Resource Efficiency community takes a multi-disciplinary approach to understand the materials requirements for complex systems. This includes the several environmental impact assessment (EIA) methodologies, including life-cycle assessment (LCA), dynamic material flow analysis (DMFA), and input-output analysis (IOA), alongside methodologies such as techno-economic analysis (TEA), multi-objective optimisation, supply chain analysis and machine learning (ML). We use these analysis tools to map the flow of resources through supply chains, assessing the social and environmental impacts, provide insights into mitigating the adverse effects and avoiding disruptions.

Method	RQs	Details	Potential collaboration
Material requirements	4.1	We assess the future demand for materials for low-carbon energy and transport systems using curated technology-material and material-impact matrices, collated from product bill-of-materials records and LCA (life-cycle assessment studies) studies. The resulting MatDP software takes in energy and transport scenario pathways from OSeMOSYS, OSMobility and other software through dedicated APIs, to anticipate material requirements and related environmental impacts	Transport systems; Energy Systems; Critical minerals

Material criticality	4.2	We map the flow of CMs through their value chains using a hybrid approach of Material flow analysis (MFA), input-output (IO), and company-to-company financial transactions. We assess the resilience of the value chains and risks to companies and countries, using established principles of risk theory, which to date has been absent from CM analysis. This will allow us to formally define criticality based on metrics of supply disruption and its consequences. We use agent-based models (ABM) and machine learning (ML) to quantify the risk of disruption for CM supplies. We will collaborate with the partner countries and the PEU to find ways to increase the value LIC s and LMICs can extract from CM value chains.	Transport systems; Energy systems; Infrastructure resilience; Critical minerals
Material circularity	4.3	We assess the potential for moving to more circular use of materials by creating dynamic stock and flow models of materials in use and by assessing role of circular strategies to mitigate environmental impacts and supply shocks. We will link with other models developed in CCG to co-develop circularity strategies in partner countries.	System planning and policy; Critical minerals; Circular economy

Table 5: Methods used to answer Resource Efficiency research questions

Research Questions

RQ4.1. How many and which materials will be needed globally to meet climate change targets?

RQ4.2. What material supply chains are at risk of disruption, where will these risks occur and what interventions can mitigate future risks?

RQ4.3. What role can material circularity strategies play in reducing demand for primary material and how does this affect environmental and social impacts?

3.5 Infrastructure Resilience

Context

Given their central importance to the functioning of economies and societies, networked infrastructure systems represent particular points of vulnerability to climate change [40]. LICs and LMICs are exposed to a range of climate hazards, from floods and droughts to tropical cyclones and landslides. The stock of infrastructure is often inadequate and in deteriorated condition, meaning that it is particularly vulnerable to climate impacts [41]. These impacts can have chronic and acute effects on national economies and human development, by preventing access to basic services (as required by the SDGs) and by disrupting economic activity. The cost of reconstruction represents a burden on public finances, whist perceived physical climate risks are a deterrent to investors [42].

Though adaptation may provide opportunities and co-benefits, the primary benefit of adaptation is avoided or reduced damage from the impacts of climate change [43]. Thus, to quantify the degree of adaptation that is needed and its associated benefits, requires projections of climate impact. As climate impacts materialize in many different ways in different places, we require methods that can explore a wide range of possible future conditions, including many different possible extreme events. Risk analysis provides such a framework, as it entails systematic analysis of the distribution of possible climate-related hazards, combined with mapping and quantification of exposure and vulnerability to climate hazards, should they materialize, which can be compared with the costs of adaptation. Estimates of climate risk can be wrapped within a framework of uncertainty analysis, to explore the implications of uncertainty regarding future climatic and socio-economic changes [44].

Research Priorities

The Infrastructure Resilience Research Community is developing open-source spatial models for assessment of climate-related risks to energy and transport infrastructure, at present and in the future, and for quantification of the risk-reducing benefits of adaptation. We will work with international partners and country partners to build capacity in climate risk analysis of energy and transport infrastructure and embed processes for prioritization of resilience interventions. We will focus activities at global and national scales.

The first focus at a global scale, provides new insights for international audiences into the scale and location of climate risks to infrastructure [45], and the investments that are needed to reduce climate risk. Our global partners include the World Bank, International Monetary Fund and Global Centre on Adaptation, which also help to provide leverage into national governments. Global or continental (e.g. Africa-scale) modelling also provides packages of spatial data starter-kits for national assessment. The scope will be narrowed to be the global south or to the continent of Africa, in cases where the computational expense of analysing countries in High Income countries with very dense infrastructure networks is not warranted. In particular, we will finalise a global (south) model of transport and trade (already used for CCG Critical Minerals analysis) which will provide capability for transport investment and asset management planning at large spatial scales, by governments, development banks and other international finance institutions. Analysis at these scales will be driven by openly available global datasets. Provision of cleaned and inter-operable versions of these spatial datasets is one valued contribution of our work.

The second focus is at national scales, where it is possible to do more in-depth analysis of resilience options, and their alignment with national sustainable development objectives [46-48]. We will continue to work with the Country Partnerships team to respond to specific country needs and demand, initially with a focus upon Ghana, where the need to assess and enhance the resilience of transport and electricity networks has been emphasised. At a national scale, our focus will be upon prioritization of resilience investments (both incremental and transformational) and integrating these within overall national infrastructure and climate strategies. Work at national scale also provides a natural focus for capacity building within country partners and alignment with country Data-to-Deal (D2D) initiatives. We will continue our methodological development to understand the wider economic impacts of infrastructure failure, both at present and in future economic scenarios, in order to make a more compelling case for resilience prioritization.

The high-resolution network analysis within the Infrastructure Resilience Research Community will be used to map access to infrastructure (including social infrastructure) for disadvantaged communities, and their vulnerability to climate-related shocks. Thus, the Infrastructure Resilience Research Community will provide new insights into GESI aspects of infrastructure systems.

The main methods in this research are system modelling, so this Research Community shares methods and works closely with the three other quantified systems Research Communities (i.e. energy, transport and resources). We complement the Transport Systems Research Community with our spatial research on transport systems, so will be able to provide high resolution spatial network analysis where that is needed, for example, to analyse transport emissions and accessibility to essential services. Ultimately, methods for appraisal of resilience fit within a governance framework, and need to be financed, so we need significant collaboration with Governance and Finance Research Communities, in particular in relation to Data-to-Deal research which provides a governance and finance context within which Infrastructure Resilience can be embedded. We will continue to make a central contribution to Critical Minerals by mapping the routing of critical minerals through the transport network for mines, to processing and ports, and beyond.

Methodologies

Method	**RQs**	**Details**	**Potential collaboration**
Spatial transport network modelling	5.1	Our spatial transport modelling is based on road, rail port and airport data obtained initially from OpenStreetMap but supplemented from a variety of other sources, which are made available in the GRI Risk Viewer. This information is combined with economic and population datasets to estimate traffic flows. The simulation modelling enables rerouting of traffic flows due to climate-related disruptions.	Transport systems
Spatial energy network modelling	5.1	Spatial energy modelling combines a variety geolocated energy generation datasets with the Gridfinder transmission network estimation tool. Our network failure models are encoded with the open-gira toolset which is located in our github repository.	Energy systems
Multi-hazard climate risk assessment, in the GRI Risk Viewer	5.1	Within the GRI risk viewer we are constantly updating our repository of publicly available climate hazard information, which currently includes river and coastal flooding, tropical cyclones, extreme heat and landslides. Most of these are available as return period maps for risk analysis.	
Geolocation of human and economic activities	5.2, 5.3	To map out economic activities we use a variety of geospatial datasets, including building locations, land cover, nightlights and macro-economic data. We are developing scripts to combine these datasets and make them widely available.	Economics, Enterprise and Finance
Agent-based modelling of transport disruptions and economic impacts	5.2	Further analysis of the impacts of transport and energy disruption will mobilise versions of agent-based modelling, in the first instance based upon the ARIO model.	Economics, Enterprise and Finance
Robust optimization of investment sequences	5.4	Prioritization of infrastructure resilience is based upon balancing the costs of resilience with the benefit of avoided losses. There are large numbers of possible interventions, as well as severe uncertainties, so developing proposals for resilience investment sequences involves robust optimization.	System planning and policy

Table 6: Methods used to answer Infrastructure Resilience research questions

Research Questions

RQ5.1. What are the climate risks to energy and transport systems at national and global scales?

RQ5.2. What are the macro-economic impacts of climate related damage and disruption to infrastructure systems?

RQ5.3. What are the patterns of (in)accessibility to infrastructure for disadvantaged communities, and how can infrastructure resilience be prioritized to address GESI?

RQ5.4. How can physical climate risk analysis inform national infrastructure investment prioritization?

3.6 Economics, Enterprise & Finance

Context

The global landscape for climate-compatible growth is significantly influenced by the declining costs of renewable energy technologies [49], particularly solar power, which holds substantial growth potential in regions like Africa and South Asia [7]. However, progress depends on the effective interaction of three interlinked factors: a supportive and equitable policy environment, innovative clean entrepreneurship and the (re)allocation of sufficient capital.

Policy: Several barriers hinder this growth, including outdated regulatory frameworks [50], skill shortages and just transition challenges [51], and a challenging investment climate characterized by administrative hurdles and macroeconomic risks [52]. Achieving climate-compatible growth necessitates the formulation of supportive public policies that align climate initiatives with economic development goals. Such policies should aim to enhance productivity-enhancing structural change and promote inclusive environmental and social outcomes. While progress has been made in understanding effective policy mixes [53], further research is needed to identify the most suitable strategies for low- and lower-middle income countries [54].

Entrepreneurship: Climate compatible growth is not just about technological change, it is also about changing business practices. New forms of private sector involvement to drive sustainable development in LICs and LMICs are gaining in importance. However, it is unclear how different forms of private sector involvement influence climate compatible innovation and growth. There is empirical research on the link of business practices and environmental outcomes [55], but very little evidence for developing countries, and indeed on the attitude of their business leaders towards the environment.

Finance: Access to finance is perhaps the most prominent barrier encountered by green entrepreneurs. Clean technology tends to be capital intensive, even if these costs are subsequently recouped through operational savings. The new business models can also be capital intensive. Working capital is needed, for example for as pay-as-you-go payment systems, which have opened renewable energy to low-income consumers, and energy-as-a-service approaches, which allows energy providers to capture additional values (e.g. by offering food cooling or recharging services).

Research Priorities

The Economics, Enterprise & Finance Research Community will pursue research that can be categorised as either global or country specific.

The global research focuses on understanding climate-compatible growth through global datasets and multi-country case studies. The route to impact is by changing people's understanding of promising climate compatible growth strategies (e.g. successful support policies or business models). The research prioritizes the identification of supportive public policies that connect climate interventions with economic growth objectives, emphasizing the need for suitable policy mixes tailored to low- and lower-middle income countries.

Additionally, the research aims to investigate how changes in business practices and new forms of private sector involvement can drive sustainable development, with a specific focus on inclusive innovation and equitable outcomes. Working with International Partnerships and potentially associated projects (e.g. if approved the forthcoming RIDE project), it will examine financing gaps in specific countries (see section on data-to-deal). In terms of business model innovation, we will explore innovative solutions, such as pay-as-you-go systems, to enhance access to clean technologies.

Country-specific research will be embedded into the wider country strategies. A key priority continues to be Zambia, where there will be an emphasis on how the Constituency Development Fund (CDF) can be an agent of change within CCG's Data to Deal (D2D) framework. We will investigate interventions through which the CDF could be a novel and innovative financial instrument to support 'blended funding' (emphasising development outcomes) as a precursor to more conventional blended finance, where the emphasis includes a financial return. This builds on past work on blended finance, particularly in the water sector [56]. Ultimately our objective is to deliver robust research outputs to support the development of a 'deal' framework that transitions from today's reality of marginal project bankability – to tomorrow's potential for investing in sustainable climate compatible growth. Apart from the CDF focus, we will also evaluate the long-term viability of the state-owned power utility ZESCO, given rapid evolution of customer behaviour in response to drought induced 'load shedding', or planned power outages [57]. This includes alternative sources of generation and storage (off grid); new contracts being established bilaterally with IPPs; and the reversion by many of the least economically secure customers to traditional biomass energy [58]. There are a range of socioeconomic and distributive welfare effects that these developments could precipitate [59] that are under-researched [60], which we will pursue in collaboration with CCG's Governance & Equity and Energy Systems Research Communities subject to resources.

Further country-specific research will focus on Nepal, Malawi and India. In Nepal, we will incorporate into CCG a three-year DPhil on climate compatible growth. A student from the country will explore how policies can be designed and implemented to align with climate goals, particularly regarding labour market impacts, green entrepreneurship, and financing barriers. In Malawi, the emphasis will be on understanding the role of the private sector, especially SMEs, in advancing low-emission technologies, while also examining financing mechanisms that support SMEs to align their activities with climate-compatible growth, and to enable the integration of gender considerations in related initiatives. In India, a part-time DPhil student from the country will explore the effectiveness of clean innovation policies, the consumer response to emerging renewable energy solutions and the implications renewables have for scaling down fossil fuels.

Methodologies

Economics, Enterprise & Finance Research will deploy a broad set of social science tools, depending on the research questions at hand. A core tool will be economic analysis, including both applied microeconomics and empirical (econometric) approaches. Economic approaches will be accompanied by financial modelling (e.g. with respect to data-to-deal) and qualitative research techniques (e.g. when studying business models). Country-focused research will also draw on the expertise of the energy and transport systems teams.

Method	RQs	Details	Potential collaboration
Microeconometrics	6.1, 6.3	Using large data sets e.g. on global project-level climate finance flows or national job market data to predict future trends and / or identify drivers of climate compatible growth.	International partnerships
Microeconomic analysis	6.1	Using industrial organisation and other microeconomic tools to understand the impact of different policy or market design choices (e.g. power purchase agreements, technology support).	
Qualitative social science techniques	6.2	Using surveys, interviews and focus groups to document business model choices by clean entrepreneurs.	GESI
Fiscal modelling	6.3	Using simple fiscal models to estimate climate finance gaps by comparing financing needs with existing finance flows.	D2D
Impact analysis	6.4	Review of CDF data to assess impact of interventions to support climate compatible growth outcomes. Development of an applied research concept (Blended Funding) as proposed intermediate step to Blended Finance; focused on impact vectors in conjunction with traditional financial returns.	D2D, Governance and Equity
Policy-based investment	6.5	Analysis of outputs from D2D work on clean investment requirements based on a fiscal planning model (MinPlan) and stakeholder interviews; to propose investment pipeline/ sequencing to meet policy objectives consistent with a credible financing pathway	D2D, Infrastructure Resilience

Table 7: Methods used to answer Economics, Enterprise & Finance research questions

Research Questions

RQ6.1. What are the economic opportunities for inclusive climate compatible growth, in terms of jobs, entrepreneurship and energy access, in different countries and what are the best policies to promote them (economy lens)?

RQ6.2. What are the business models and strategies that can unlock the economic opportunities and, if successful, deliver inclusive climate compatible growth, particularly in clean energy and agri-technology (business lens)?

RQ6.3. What are the financing needs to realise the economic opportunities, what is the public and private funding gap in different countries and what financing strategies are available to close it (finance lens)?

RQ6.4 How can existing international frameworks for defining, measuring and reporting impact be enhanced to improve their applicability for projects in Zambia and other CCG countries, and support the mobilisation of additional funding (Zambia case study)?

RQ6.5 How can policy-based investment decisions in Zambia on increasing electricity generation capacity from both renewable and non-renewable sources be evaluated to better consider factors including urgency, cost, equity, inclusion; along with climate compatibility (Zambia case study).

4 Cross-Cutting Themes

Collaboration among Research Communities is enabled via several cross-cutting themes that have been identified as focal points for the 2025-2028 period. As per Figure 1, these are:

1. System Planning & Policy
2. Data-to-Deal Research
3. Critical Minerals
4. Green Hydrogen & Alternative Fuels
5. Circular Economy

These themes are broad enough to allow the research to remain responsive to changing global, country and FCDO priorities. As outlined in Section 2, advancing our research agenda requires interdisciplinary collaboration. The cross-cutting themes serve as the primary interdisciplinary focus areas, bringing together the CCG Research Communities to address the most pressing opportunities and challenges related to climate compatible growth in LICs and LMICs. They facilitate collaboration between Research Communities and partners. They are designed to evolve and be revisited as the global context shifts, ensuring that CCG research retains a balance between responsiveness to emerging needs and delivering deep research that advances knowledge the fields.

The following five sub-sections outline the focus of these themes and provide one example of current or planned Research Projects that fall within each.

4.1 System Planning and Policy

System Planning and Policy brings together Research Communities to tackle localised requests for research relating to the planning of, and policies for, energy and transport systems. CCG partner countries typically follow regular cycles of creating and updating planning guidelines and policies, for example relating to power system investment, transport infrastructure roll-out, Nationally Determined Contributions (NDCs) and Long-Term Strategies (LTSs) with respect to UNFCCC processes, to name a few. They also regularly develop and implement more specific policies, for example to finance the deployment of renewable energy generation. CCG Programmed Research engages with selected activities in these processes, working with in-country stakeholders to frame challenges and solution scenarios, and to co-create and apply quantitative and qualitative approaches to address pressing policy questions.

Box 1: System Planning & Policy in Zambia

A team led by Imperial College London and University College London researchers is exploring sustainable development pathways in Zambia, through the development of an OSeMOSYS whole energy system model, complemented by other analytical approaches (see TRAP report for overview). The model for Zambia was originally developed to understand the potential for a 'greener' recovery from Covid-19 in Zambia. It was used to quantify scenario narratives, to complement policy analysis and to underpin a series of policy recommendations to the Zambian government. Subsequently, this model has been further developed with local stakeholders including Cities and Infrastructure for Growth Zambia (CIGZ) and government ministries and is being used to support the development of the Clean Cooking Strategy Action Plan, led by the Ministry of Energy. Pathways are being developed collaboratively to reflect the views of different Zambian stakeholders and seek to inform targets and policies to promote clean cooking options. The modelling is also integrating research from the Governance & Equity community, focused on biomass consumption, charcoal production and land-use change, which can significantly impact modelling outcomes. Modelling results are also being used in the Data-2-Deal process to inform financing of the Integrated Resource Plan (IRP), a process led by CCG Partnerships in collaboration with CIGZ and the Ministry of Energy. In addition, the model is also being used to support the World Bank's Climate Change Development Report (CCDR) efforts, and potentially the revision of the NDC. Finally, capacity building on OSeMOSYS has supported technical stakeholders from various institutions including government ministries, utilities and other development partners to support the uptake of the model more widely in Zambia. The model will also provide the basis for the energy part of the Climate Land Energy Water systems (CLEWS) model development programme, which is just starting in partnership with UN DESA. While stakeholders are currently organised in the Energy Planning SIG, it is also hoped that the OSeMOSYS model will be formally incorporated into the new Energy Planning Centre (overseen by the Ministry of Energy) for continued use in support of energy planning and policy in Zambia.

4.2 Data-to-Deal Research

The **Data-to-Deal** (D2D) **Research** Cross-Cutting Theme brings together CCG Programmed Research Communities to provide foundational interdisciplinary research to support CCG's ambition to offer a systematic approach to facilitating the financing of climate transition projects. Recognising that substantial investment is required, and that robust institutional frameworks and capacity is needed to support this, along with aligning objectives with broader development goals, this theme provides a wide range of research to support the D2D framework. It brings together, often in specific country contexts, insights from political economy research (understanding power dynamics and decision-making), energy and transport system design (devising effective decarbonisation and estimating related investment needs) and policies (formulating policy instruments that can support implementation of plans), financial modelling (establishing financing gaps), economic analysis (designing policy instruments to unlock further funding) and distributional analysis (reviewing the equity implications of funding plans). As such, it provides the analytical underpinnings for the wider CCG activities on D2D, involving researchers, country partnerships and international partnerships.

The rationale that underpins D2D Research is that a systematic approach to facilitating finance will support entrepreneurial activity that is aligned with the climate transition, in local economic contexts. A practical example of this support is an initiative led by the Economics, Enterprise and Finance RC between the middle of 2024 and early 2025. The initiative, *"Building Pipelines of Bankable Climate Compatible Growth Projects in Zambia",* engaged over 50 local stakeholders including entrepreneurs, project developers, investors and government representatives through four in-person workshops, across five thematic areas: energy, transport, land use, critical minerals and the circular economy. Outcomes from this initiative were consolidated within a report, that highlighted financing opportunities for climate-aligned entrepreneurship in Zambia, key capacity gaps that needed to be bridged, and the role that structured programmes such as accelerators or government-led technical support could play in overcoming identified barriers to growth and scale. Stakeholder feedback from the initiative was very positive, and the RC is currently exploring which countries may be suitable for replication.

Box 2: Data-to-Deal Research in South Africa

A D2D pilot project in South Africa used energy modelling (Energy System community) outputs to identify a credible decarbonisation plan for the country. The MinFin model (Economics, Enterprise & Finance community) was used to quantify the investment implications of the plan. Financial and economic sensitivity analysis was used to estimate the funding gaps and what changes in financing terms (e.g. JETP terms or Article 6 funding) may be required to close them. An evolving component of D2D research here is to map out a working hypothesis of how projects, programs, and policies align with robust long-term scenarios agreed upon and with the conditional release of available RPP (Readiness, Policy-based-loans and Project Financing) funding pots, in a sequenced manner. Next steps likely include the development of a taxonomic framework on the 3Po's (Policy, Programme and Projects) to support SCARPP (Sequential, Conditional, Aligned, Ready, Policy-based, Project-focused) finance mobilisation. This is an example of CCG Programmed Research interfacing with an Affiliate Country (AC), where CCG core effort on knowledge product creation is leveraged to support climate compatible growth in countries outside of CCGs core partners (see Section 6.4).

4.3 Critical Minerals

The **Critical Minerals** (CMs) initiative highlights the importance of resources in the clean energy transition, examining how these materials influence, and are influenced by, broader transition processes. Minerals such as lithium, copper, nickel, cobalt, graphite and rare earth elements are critical ingredients in future low-carbon technologies, including wind turbines, solar panels, electric vehicle batteries and electricity distribution networks. Demand for CMs is increasing rapidly as countries accelerate their efforts to reduce emissions. The CM initiative focuses on ensuring the resilience and equitability of CM values chains, which are needed to deliver the future low-carbon transition for energy and transport systems in LICs and LMICs. Benefiting from non-ODA work on global modelling of CMs value chains, this involves research from the Resource Efficiency community, to: map CM supply chains, from mines mostly in LICs and LMICs, through to final products purchased; assessing the social and environmental impacts of extraction, processing and manufacturing; analysing policies, actors and institutions that influence mining sectors, considering evolving geopolitical complexities; developing new metrics to assess supply chain resilience and disruption risk.

The Cross-Cutting Theme highlights the importance of providing evidence on how countries in Southern Africa could move up the CM value chain, an example of which from CCG Phase 1 is provided in Box 3 below.

Alongside the Resource Efficiency Research Community, the Energy Systems and Transport Systems communities can assess the future electricity and transport infrastructure needs for mining, processing and moving CMs to markets. These quantified approaches to understanding critical minerals are complimented by: the Governance & Equity community's work on critical mineral resources and research into inequal health and income outcomes across genders and different socio-economic levels; the Economics, Enterprise & Finance community's assessment price volatility, geopolitical influence and regulation, labour requirements, investment provision and value addition.

Box 3: Critical Minerals Collaboration and Chatham House Event

Resource Efficiency, Infrastructure Resilience, Governance & Equity and Energy System Design communities collaborated in 2023 and 2024 to produce techno-economic assessments of critical minerals supply chain possibilities in southern Africa, and a country-specific study on Zambia. This culminated with the event "Beyond extraction: Value addition for Africa's critical minerals" at Chatham House, bringing together interest groups from government, policymakers, international organisations, the private sector, civil society and academics to discuss the current research frontiers on critical mineral processing in Africa, reflect on the current array of knowledge products and implementation plans, and hear from key interest groups on and future research needs. Knowledge products related to this effort will be developed as an offering to CCG partner countries focused on capturing value from critical minerals supply chains. This Critical Minerals in Africa effort was a CCG-wide cross-cutting activity bringing together International Partnerships, Country Partnerships, Programmed Research and external interest groups.

4.4 Circular Economy

The **Circular Economy** theme explores the potential for a circular strategies and policies as an enabler of the low-carbon transition in LICs and LMICs. This will include sector specific analysis, focused on the transport and energy sectors, at different scales and the wider country level resource implications of circularity initiatives. This analysis will involve a variety of quantitative, qualitative and mixed methods approaches to explore how circularity can support climate compatible futures.

Quantitative assessments of economy-wide circularity can help identify the opportunities for material efficiency, reuse and recycling, which can play a role in alleviating supply risks (Resource Efficiency community and Critical Minerals theme). These opportunities may exist in different scales, timings and geographies and care must be taken to ensure circularity actions lead to improved social and environmental outcomes, and unintended outcomes are anticipated.

A circular shift entails adopting new business models and strategies. Circular business models from high income countries may not be appropriate and thus new business models and ecosystems may need developed to suit local needs in LMICs and LICs. It is essential, therefore, to analyse and assess different business models to support climate compatible growth, particularly in the energy and transport sectors (Economics, Enterprise & Finance community). Identifying successful case studies can also help provide evidence for investment and policy decisions.

Since policy can be an enabler of circular economy transitions [61], developing effective governance and policies to support circularity is essential (Economics, Enterprise & Finance community). Stakeholder analysis, policy review and exploratory methods are all useful to understand the current waste and material landscape and identify context-appropriate circular solutions and assess their real impact.

Box 4: Demand for Research on Circular Economy

Circular Economy focused research will begin in Phase 2, based on notable country demand. This work will start by the quantification of the impact of recycling and opportunities for material reuse using the models developed by the Resource Efficiency community. This assessment will enable the identification of the role of reuse and recycling in reducing supply pressures on critical minerals, particularly in LICs and LMICs. This will assist the prioritisation of circularity interventions and inform the development of circularity business models able to bring about sustainable value creation initiatives in developing countries.

4.5 Green Hydrogen & Alternative Fuels

Finally, **Green Hydrogen & Alternative Fuels** are recognised as vital components for decarbonising difficult-to-abate sectors, such as steel, concrete, aviation, and shipping, while also acting as a feedstock in various industrial processes to extend decarbonisation beyond power provision. At the same time, there are significant debates about the extent of their role, and a need for independent and critical analysis. CCG therefore investigates their viability in future decarbonisation, as well as the economic opportunities and challenges this presents in partner countries. This considers aspects of financing and risk, import/export relationships, spatial techno-economic feasibility, policies and governance, and social acceptability. This frequently requested research area naturally cuts across all Research Communities.

Box 5: Green Hydrogen & Alternative Fuels in Laos

CCG Programmed Research has collaborated with Laos partners; Department of Energy Policy and Planning (DEPP), Department of Energy Efficiency Promotion (DEEP), Ministry of Natural Resources and Environment (MONRE), Research Institute of Energy and Mines (RIEM), National University of Laos (NUOL), and Electricite du Laos (EDL) in the co-creation of an OSeMOSYS-based energy systems model. In 2024 this was applied in collaboration with LAPSEG (Laos-Australia Sustainable Energy Partnership), to produce the Laos Government's Green Hydrogen Strategy. This focused on utilisation of excess hydro power in Laos to produce hydrogen, then feeding a green ammonia production process. This is an example demand-led collaboration between CCG Programmed Research, CCG Country Partnerships, CCG International Partnerships, and external partners aligned with Economics and Governance Research Communities.

5 Pathways to Impact

CCG Programmed Research (PR) activity is represented in the CCG Theory of Change, which presents research and capacity building activity areas, leading to target outcomes and impact. The following sub-sections provide further detail on activities relevant to impact, including integration with other parts of CCG (IP & CP), and flexible funding mechanisms.

5.1 Localisation & Context-Relevance of Research Questions

Programmed Research (PR) recognizes that impact cannot be achieved unless the right questions are asked, and therefore tailors research questions to partner needs and observed research gaps, including in collaboration with CCG **Country Partnerships** (CP) and CCG **International Partnerships** (IP). Where research is country-specific, PR participates in scoping missions, drawing on CP connections with decision-makers to understand research needs and beneficiaries, and to identify potential project collaborators. Moreover, collaborations with CP and IP are drawn upon throughout PR project formation, with participation on selected **Special Interest Groups** (SIGs), interface with CP **Country Coordinators** and use of CP **Country Strategies**, and research collaboration related to **Southern Partner Fund** (SPF) proposals, **Engagement Fund** (EF) and **Flexible Research Fund** (FRF) (see Appendix C: Flexible Research Funds for definitions). Each of these activities enables research questions to be generated by local stakeholders, for research questions to be formulated via exchange of ideas between CCG researchers and local stakeholders, and for CCG-initiated research questions be tested with local stakeholders (see section 2.2.1 for more information on processes for project origination and shaping). This cross-fertilisation applies to research questions taken forward in PR projects, flexible fund projects (SPF, FRF, EF), and additional adjacent projects leveraged through IP **Partner Engagement**. Furthermore, capacity building IP initiatives such as the **Catalyst Facility**[5] also generate localised research questions, with selected instances where there is direct collaboration with PR academics. Within PR projects, after scoping and team formation, research questions are further tailored to local context with partners. Finally, context relevance is also pursued via PR proposals in **Agile** and **Responsive** funding calls, where projects are typically directed at horizon scanning for relevant research directions, through literature review and local stakeholder engagement.

5.2 Inclusive Research and Uptake Support

PR co-creates, with local and regional partners, knowledge products and global goods that have practical application value. As such the CCG Theory of Change envisages outcomes relevant to government, institutions and other stakeholders. Where knowledge products are generated in collaboration with stakeholders through, for example, **policy-relevant research** in collaboration with a government ministry and a research institution, an important pathway to impact is uptake of those knowledge products by those stakeholders. PR supports this uptake through long-term collaboration with project partners, and assistance incorporating the knowledge generated into relevant initiatives such as **policy-related plans and strategies, models, data** and **educational material**. As knowledge products are generated, uptake is sought by supporting central CCG communications activities (e.g. social media, newsletter, promotional material), production of **Policy Briefs** where appropriate, presentation of findings in local fora including CP **Special Interest Groups**, country-specific **CCG Annual Meetings**, and stakeholder-facing conferences and events. The CCG **Southern Partner Fund** (SPF), **Engagement Fund** (EF) and **Flexible Research Fund** (FRF) also support this process, enabling for example creation of Centres of Excellence in LIC and LMIC institutions or supporting further

[5] The Catalyst Facility is an IP initiative aimed at supporting Southern researchers to carry out extended projects via mini sabbaticals. The aim is to further embed CCG analysis capability in their home institutions.

collaborative research that includes external partners. We expect this pathway to impact to ultimately result in new policies, practices and knowledge becoming embedded in local and regional organisations, leading to locally owned robust decision making that supports climate compatible growth.

5.3 Academic Publication & Outreach

In order to contribute to knowledge and global goods, PR also produces core academic outputs, including **peer-reviewed journal publication** and relevant academic **conference publication.** These mark key advances in the fields and support peer-to-peer communication of those advances, enabling future research on climate compatible growth in LICs and LMICs to push the frontier beyond that established by CCG. PR support outreach related to these knowledge products, through CCG communications channels, academics' own institutional channels, and broader outreach such as media interviews, blogs, social media and public-facing speaking engagements.

5.4 Accessible Methodologies, Tools, Data and Training

Following the broader ethos of CCG, PR also supports development of **open-source** software and adopts **open access** principles wherever possible. Part of PR activities include creation or revision of software products that can be applied in energy, transport and critical minerals related analyses. Core products are made available through IP's **Data and Tools** unit (e.g. OSeMOSYS) with associated documentation and educational courses via IP's CCG **Open Learn Collection**. Additionally, PR produces a further range of software and data products, similarly hosted in persistent open source and open access locations (e.g. Github, Zenodo). PR collaborates with IP's **Capacity Building** offer (e.g. **EMP, EMC, Scholars' Bootcamps, Catalyst Facility**) via maintenance of selected software products and related training material hosted in the Open Learn Collection, and via coordination with IP on country training needs, where IP can support broad entry-level training to CCG tools. PR leverages this local training to rapidly upskill project stakeholders on relevant approaches and then pursues planned collaborative research projects from this advanced starting point. PR may also engage in strategic research partnerships beyond Partner Countries, building on IPs network of contacts and partnership agreements with International Organizations.

5.5 Long-term Capacity Building

As the CCG phase 2 period commences, focus on embedding research capability in partner institutions becomes more important, with a view to such capability lasting beyond the lifetime of the CCG program. The aim is to leave countries with better absorbative capacity, stronger institutions with institutional ecosystems that surrounds embedded knowledge products, noting the need for multiple institutions to have capacity, not just one. Capacity created must be able to withstand staff turnover. And our approach notes that no one single modality of embedding capacity will be effective across different country contexts. To this end, CCG Programmed Research plans to work with Country and International Partnerships on delivering research and building partnerships that can meet this aim by:

- **Building capacity in research organisations:** CCG Programmed Research aims to build upon successful examples of government to academia collaboration (e.g. Laos energy modelling and green hydrogen initiative) and embed the underpinning principles from these examples in future collaboration where possible and appropriate. Core in this is the inclusion of research organisations in co-creation activities from the outset, establishing groupings including CCG researchers, government, and local academia in delivery of policy-facing outcomes. Where research organisations build-in CCG knowledge products, the likelihood of continuing activity beyond the life of CCG and the production of a pipeline of able graduates to continue using and developing CCG products is increased.

- **Seeking institutional support in SPF, FRF and EF collaborations:** For SPF, FRF and EF projects, we will explore including a requirement for institutional support of Investigator applicants from their respective research organisations. Where institutional support can indicate long-term engagement with the CCG-aligned initiative, this will foster long-term local capacity. For example, the creation of a Centre of Excellence led by the investigator within a university, benefitting from initial funding from SPF, FRF or EF.

- **Building effective partnerships with well-resourced organisations for joint efforts in local and national capacity strengthening.** Via CCG's cross-programme co-funding strategy and working with International Partnerships as the lead, CCG PR will engage with financially strong programmes and institutions, such as international organisations, philanthropic and corporate foundations and major NGOs to support collaboration with country institutions on a long-term and sustainable capacity development initiatives. CCG will identify organisations whose missions and capabilities are complementary, particularly those with strong local networks and understanding of national contexts. Success depends on long-term commitment, adequate resource allocation, and flexibility to adapt to changing circumstances.

5.6 Affiliate Countries

Programmed Research recognizes that a range of LICs and LMICs that are not core country partners have an interest in the knowledge products that CCG produces. Coordination of CCG activities with these countries contributes to achieving the CCG Theory of Change. Engagement of Programmed Research with these Affiliate Countries is therefore an important avenue for CCG impact, and an opportunity to expand research topic coverage. Affiliate Countries are co-funded, providing additional resources for CCG, including for Programmed Research, to deliver impact on a wider scale. Affiliate country management is currently undertaken by the Central Directorate (CDr) with the Partnerships Directorate. It is evolving from a limited number of pilots to a structured process which provides important opportunities for PR.

References

1. IEA, *World Energy Outlook 2024*. 2024, International Energy Agency: Paris, France.
2. Alova, G., P.A. Trotter, and A. Money, *A machine-learning approach to predicting Africa's electricity mix based on planned power plants and their chances of success.* Nature Energy, 2021. **6**(2): p. 158-166.
3. Ecker, S., E. Ortiz-Juarez, and G.G. Molina, *Growth without gains: Poverty and carbon emissions on the rise*. 2023, UNDP.
4. World Bank, *International Debt Report 2023*. 2023, World Bank: Washington, DC.
5. UNDP, *Institutional and coordination mechanisms: guidance note on facilitating integration and coherence for SDG implementation*. 2017, United Nations Development Programme: New York, USA.
6. Mulugetta, Y., et al., *Africa needs context-relevant evidence to shape its clean energy future.* Nature Energy, 2022. **7**(11): p. 1015-1022.
7. Trotter, P.A., R. Maconachie, and M.C. McManus, *Solar energy's potential to mitigate political risks: The case of an optimised Africa-wide network.* Energy Policy, 2018. **117**: p. 108-126.
8. Tesfamichael, M. and J. Fuchs, *Navigating complexity: integrating political realities into energy system modelling for effective policy in Sub-Saharan Africa.* Progress in Energy, 2024. **6**(4): p. 043001.
9. Blimpo, M.P., et al., *Climate change and economic development in Africa: A systematic review of energy transition modeling research.* Energy Policy, 2024. **187**: p. 114044.
10. Mutiso, R.M., *African energy transitions should be driven from the ground up.* Science. **382**(6673): p. eadl3462.
11. Dioha, M.O. and R.M. Mutiso, *Generating Meaningful Energy Systems Models for Africa.* Issues in Science and Technology, 2023. **39**(3): p. 54–57.
12. Urban, F., R.M.J. Benders, and H.C. Moll, *Modelling energy systems for developing countries.* Energy Policy, 2007. **35**(6): p. 3473-3482.
13. Fuso Nerini, F., et al., *Mapping synergies and trade-offs between energy and the Sustainable Development Goals.* Nature Energy, 2018. **3**(1): p. 10-15.
14. Arent, D., et al., *The Political Economy of Clean Energy Transitions*. 2017, UK: Oxford University Press.
15. UNCTAD, *A world of debt: a growing burden to global prosperity*. 2024, United Nations Trade & Development.
16. Musonye, X.S., et al., *Integrated energy systems' modeling studies for sub-Saharan Africa: A scoping review.* Renewable and Sustainable Energy Reviews, 2020. **128**: p. 109915.
17. Bazilian, M., et al., *Considering the energy, water and food nexus: Towards an integrated modelling approach.* Energy Policy, 2011. **39**(12): p. 7896-7906.
18. Mutiso, R.M., *Net-zero plans exclude Africa.* Nature, 2022. **611**(10).
19. Gannon, C. and Z. Liu, *Poverty and Transport*. 1997, World Bank: Washington DC, United States.
20. Maluleke, R., *Marginalised Groups Indicator Report, 2021*. 2021, Statistics South Africa.
21. Lucas, K., *Making the connections between transport disadvantage and the social exclusion of low income populations in the Tshwane Region of South Africa.* Journal of Transport Geography, 2011. **19**(6): p. 1320-1334.

22. Owusu-Ansah, J.K., A. Baisie, and E. Oduro-Ofori, *The mobility impaired and the built environment in Kumasi: structural obstacles and individual experiences.* GeoJournal, 2019. **84**(4): p. 1003-1020.
23. Hallegatte, S., J. Rentschler, and J. Rozenberg, *Lifelines: The Resilient Infrastructure Opportunity.* , in *Sustainable Infrastructure Series*. 2019, World Bank: Washington, DC.
24. IPCC, *Sixth Assessment Report. WG III. Chapter 10 (Transport)*. 2022.
25. Unruh, G.C., *Understanding carbon lock-in.* Energy Policy, 2000. **28**(12): p. 817-830.
26. Baumgartner, J., M. Brauer, and M. Ezzati, *The role of cities in reducing the cardiovascular impacts of environmental pollution in low- and middle-income countries.* BMC Medicine, 2020. **18**(1): p. 39.
27. Organisation, W.H. *Ambient (outdoor) air pollution*. 2024; Available from: https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.
28. Sturgess, D., et al., *Transport-energy modelling in sub-Saharan Africa: innovations and opportunities to support informed policymaking towards equitable, clean access for all*. 2024, University of Strathclyde.
29. Brand, C., J. Anable, and C. Morton, *Lifestyle, efficiency and limits: modelling transport energy and emissions using a socio-technical approach.* Energy Efficiency, 2019. **12**(1): p. 187-207.
30. Dixon, J., et al., *How can emerging economies meet development and climate goals in the transport-energy system? Modelling co-developed scenarios in Kenya using a socio-technical approach.* Energy Strategy Reviews, 2024. **53**: p. 101396.
31. Barron, K.C., S. Dhir, and J.M. Cullen, *The geopolitics of critical materials and minerals and implications for the low-carbon transition*, Climate Compatible Growth, Editor. 2023.
32. Calderon, J.L., et al., *Critical mineral demand estimates for low-carbon technologies: What do they tell us and how can they evolve?* Renewable and Sustainable Energy Reviews, 2024. **189**: p. 113938.
33. Allwood, J. and J. Cullen, *Sustainable Materials - with both eyes open*. 2011, Cambridge, UK: UIT Cambridge LTD.
34. Radebe, N. and N. Chipangamate, *Mining industry risks, and future critical minerals and metals supply chain resilience in emerging markets.* Resources Policy, 2024. **91**: p. 104887.
35. National Minerals Information Center, *U.S. Geological Survey Mineral Commodity Summaries 2022 Data Release*, U.S. Geological Survey, Editor. 2022.
36. IEA, *The Role of Critical Minerals in Clean Energy Transitions*. 2021, International Energy Agency,: Paris, France.
37. Olivetti, E.A., et al., *Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals.* Joule, 2017. **1**(2): p. 229-243.
38. IEA, *Global Critical Minerals Outlook 2025*. 2025, International Energy Agency: Paris, France.
39. Cervantes Barron, K. and J.M. Cullen, *Using open-source tools to project bulk and critical material demand and assess implications for low-carbon energy and transport systems: Introducing Mat-dp model tools.* Resources, Conservation and Recycling, 2024. **209**: p. 107803.
40. Hall, J.W., et al., *Adaptation of Infrastructure Systems: Background Paper for the Global Commission on Adaptation*. 2019.

41. Rozenberg, J. and M. Fay, *Beyond the Gap : How Countries Can Afford the Infrastructure They Need while Protecting the Planet*. 2019, World Bank Group: Washington, D.C.
42. Bangalore, M., et al., *Shock Waves: Managing the impacts of climate change on Poverty*. 2016, World Bank: Washington, DC.
43. *Realising the 'Triple Dividend of Resilience'*. Climate Risk Management, Policy and Governance, ed. S. Surminski and T. Tanner. 2016: Springer Cham.
44. Harvey, H., J. Hall, and R. Peppé, *Computational decision analysis for flood risk management in an uncertain future.* Journal of Hydroinformatics, 2011. **14**(3): p. 537-561.
45. Koks, E.E., et al., *A global multi-hazard risk analysis of road and railway infrastructure assets.* Nature Communications, 2019. **10**(1): p. 2677.
46. Adshead, D., et al., *Ghana: Roadmap for resilient infrastructure in a changing climate*. 2022, Ministry of Environment, Science, Technology & Innovation: Accra, Ghana.
47. Koks, E., T. Russell, and R. Pant, *Transport Risks Analysis for The United Republic of Tanzania – Systemic vulnerability assessment of multi-modal transport networks*. 2018.
48. Pant, R., *Analysis and development of model for addressing climate change/disaster risks in multi-modal transport networks in Vietnam*. 2019, Infrastructure Transitions Research Consortium (ITRC).
49. Way, R., et al., *Empirically grounded technology forecasts and the energy transition.* Joule, 2022. **6**(9): p. 2057-2082.
50. Srivastav, S. and R. Rafaty, *Political Strategies to Overcome Climate Policy Obstructionism.* Perspectives on Politics, 2023. **21**(2): p. 640-650.
51. Khosla, R., et al., *Can 'Net Zero' still be an instrument of climate justice?* Environmental Research Letters, 2023. **18**(6): p. 061001.
52. Fankhauser, S., et al., *Rolling out Renewables in the Global South: A Developer Perspective*. 2023, Smith School of Enterprise and the Environment, University of Oxford.
53. Stechemesser, A., et al., *Climate policies that achieved major emission reductions: Global evidence from two decades.* Science, 2024. **385**(6711): p. 884-892.
54. Caucheteux, J., S. Fankhauser, and S. Srivastav, *Climate Change Mitigation Policies for Developing Countries.* Review of Environmental Economics and Policy, 2025. **forthcoming**.
55. Bloom, N. and J. Van Reenen, *Why Do Management Practices Differ across Firms and Countries?* Journal of Economic Perspectives, 2010. **24**(1): p. 203-24.
56. Money, A., *Blended Finance in the Water Sector: Challenges and Attributes*. 2022, World Water Council.
57. Chimbaka, B., *Power sector management failure and load shedding in Zambia.* Int. J. of Adv. Res., 2024. **Aug**: p. 1394-1401.
58. Ahmed, I., et al., *The impact of power outages on households in Zambia.* Economia Politica, 2023. **40**(3): p. 835-867.
59. Ahmed, I., et al., *The cost of power outages to Zambia's manufacturing firms*. 2019, International Growth Centre.
60. Umar, B.B. and C.F. Kunda-Wamuwi, *Socio-economic effects of load shedding on poor urban households and small business enterprises in Lusaka, Zambia.* Energy and Environment Research, 2019. **9(2)** p. 20-29.

61. Clube, R.K.M. and M. Hazemba, *From waste to resource: demystifying the policy challenges and identifying opportunities for a circular economy in Zambia.* Frontiers in Sustainability, 2024. **5**.
62. Brand, C., et al., *Transport Energy Air pollution Model (TEAM): Methodology Guide*. UKERC.
63. Brand, C., et al., *Achieving deep transport energy demand reductions in the United Kingdom.* Renewable and Sustainable Energy Reviews, 2025. **207**: p. 114941.
64. Thacker, S., et al., *Infrastructure for sustainable development.* Nature Sustainability, 2019. **2**(4): p. 324-331.

Appendix A: Programmed Research Committee

Programmed Research Committee (PRC) Terms of Reference

Purpose

- Provides a bi-directional communication channel between CCG Programmed Research and CCG Directorate (and other stakeholders such as the FCDO).
- Facilitates collaboration within Programmed Research via regular communication.
- Provides a forum for coordinated interaction with CP and IP including response to demand-led opportunities.

Membership

- Required: Research Community leads and co-leads
- Optional: Research Investigators

PRC meeting schedule

- PRC online catch-up monthly (1-hour)
- PRC face-to-face meeting quarterly (1/2 day) – replaces monthly catch-up for that month.

As of November 2024, the nominated Research Community leads and co-leads are:

Research Community (RC)	RC Lead / Co-lead (PRC members)	Investigators
Governance & Equity	Julia Tomei / Stephi Hirmer	Jim Watson, Yacob Mulugetta
Energy Systems	Steve Pye / Adam Hawkes	Nilay Shah, Will Usher, Francesco Gardumi, Francesco Fuso-Nerini, Koen Van Dam
Transport Systems	Holger Dalkmann / James Dixon	Aruna Sivakumar, Tim Schwanen, Christian Brand
Resource Efficiency	Jonathan Cullen / André Cabrera Serrenho	
Infrastructure Resilience	Jim Hall	
Economics, Enterprise & Finance	Sam Fankhauser / Alex Money	Philipp Trotter, Sugandha Srivastav, Jessica Omukuti

Mapping between Research Units and Research Communities

Research Community (RC)	Research Unit
Governance & Equity	UCL-Institute for Sustainable Resources (ISR) UCL- Department of Science, Technology, Engineering and Public Policy (STEaPP) Oxford – Energy & Power Group (EPG)
Energy Systems	UCL - Energy Institute (EI) Imperial College - Chemical Engineering (CE) University of Oxford - Energy & Power Group (EPG) KTH-Energy Systems
Transport Systems	University of Strathclyde – Civil & Environmental Engineering (CEE) Imperial College - Urban Systems Lab University of Oxford – Transport Systems Unit (TSU), Sustain2030
Resource Efficiency	University of Cambridge -Resource Efficiency Collective (REC)
Infrastructure Resilience	University of Oxford – Oxford Programme for Sustainable Infrastructure Systems (OPSIS)
Economics, Enterprise & Finance	University of Oxford – Smith School (SS)

Appendix B: Detailed Research Questions

Governance and Equity Research Community

RQ1.1. How can transitions to climate-compatible and equitable energy and transport systems be governed to ensure no one is left behind, and what are the political economy challenges? *[Justice, Political Economy and Governance]*

Acknowledging that transitions will be disruptive, this RQ aims to understand how they can be governed to ensure fair, just and inclusive outcomes for all, and especially people who are marginalised. This includes paying special attention to poor communities, women, persons with disabilities, youth and aged populations. It will seek to understand the distributional impacts of different policy options (i.e. across social groups, sectors, and spatial and temporal scales) and identify measures to minimise potential harms. It will also examine opportunities for place-based transitions that recognise local contexts (e.g. rural/ urban, productive and community uses of energy, unmet needs) to foster transitions at multiple scales. Going beyond the distributional impacts of transitions, this RQ will also examine procedural and recognition justice. This will facilitate an inclusive approach by identifying whose voices are well-represented or neglected in current approaches, and to subsequently ensure marginalised groups are empowered in the transition.

RQ 1.2. How do the political and economic interests of stakeholders shape the formation and effectiveness of coalitions for climate-compatible and equitable transitions, and how does this influence the use of knowledge, data, and evidence in decision-making? *[Political Economy]*

This research will map out the interests, priorities and decision-making powers of key national and international stakeholders in specific countries with a view to understand how their priorities and agendas intersect or conflict. Governments may prioritize national energy security or development goals, while private sector actors often focus on profitability and market expansion. International organizations may emphasize global climate commitments, whereas local communities seek equitable access to resources and social benefits. These varying interests can create tensions or synergies, influencing coalition-building processes and the alignment of objectives. Successful coalitions depend on balancing these competing agendas to ensure that low-carbon transitions are both economically viable and socially inclusive, fostering collaboration rather than conflict. Ultimately for CCG, understanding these dynamics is crucial for designing partnerships that are not only productive but also resilient and equitable in the face of competing interests.

RQ1.3. What are the visions of and pathways to climate-compatible and equitable energy and transport systems, and what synergies or trade-offs exist between national macroeconomic goals and local community development needs? *[Visions and Pathways]*

This RQ aims to identify existing visions and transition pathways towards climate compatible growth that underpin political discourse and policy strategies in partner countries. Through stakeholder engagement, research driven by this RQ will co-create transition pathways in specific national, sub-national and sectoral contexts. Not only will this facilitate dialogue about desirable futures, but it will support local capacity development in scenario methods. This RQ involves working closely with other research units, particularly those developing energy system models.

RQ 1.4. What strategies, policies, institutional changes, and timelines are required to develop climate-compatible and equitable energy and transport systems, and how can cross-sectoral

collaboration ensure alignment between national priorities, social equity, and climate impacts? *[Policy and Institutions]*

This RQ will examine strategies and policies to support inclusive, low carbon transitions at different levels of governance (i.e. local, regional, national and international) and at the sectoral level (e.g. transport, energy, industry). It will evaluate current policies and future policy options to support low carbon development, including their design, institutional settings, anticipated and actual implementation processes, and outcomes for climate and development. This will consider the likely impact of policies and institutional changes on Gender Equality and Social Inclusion (GESI). Working with other research units, this RQ will also analyse the relationship between policy and institutional change and identify key implications for financing.

RQ1.5. How can soft and hard infrastructure be developed to meet both top-down national macro-economic and policy goals, and local bottom-up community development needs, and where are the synergies and trade-offs in decision-making? *[Place-Based Impacts]*

This research question addresses the need for national-level planning to identify areas within a country best suited for developing certain HIEOs (High-Income Economic Opportunities). This research investigates how perceived values and community needs data (elicited as part of RQ1.6) can be integrated into economic, infrastructure, and development planning at the sub-national (and subsequent national) levels to align with national priorities while building local resilience to climate change (RQ1.6) and considering existing infrastructure and networks. It will also identify rigorous, verifiable, data-driven proxies for community needs available at high spatial resolution to fill gaps where on-the-ground data is scarce (e.g., distance to a forest as an indicator of firewood access and potential cookstove needs). This research aims to inform policy decisions at the sub-national level, guiding planning at the national level.

RQ1.6. How can local community development needs be captured and accounted for in decision-making to increase community resilience, reduce existing vulnerabilities and minimise negative impacts of transitions? *[Community Resilience and Justice]*

This question examines community needs in LICs and LMICs and how HIEOs can address them to enhance local resilience and reduce vulnerabilities while understanding social benefits in monetary terms. There is an opportunity to incorporate more geolocated and locally based values data to enable HIEOs and relevant infrastructure to better meet community needs and strengthen climate change resilience. This question aims to investigate how to collect more accurate data on community needs, disaggregated by demographics, to account for GESI considerations in planning (feeding into RQ1.9) and measure inequalities. It also investigates what business opportunities to support climate adaptation and build resilience exist on-the-ground, how these businesses align with community needs, and which ones can be feasibly scaled into HIEOs. This work will incorporate the concept of social return on investment (SROI) to quantify the social benefits and value created by businesses and HIEOs, ensuring that social benefits are accounted for in the geospatial planning tools used as part of this workstream. It will evaluate how local policy and regulation can support private-sector-driven local climate adaptation. This research will also investigate how disaggregated community data can be more meaningfully integrated into the design of HIEOs and associated energy and transport infrastructure, including the aggregation of local data into national planning tools (RQ1.9). The importance of this local-to-national link has become evident from work undertaken in Kenya, where sub-national teams consider community needs that are then communicated to the national energy modelling teams.

RQ1.7 (KTH). What are the key design attributes of a sustainable data infrastructure architecture for developing country contexts?

While multiple CCG partner countries have expressed interest in a data repository to support energy and transport planning, numerous examples of abandoned data hosting efforts exist. The distinction between data catalogues, which support finding and accessibility of data sets, and repositories, which deal with hosting and storing data, is poorly understood. It is also clear that a national data repository, while beneficial for energy planning at national and devolved levels, overlaps with efforts towards national data governance strategies. With these concerns, capacity and resource limitations present significant challenges to identifying sustainable solutions that can be developed, supported, and resourced locally.

Energy Systems Research Community

RQ2.1 (UCL-EI & IMP-CE). How can energy system planning tools and approaches better represent the energy transition opportunities and challenges faced by LIC and LMIC countries, and be shaped by local expertise?

This research question builds on CCG's system design research under Phase 1, and the emerging needs of modelling approaches identified under EIMET (an ongoing project horizon scanning LIC and LMIC modelling needs) to better support planning for energy system transition / transformation. The key motivation is the need to i) improve interdisciplinary understanding, notably around how socio-political factors can be represented in modelling transitions, through model development and mixed method approaches, and ii) ensure that such approaches are better aligned with context-specific priorities focused on energy for development. The specific topics of focus (GESI, finance, PE, macroeconomic, policy, governance) will be shaped by the broader agenda emerging from EIMET, country needs and focus of research partners.

The key outputs would be improved modelling tools and approaches, allowing for new research insights and more effective support for the planning process.

RQ2.2 (UCL-EI & IMP-CE). How can the assessment of transition risks and the robustness of decision-making under uncertainty be enhanced to improve planning and better support investment?

Due to the timescales of interest, uncertainty in planning is pervasive, and cuts across societal, political, economic, technological and environmental domains. Unless it is incorporated into the system design and planning process, decision makers cannot determine trade-offs / risks and understand what strategies work well under multiple future conditions. Poor policy choices could result. The 'classic scenario' approach can help – but often provides insufficient coverage of the uncertainty space. The above motivates this question, to develop and apply methods, notably from the Decision Making Under Deep Uncertainty (DMDU) community such as Robust Decision Making (RDM), to different country contexts as they plan the transition to a future energy system.

The key output would be improved representation of uncertainty in models used for planning, allowing for strategy development that is both robust but is also much more participatory in nature.

RQ2.3 (UCL-EI). What approaches can be developed to better represent location-specific determinants of energy infrastructure investment, as well as multi-level governance systems in energy models?

It is well understood that country-level energy models that represent the system as a single node (region) miss important spatial information that is material to the decisions that need to be made in system planning and energy policy. Two specific areas of interest include: first, an improved representation of spatial location of energy demands, resources (such as renewables) and infrastructure in national level models, where this is material to investment decisions; and second, representation of multi-level governance systems, where countries are aiming to decentralise some planning and policy functions to sub-national authorities. Representing multi-scale governance e.g. subnational regions in a national model can support stakeholders at both governance level, enhance dialogue and improve modelling of subnational areas.

RQ2.4 (IMP-CE): How can highly resolved data sets for demand, infrastructure, resource availability, industrial production, etc, be used, combined and interpreted for use in energy system planning?

This research will draw upon data sets with high spatial and temporal resolution to characterise service demand, energy supply potentials, and existing technology stock in LICs and LMICs. It will interpret and combine novel data sources to provide the underpinning geospatial resources for CCG analyses. A range of questions can be tackled under this umbrella, such as the characterisation of socio-technical and/or socio-economic factors that influence transitions, consideration of the parameters that best define energy services in the CCG context, and investigating how the spatial and temporal nature of supply, infra-structure and demand emerge over time as a country grows. This RQ intersects with RQ2.3 in that resulting approaches and data can be used to support planning in multi-level governance situations and can provide empirical evidence on spatial relationships between energy assets.

RQ2.5 (KTH & UCL-EI): What system modelling approaches and granularity can help identify technological innovations that mitigate conflicts over the use of scarce resources under uncertain climate change?

This question aims to address current limitations of CLEWs applications in representing the opportunities technological innovations may offer in mitigating conflicts in the use of resources across the energy, agriculture and water supply domains when climate change and shocks affect their availability. Reaching such goal requires first to improve methods for managing climate uncertainty in the model inputs (and understanding its impacts on the outputs) and for representing the spatial and temporal variability of resource availability and resource needs. We will explore the inclusion of uncertainty analysis in CLEWs models and the appropriate level of geospatial disaggregation and temporal disaggregation to better assess infrastructure impacts on food, water, and energy security (for example, different options of water routing and improvement of irrigation techniques in contexts affected by droughts), We will evaluate innovations proposed by various stakeholders in LMIC country contexts with a participatory approach.

RQ2.6 (KTH): How can energy access planning be coordinated with planning in other spheres such as climate, economy and other resources?

The question aims to integrate energy access modelling with other geospatial approaches including in infrastructure resilience. Current energy access approaches could be extended to better account for productive uses, the influence of climate change on demand and supply of energy services, and to synergise with other infrastructure developments (e.g. sanitation, mobile telecommunications). There is little concrete understanding of how to embed appropriate AI methods to improve modelling and policy support for climate and energy. Therefore, as part of this question, we will also investigate the opportunities and risks of AI methods to fill gaps in current modelling processes, such as data collection, modelling and synthesis of results and policy advice.

RQ2.7 (KTH). How and to what extent can open science practices achieve positive development outcomes relating to energy and transport in CCG partner countries?

In this research question, we try to understand the opportunities presented by open data sets, open-source tools, and open educational resources and the barriers to adoption presented by limitations in individual, institutional and governance capacity, societal norms and culture. The question will be investigated using mixed methods: interviews, action research, desktop studies and literature review. We hypothesise that effective data opening will achieve multiple efficiencies in CCG partner countries, reducing the overhead and resources required to find and access data, improving the adoption of standards, increasing quality and boosting ownership and understanding across institutions. Open tools have been shown to remove barriers to entry in developing country contexts. Still, there are few assessments of open-source tools' tangible effects in supporting higher-quality planning processes. One area of special focus will be the collaborative development of open access educational resources. The Climate Compatible Curriculum website provides a platform for the sharing and remixing of open education material. The recent launch of the website with several published courses provides an opportunity to understand better how the users will interact with the site, and if it is fit for purpose. The website has been developed by a web design consultancy in close collaboration with WS7a, but users have yet to be available for testing purposes. More work needs to be done to understand better how website visitors use the material, and what challenges and benefits are presented by the current website.

Transport Systems Research Community

RQ3.1. How can open data and tools be leveraged to i) enable better reporting, monitoring and analysing and ii) support better policy in transport systems in LICs and LMICs, and how can platforms and infrastructures to support those data and tools best be developed?

“Garbage in, garbage out” is a common phrase mentioned in modelling; reliable data is necessary in creating tools that can be useful in formulating robust policy and finance pathways that can support clean, just transport systems that can contribute to clean economic growth. Answering this RQ involves the development of datasets and tools to kick-start the development of better models to support LICs and LMICs long-term development goals. Engaging in global initiatives such as the Transport Data Commons Initiative (TDCI) and SUM4ALL’s Data tracking initiative is key for further strengthen LIC and LMIC transport data collection and analysis.

RQ3.2. How does passenger travel demand and e-mobility adoption vary between population groups in LICs and LMICs, and how can approaches to gather this data be tailored to suit localised contexts?

Answering this RQ is concerned with the collection of data to fill gaps identified in the collation of data (RQ3.1): namely, data on travel habits and vehicle preferences that is required to build useful quantitative tools (RQ3.3). So far, this work has been carried out in Kenya (2023), and there are ongoing activities to carry out similar surveys in Laos, Zambia, and India to scale the activity and benefit from earlier efforts. In India, this activity will extend to the development of new toolkits for policymakers and small and medium enterprises (SMEs) to support informed Electric Vehicle (EV) adoption and charging infrastructure design.

RQ3.3. How can the transport sector be represented in whole energy system models, guided by the tenets of open-source data and stakeholder inclusion, be used to co-develop quantitative analyses that supports the development of policy and investment resulting in equitable and low-carbon transport system pathways?

Answering this RQ is concerned with the development of an open-source, modular framework for the analysis of transport system pathways in the context of energy system transitions. The maths of the new modelling framework will be based largely on the Transport Energy Air pollution Model (TEAM) [62, 63], but it will be developed in a modular structure to allow its suitability to different data contexts. The requirements of this modelling framework, OSeMobility, will be captured from ongoing consultation with CCG partners and the model itself will be co-developed between UK-based CCG researchers and researchers based in partner countries. It will explore opportunities to include local air pollution effects in terms of $PM_{2.5}$ emission reductions, changes in personal exposure and/or health impact assessments. OseMobility will take an accessibility-based focus in order to enable equitability analysis of transport policies where the data permits.

RQ3.4 How can the distribution and effects of air pollution be integrated into the development of pathways for equitable, low-carbon and climate-resilient transport systems in ways that capture the differentiated health impacts among marginalised groups?

This research question is concerned with the various ways in which the air pollution effects can be measured and what the choice of available tools means in terms of equitable transport. Evaluating emission reductions of $PM_{2.5}$ or NOx, for example, implies minor technical challenges but fails to capture environmental injustices such as the health effects being experienced most severely by those who typically emit the least. On the other hand, an approach based on personal exposures can help identify highly exposed societal groups but involves much larger technical challenges particularly in terms of data availability. Understanding the various tools and their limitations will be key in the assessment of health impacts of low-carbon transport system pathways.

RQ3.5. How can equitable and low-carbon transport system pathways, co-developed with stakeholders and supported by CCG's modelling offer, be integrated to support a wider and cross-sectional understanding of SDGs, including the development of GESI-transformative transport policies and investments?

Answering this RQ includes the production and co-creation of integrated narrative storylines exploring the interplay of technological, societal and political shifts in context-specific futures for CCG partner countries' transport systems. It includes the development of context-specific models using the frameworks generated in RQ3.3, but also notably includes a significant amount of research on scenario development, and the development of impact assessment frameworks to allow stakeholders to quantify the wider impacts from these pathways.

RQ3.6 What are the cross-sectoral impacts of the transport-energy pathways discussed in RQ3.3 and RQ3.5, including electricity demand growth, air pollution reduction, critical minerals, taxation revenues from fuel sales, fuel import bills and job creation?

Answering this RQ includes broadening the discussion from the energy and emissions implications of transport-energy pathways to wider economy-wide impacts. Many LICs and LMICs in Africa and Asia have few fossil reserves, and must rely on imported fuels to supply the energy for their transport demand. This is expensive and economically inefficient. This RQ is designed to investigate the potential of clean transport pathways (e.g., the uptake of e-mobility) to reduce the burden of fuel import bills and incentivise circularity in cash flows within an economy. Furthermore, this RQ will investigate impacts across the rest of the energy system outwith transport (including electricity systems) and further socio-economic impacts (e.g. job creation).

RQ3.7 What are the most effective and locally appropriate financing mechanisms to support investments to promote clean and equitable transport pathways in LICs and LMICs, including public-private partnerships? (Note that this RQ will be addressed in collaboration with ADB.)

Answering this RQ looks at the viability of different financing options for delivering desirable transport pathways as described in the research questions above. This research will be conducted as part of the ongoing collaboration between CCG's Transport Research Community and the Asian Development Bank (ADB), leveraging expertise in finance and transport across the transport-energy nexus.

Resource Efficiency Research Community

RQ4.1 (CU-REC). How many, how much and which materials will be needed globally to meet climate change targets?

This research will build on the existing aspects of Mat-DP and combine them with CCG electricity and transport models. Additionally, an historical and future prospective assessment of the material flows required to low-carbon infrastructure will explore the dynamic aspects of material accumulation in service. This will enable the development of robust demand models to identify future material demand and how this demand can be supplied.

RQ4.2 (CU-REC). What material supply chains are at risk of disruption, where will these risks occur and what interventions can mitigate future risks?

This research will use the modelling capability for RQ1 to develop metrics of material supply risk and resilience to identify potential issues around material criticality. This analysis will enable the prioritisation of areas of supply resilience and disruption risk and reveal options for mitigation. This analysis will map and reveal trade-offs associated with the impacts of prioritised interventions to support decision-making.

RQ4.3 (CU-REC). What role can material circularity strategies play in reducing demand for primary material and how does this affect environmental and social impacts?

This research will assess the potential for circularity strategies, such as recycling, reuse, and better product design, to reduce environmental and social impacts, and to improve resilience of CM value chains. This analysis will use the modelling developed for RQ1 and RQ2 to test the effectiveness, timing, and location of material circularity strategies.

Infrastructure Resilience Research Community

RQ5.1 (OX-OPSIS). What are the climate risks to energy and transport systems at national and global scales?

This research involves developing and applying methods for climate risk analysis at a range of scales. It aims to quantify climate risks in aggregate economic terms and provide evidence for prioritization of resilience interventions. Infrastructure network models will be used to model the flows of infrastructure services and interactions between infrastructure sectors. These will be stress tested with large numbers of climate-related extreme scenarios to identify points of vulnerability and prioritise adaptation actions. Distributional data (e.g. relating to poverty) enables the identification of risks to people's wellbeing and means to assess GESI issues [64]. The research involves the development of tools with international and country stakeholders. The results can be integrated in broader packages of infrastructure prioritization i.e. as part of D2D.

RQ5.2 (OX-OPSIS). What are the macro-economic impacts of climate related damage and disruption to infrastructure systems?

This research will focus upon simulating and understanding the propagating impacts of infrastructure failure on businesses and the economy, within a framework that addresses: (i) the processes and consequences of physical infrastructure failures in terms of physical capital losses and service flow disruptions, and (ii) the resulting business disruptions and economic flow losses across the wider macroeconomic sectors. Additionally, due to the spatial and temporal nature of both infrastructure failure itself and the economy it affects, it is necessary to include the wider multi-regional losses and the possible gains under substitution effects.

RQ5.3 (OX-OPSIS). How can physical climate risk analysis inform national infrastructure investment prioritization?

Prioritization of resilience interventions relies upon quantification of the risk-reducing benefits (in the broadest sense) of a set of possible interventions, the costs, and the co-benefits. We will develop methodologies for prioritizing resilience interventions at national scales and more broadly. We will analyse how infrastructure systems will evolve in the future, subject to demographic, economic and climatic drivers. We will explore how resilience prioritization aligns with national infrastructure prioritization and finance.

Economics, Enterprise, and Finance Research Community

RQ6.1 (OX-SS): What are the economic opportunities for inclusive climate compatible growth in different countries and what are the best policies to promote them?

This research question explores the interface between climate action and sustainable development. We will explore how national net zero pathways and transition strategies can reflect institutional contexts (e.g. how power markets are designed) and development needs (e.g. energy access gaps) and what the impact of these pathways is on investment, jobs and growth. In answering this question, we are interested both in strategies to scale down dirty (e.g. job redeployment, the future of fossil fuels) and scaling up clean (e.g. clean entrepreneurship support).

RQ6.2 (OX-SS): What business models and strategies are being deployed to, and are successful in, delivering inclusive climate compatible growth?

This research question takes an entrepreneurship lens. It seeks to document the clean technology landscape of the global south and identify successful business models (e.g. related to energy services). In answering this question, we will seek to collect primary evidence from successful entrepreneurs, as well as using secondary data.

RQ6.3 (OX-SS): What is the public and private funding gap for inclusive climate compatible growth and what financing strategies are available to close it?

This research question explores the magnitude, structure and drivers of climate finance to the global south. We will seek to predict future climate finance flows at a granular level (i.e. by country, technology and financing type) and compare those flows with expected climate finance demand. We will explore how different financing modalities can help to close the financing gap (e.g. blended finance, extended tenors). In answering this question, we will use and expand the fiscal model MinFin and apply and test CCG's data-to-deal framework, among other analytical approaches.

RQ6.4 (OX-SS) How can existing international frameworks for defining, measuring and reporting impact be enhanced to improve their applicability for projects in CCG client countries, and support the mobilisation of additional funding?

We build on recent research that explores frameworks for measuring investment impact, noting that current approaches often risk entrenching existing inequalities in terms of access to finance. This is due both to path dependence; as well as the economic structure of many LMICs, where a significant proportion of output comes from primary and secondary sectors such as agriculture and mining, which are often characterised by higher (and harder to abate) emissions.

RQ 6.5 (OX-SS) How can policy-based investment decisions on increasing electricity generation capacity from both renewable and non-renewable sources be evaluated to better consider factors including urgency, cost, equity, inclusion; along with climate compatibility.

This question is informed by recent policy decisions to prioritise generation from non-renewable sources such as coal as a cheaper and more expedient solution to closing capacity gaps in electricity generation. These decisions reflect context specific circumstances in CCG client countries; for example, Zambia, where the majority of generation is derived from hydropower, is experiencing reduced output due to drought conditions. The research emphasises a technologically neutral approach, consistent with CCG mandate, in evaluating investment decision-making frameworks.

Appendix C: Flexible Research Funds

CCG hosts several flexible research funds that are referenced in this Research Strategy. These are further described here:

Flexible Research Fund (FRF): The FRF commissions research though a competitive procurement process. This modality is specifically designed to commission high quality research globally from eligible organisations including universities, research centres and consulting firms. These calls are only open to researchers outside the core CCG consortium. To ensure the integrity of the competitive process proposals are only evaluated by subject experts not otherwise engaged with CCG. (Though sign-off by the directorate is required to ensure projects that are funded are coherent with CCG operations.) After the research is commissioned, it is expected that researchers will be linked with relevant CCG core researchers to ensure their research findings are integrated with the overall programme.

Southern Partner Fund (SPF): SPF projects are developed collaboratively between the core CCG research team and local partners, embedding local knowledge into research creation. The SPF enables CCG researchers to engage local partners to undertake their core research activities and ensures these funds are ringfenced from the main programme budget. This will not only ensure that work is carried out effectively and appropriately in a country, for a country, and with academics or other partners in that country, but also will build in-country expertise and capacities when developing models, designing policies, and assessing impact.

Engagement Fund (EF): The EF supports partner countries and international organizations in benefiting from the CCG program. It funds activities aligned with CCG's partnership strategies and objectives, fostering mature strategic partnerships and addressing partner requests. The EF aims to achieve CCG's five key outcomes by offering targeted activities, ensuring partner-driven research and capacity building, and mobilizing co-funding. Eligible activities span knowledge product use, nationally and internationally embedded processes, educational integration, and research excellence, covering areas like training, data units, stakeholder engagement, and applied research. Projects are selected based on their contribution to CCG outcomes, knowledge embedding plans, value for money, and alignment with partnership and research strategies. Co-funding is encouraged to maximize impact.

Appendix D: Engagement with International and Country Partnerships

CCG’s Programmed Research will actively engage using its dynamic process for developing high impact projects closely with CCG’s Country Partnerships and International Partnerships.

The Climate Compatible Growth (CCG) program utilizes three interconnected strategies: Country Partnerships (CP), International Partnerships (IP), and Programmed Research (PR). Each strategy generates distinct knowledge products, activities, and communities. These strategies are integrated through **Transversal Activities (TRACs)** (further detail below), which are actively managed across one or more of CCG's "legs" (IP, CP, and PR) with the central directorate (CDr). TRACs meet bi-monthly with the CDr.

Programmed Research (PR) enhances its impact by interacting with CP and IP through TRACs and direct engagement. Direct interaction also occurs where PR overlaps with CP and IP strategies.
The CDr prioritizes support for overlapping PR, IP, and CP activities (whether within or independent of TRACs) due to the potential for increased efficiency. However, IP and CP strategies and projects are not obligated to align with PR if they don't efficiently meet IP or CP goals. Overlapping areas with potential for greater impact are identified and evaluated at least bi-annually during CCG General Meetings.

CCG is demand-driven. IP and CP strategies, including their research needs, are a primary (though not exclusive) source of topics for aligned PR projects and research questions. If IP and CP strategies demonstrate impact but PR lacks resources to conduct some or all of the underlying research, funding may be requested (via agreed processes) from the CCG Funding Mechanisms.

TRAC Summaries and PR Interfaces:

- **Data-to-Deal (D2D) TRAC:** Oversees D2D implementation, integration, investigations in partner countries, engagement with International Organisations, and D2D Programmed Research. [PR actively participates in D2D TRAC activities, and its working groups.]
- **Gender Equity and Social Inclusion (GESI) TRAC:** Develops the CCG GESI Strategy and its task force to advise CCG operations, research, and activities. [PR actively contributes to the GESI task force]
- **Empowerment Ecosystem (EECo) TRAC:** Develops CCG’s ecosystem of activities, knowledge products, and public goods to empower southern analysts, actively promoting their research and development opportunities. [PR researchers actively contribute to activities of mutual interest. This is exemplified by recent support for the development of the African Institute for Energy Systems Analysis (AISESA)]
- **Operational Intelligence Framework (OIF) TRAC:** Evaluates CCG outputs, outcomes, and impact, and annually updates the CCG Philosophy of Change, Theory of Change, Logframe, and Logframe targets. [PR actively contributes to the evolution of the ToC, LF and targets annually, as well as reporting its outputs, outcomes and impact]
- **Political Economy Unit (PEU) TRAC:** Provides advisory services for CCG partner country activities and guides an associated research agenda (under development). [PR provides active research by examining political economy elements of CCG’s engagements and challenges in target regions]
- **Funding Mechanisms (FM) TRAC:** Oversees several funding mechanisms, including Responsive Unit and Agile Funding (RUAF), Engagement Funding (EF), and Southern Partner

Funds (SPF). [PR actively contributes to the management, evaluation and resourcing of the FM TRAC as a function of the fund modality]

- **Critical Minerals (CM) TRAC:** Coordinates CCG CM research, development, and deployment into a country 'offer' comprising IP Knowledge Products (IP-KPs) delivered by International Organisations and CCG's Country Partner activities. [PR is actively developing knowledge products to be taken up in IP-KP and deployed at country level. One such example is the tool MATdp]
- **CCG Shop Window Offer (SWO) TRAC:** Provides a consolidated offer of CP, IP-KPs, and Research Offerings to complement Affiliate and Partner Country activities, particularly D2D. [PR provides topical areas for it to support engagement and the potential of success]

Research Types Promoted by CP and IP:

While CCG's Programmed Research (PR) has relatively insulated three-year research windows, research undertaken and supported by CP and IP are also significant. However, their underpinnings and process are different. Nonetheless they create a useful interface for CCG's ground-breaking and sometimes slower-burn PR. These are described below.

- **Interfacing Research:** Typically led by Partnerships (overall) and IP, this research occurs during the development, testing, or application of IP-KPs for use by International Partners or in-country, often in demonstrator countries or with international partners directly.
- **Induced Research:** Research led by partners in Demonstrator, Partner, or Affiliate Countries when using and applying CCG knowledge products, including IP-KPs.

International Partnerships (IP) and IP Knowledge Products (IP-KPs):
IP curates specific CCG IP Knowledge Products (IP-KPs), including tools, energy modelling platforms, methods, and data. These are distinct from other CCG data or tools due to their active curation and application, often with International Organisation partners, and are provided as a public good.

- **Affiliate Countries:** Located in CCG's target regions (developing Africa and Asia) but not Partner Countries. They receive direct, indirect, or autonomous CCG engagement but lack dedicated CCG-central budget.
- **Demonstrator Countries:** Countries where CCG analysts demonstrate the potential of knowledge products, often IP-KPs.

Specific Interfaces between IP-KPs and PR:

- **Energy Modelling Community (EMC):** A community of practice supporting long-term, southern-led research. [PR actively participates.]
- **Energy Modelling Platforms (EMPs):** Two-week events for technocrats and academics. [PR uses EMPs to increase Southern Researcher absorptive capacity in Country Partnerships.]
- **IP Flatpack:** Integrates OLC teaching materials into Southern university MSc curricula. [PR researchers are encouraged to assist with embedding FlatPacks where interests align.]
- **Open Learn Collection (OLC):** Online courses with certification. [PR develops material and expertise for the OLC.]
- **Data and Tools:** Offers free and open-source data and tools. [PR is invited to contribute to tool and data development, exemplified by OSeMOBILITY and the Transport Data Commons Initiative.]

- **Knowledge to Paper (K2P):** Coaches EMC members to publish their reports. [Programmed Researchers and other CCG analysts volunteer as coaches.]
- **Catalyst Facility:** A trust fund building research and analytical capabilities in southern institutions. It has several windows:
    - **MSc Scholarship Window:** Encourages student internships with government institutions.
    - **Research Collaboration Window:** Requires academics to develop proposals for external funding. [PR researchers can co-create and partner in proposals, increasing co-funding.]
    - **Academic Training Window:** Sponsors academics to participate in EMPs.
    - **Sabbatical Window:** Provides opportunities for advanced research, publication, and capacity building at renowned research institutions. [This provides opportunities for PR researchers to engage, co-create, co-publish, and coach southern researchers.]

CCG CP Inclusive Innovation and the Interface with PR:
At the country level, CCG works with partner universities to establish "special interest groups" (SIGs) that define research priorities and ensure practical application. PR and IP researchers work with SIGs in various ways, often including government officials. PR-enabled research, funded through SPF, FRF, and EF, requires SIG development. CP encourages SIG development as part of inducing research, often without CCG PR or IP researcher involvement, but providing a valuable entry point for researchers. [PR researchers contribute to bi-annual General Meeting (GM) dialogues to ensure that SIG support is maximised]

CP is co-creating 'sustainability' strategies focusing on embedding PR activities and ensuring IP-KP uptake, fostering a thriving local research ecosystem. The EECo TRAC will facilitate coordination. [PR will provide input into those strategies]