# Calculating countries' fair shares for addressing climate change

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# Abstract

Equity and responsibility are central concepts in the climate ethics literature and also the international climate regime. These concepts underpin debates about fair distributions of financial costs for addressing climate change, as well as rights to emit greenhouse gases. Ethical principles are often drawn on by climate ethicists and negotiators – in the abstract – to inform such debates.

However, without clear relationships to data, these principles remain underutilised. This leaves international negotiators and policymakers in sub-optimal positions, as they seek to clarify country-level shares of collective climate finance goals and global emissions budgets, in line with internationally agreed temperature targets. While studies and tools to support such ethical analysis do exist, these tend to aggregate data at higher regional levels, do not include a warming-specific focus, follow untransparent methodologies, apply a form of moral objectivism that presupposes a single moral truth, and conflate ethical domains by combining the sharing of climate-related costs and rights to emit greenhouse gases within the same assessment.

Motivated by the aim to develop tools which support democratic deliberation amongst the international climate policy community, this research builds a bespoke tool, the Science and Ethics of Fair Shares dashboard, to carry out top-down assessments of countries' fair shares for addressing climate change. The research employs a multidisciplinary approach, by drawing on outputs from a simple climate model and environmentally extended input-output analysis to conduct a data-rich applied ethics. Dynamic comparisons of possible effort-sharing distributions are enabled via the operationalisation of five distributional principles: Polluter Pays, Beneficiary Pays, Ability to Pay, Grandfathering and Equality-over-time.

The dashboard presents a proof-of-concept for a technology-assisted form of reflective equilibrium, which enables decision makers to explore and test the practical implications of distributional principles by combining multiple scientific and ethical parameters. Use of historical warming and consumption-based emissions on a per country, per gas basis reveal the importance of accounting for short-lived and long-lived gases differently. Additionally, the application of principles with warming-related information aligns countries' fair shares with the Paris Agreement's temperature targets. The design of a new Equality-over-time Principle explicitly includes future generations by incorporating countries' projected populations in warming target calculations. Finally, a climate justice typology is developed so as to avoid the conceptual confusion that has arisen in other assessments.

Rather than producing absolute answers to questions of moral responsibility, the dashboard invites users to test their own intuitions of fairness as they encounter a range of possible solutions, reflective of wider perspectives on equity and responsibility. In the penultimate chapter, questions are raised about the adequacy of currently available data, whether new data ought to be collected to better reflect the principles, or whether the principles themselves need to be revised in the face of data constraints. In light of this, the research strengthens the case for greater collaboration between communities of climate ethicists, economists, physical and social scientists. By enabling theory to better inform practice, future research can more readily support climate negotiators and policymakers in their real-world, effort-sharing debates.

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# List of Acronyms

| | |
|---|---|
| AAUs | Assigned Amount Units |
| BASIC bloc | Brazil, South Africa, India and China |
| BCE | Before Common Era |
| BLUE | Bookkeeping of Land Use Emissions |
| BURs | biennial update reports |
| C&C | Contraction & Convergence |
| C40 cities | a global network of mayors |
| CBA | consumption-based accounting |
| CBAM | Carbon Border Adjustment Mechanism |
| CBDR-RC | Common But Differentiated Responsibilities and Respective Capabilities |
| CDM | Clean Development Mechanism |
| CDR | carbon dioxide removal |
| CEDS | Community Emissions Data System |
| CGTP | Combined Global Temperature Change Potential |
| $CH_4$ | methane |
| CICERO | Center for International Climate and Environmental Research–Oslo |
| CMIP | Coupled Model Intercomparison Project |
| $CO_2$ | carbon dioxide |
| $CO_2e$ | carbon dioxide equivalent |
| $CO_2$-fossil | carbon dioxide emissions from burning fossil fuels |
| COP | Conference of the Parties |
| DAI | dangerous anthropogenic interference |
| DGVM | Dynamic Global Vegetation Model |

| | |
|---|---|
| EAS | Eastern Asia |
| EBMs | energy balance models |
| EBSR | Economic Benefit Shared Responsibility (scheme) |
| ECPCE | Equal Cumulative Per Capita Emissions |
| EE-IOA | environmentally extended input-output analysis |
| EIT | Economies in Transition |
| ESMs | earth system models |
| ETSs | emissions trading schemes |
| EU | European Union |
| EU ETS | European Union Emissions Trading System |
| EU28 | the European Union and its 28 members |
| EUR | Europe |
| EVI | Environmental Vulnerability Index |
| FaIR | Finite Amplitude Impulse Response |
| FAO | Food and Agriculture Organization |
| FAR | First Assessment Report |
| FRAs | Forest Resources Assessment |
| G20 | Group of Twenty |
| G77 + China | Group of 77 developing countries and China |
| GCMs | global circulation models |
| GCP | Global Carbon Project |
| GDP | Gross Domestic Product |
| GFED | Global Fire Emissions Database |
| GHGs | greenhouse gases |
| GMRIO | global multi-regional input-output |

| | |
|---|---|
| GMST | global mean surface temperature |
| GNI | Gross National Income |
| GPC | Global Protocol for Community-Scale Greenhouse Gas Emission Inventories |
| GTAP | Global Trade Analysis Project |
| GWP | Global Warming Potential |
| GWP* | Global Warming Potential Star |
| $GWP_{100}$ | Global Warming Potential over a 100-year time horizon |
| HDI | Human Development Index |
| HFCs | hydrofluorocarbons |
| HYDE | History Database of the Global Environment |
| ICJ | International Court of Justice |
| IE | industrial ecology |
| INDCs | Intended Nationally Determined Contributions |
| IOA | input-output analysis |
| IOTs | input-output tables |
| IPCC | Intergovernmental Panel on Climate Change |
| IPLCs | Indigenous peoples and local communities |
| IPPU | industrial processes and product use |
| IR | International Relations |
| ISO | International Organization for Standardization |
| JI | Joint Implementation |
| LDCs | Least Developed Countries |
| LULCC | land use and land cover change |
| LULUCF | land use, land-use change, and forestry |
| MACCs | marginal abatement cost curves |

| | |
|---|---|
| MAGICC | Model for the Assessment of Greenhouse Gas Induced Climate Change |
| MERs | market exchange rates |
| MOP | Meeting of the Parties to the Kyoto Protocol |
| MRIO | multi-regional input-output |
| MVPs | minimum viable products |
| $N_2O$ | nitrous oxide |
| NAM | North American |
| NCQG | New Collective Quantified Goal (on climate finance) |
| NCs | national communications |
| NDCs | Nationally Determined Contributions |
| NGOs | non-governmental organisations |
| $NH_3$ | Ammonia |
| NOx | nitrogen oxides (= NO + $NO_2$) |
| NPISH | Non-profit Institutions Serving Households |
| NRE | narrow reflective equilibrium |
| NSOs | National Statistics Offices |
| OC | Organic carbon |
| OECD | Organization for Economic Co-operation and Development |
| OPEC | Organization of the Petroleum Exporting Countries |
| PBA | production-based accounting |
| PFCs | perfluorocarbons |
| ppb | parts per billion |
| ppm | parts per million |
| PPP | purchasing power parities |
| PRIMAP | Potsdam Realtime Integrated Model for probabilistic Assessment of emissions Paths |

| | |
|---|---|
| RCB | remaining carbon budget |
| RCMIP | Reduced Complexity Model Intercomparison Project |
| RE | reflective equilibrium |
| RoW | Rest of the World |
| RQs | research questions |
| SBTi | Science Based Target initiative |
| SCM | simple climate model |
| SEFS | Science and Ethics of Fair Shares (dashboard) |
| $SF_6$ | sulphur hexafluoride |
| SLCF | short-lived climate forcer |
| SLCP | short-lived climate pollutant |
| $SO_2$ | Sulphur dioxide |
| $SO_4$ | Sulphate |
| SOPAC | South Pacific Applied Geoscience Commission |
| SRM | solar radiation management |
| SSPs | Shared Socioeconomic Pathways |
| TCFD | Taskforce on Climate-related Financial Disclosures |
| TCRE | transient climate response to cumulative emissions of carbon dioxide |
| TNFD | Taskforce on Nature-related Financial Disclosures |
| UNDP | United Nations Development Programme |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UNSNAs | United Nations Systems of National Accounts |
| US$ | United States Dollars |
| USSR | Union of Soviet Socialist Republics |

| | |
|---|---|
| W.E.I.R.D | Western, Educated, Industrialized, Rich and Democratic |
| WMA | World Meteorological Association |
| WRE | wide reflective equilibrium |

# Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signature Date 14 April 2025

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# Chapter 1 Introduction

> *"[I]n order to guide action, our ideal principles of climate justice need to be reformulated in the light of real-world considerations, which we only obtain by integrating the relevant empirical work on the matter."*
>
> (Gajevic Sayegh, 2018, p. 407)

## §1.1 Background

Since the early 2000s, climate ethicist Stephen Gardiner has argued that "Climate change is fundamentally an ethical issue" (Gardiner, 2004, p. 556). Gardiner's characterisation of the challenge as "the perfect moral storm" has helped to explain climate change's multiple ethical dimensions including its global form, the way it builds over time across generations, and how it tests the adequacy of our current theories and approaches to issues that are of an interdisciplinary nature (Gardiner, 2006, 2011).

For climate change – caused by rising atmospheric concentrations of greenhouse gases (GHGs) from human activity – is a long-term, global issue which will continue to have adverse impacts on human and non-human communities around the world for many decades at least. Despite climate science knowledge stretching back to the early 19th century and observational evidence for the issue being in place since the 1960s, human-induced GHG emissions have continued in recent times at an alarming rate (IPCC, 2021). Higher levels of GHGs in the atmosphere are warming the Earth, with 2024 marking the hottest year on record and the first time that global average temperatures exceeded 1.5°C above pre-industrial levels for an entire year (Copernicus Climate Service, 2025).

As Gardiner explains, a unique feature of climate change are its spatial and temporal dimensions, where distinctions between its human causes and downstream effects make the issue particularly difficult to analyse from an ethical standpoint. For instance, GHG emissions are released by people in locations all over the world in the past, present and future, and the link between cause and harm is neither immediate, nor obvious (Gardiner, 2006, 2011). This can, in part, explain why climate change has been classified as a "wicked problem" where "[t]here is no unambiguous formulation of what the problem is and no opportunity to learn from other, similar cases"(Hulme, 2010, p. para 3).

Climate change's collective nature further complicates matters. The issue is often conceived of as a "collective action problem," where countries collectively contribute to the issue and, at the same time, must work together to preserve the global public good of a stable climate (Barrett, 2007; Gardiner, 2011; Jamieson, 2014, p. 4; Roser & Tomlinson, 2014). However, it is not immediately clear how much action different actors ought to take. This is where issues of distributive justice arise.

These issues are of relevance to the communities of international climate negotiators and policymakers, as well as climate ethicists, who have been debating possible effort-sharing approaches since at least the early 1990s. The issues are often discussed or investigated by way of two prominent burden-sharing questions, which focus on distributing financial costs for addressing climate change, and rights to emit GHGs within constrained carbon budgets. Carbon budgets represent permissible quantities of GHGs which can be emitted while remaining within global average temperature change targets.

At the heart of these burden-sharing questions are the concepts of equity and responsibility. Equity, as described by climate ethicist Henry Shue, is a term used by diplomats and lawyers which "incorporates important aspects of what ordinary people everywhere call fairness" (Shue, 1999, p. 531). It belongs to no one culture and is universally recognisable: "People everywhere understand what it means to ask whether an arrangement is fair or biased towards some parties over other parties" (p. 532).

Responsibility, on the other hand, involves the assignment of duties or obligations: "As a moral concept, responsibility picks out those persons who owe a debt, and conceptions of responsibility will vary according to the understanding of the debt" (Moellendorf, 2014, p. 154). Like equity, responsibility is also globally recognised. However, the complicated nature of climate change raises questions about distinctions between causal and moral responsibility, on which grounds and by which means they should be distinguished and measured (Jamieson, 2015; Vanderheiden, 2004).

The establishment of the United Nations Framework Convention on Climate Change (UNFCCC) over thirty years ago – often referred to as the international climate regime – saw these concepts formalised through the Common But Differentiated Responsibilities and Respective Capabilities (CBDR-RC) principle. This principle established the developed/developing country divide as a critical fulcrum point in climate change negotiations. Initially, CBDR-RC was used to justify a hard distinction between the obligations of developed versus developing countries where, under the 1992 UNFCCC and 1997 Kyoto Protocol, emission reduction targets were specified for developed countries only.

However, between the 2009 Copenhagen Accord and the 2015 Paris Agreement, the developed/developing country dichotomy began to dissolve as developing countries' emissions rose rapidly, prompting recognition that all countries would need to act. Thus, the CBDR-RC has evolved with time in light of countries' changing circumstances and contributions to the issue. A rapidly dwindling global carbon budget and growing urgency to address the issue in more recent decades provided the justification for all countries, not just developed ones, to act.

The stalling and unsuccessfulness of international diplomacy efforts to address climate change can, in part, be explained by the inherent contentiousness of this principle, and countries' varying interpretations of it (Fuglestvedt & Kallbekken, 2016; Grubb, 2015; Macey, 2019; Rajamani, 2012). Deep-seated disagreements over how much action each country ought to take, based on this principle, and the broader concepts of equity and responsibility, have resulted in international negotiations entering "gridlock" when countries become uncooperative and disrupt efforts to arrive at consensus-based decisions (Victor, 2011).

Part of the issue is that while negotiators and policymakers tend to draw on the CBDR-RC principle in their high-level discussions, the principle is often applied without a clear relationship to data and therefore cannot offer sufficient guidance (Bodansky, 2001a; Hermwille et al., 2017). This leaves the question of how much action individual countries ought to take unresolved.

### §1.1.1 Applying ethical principles

Discussions of country-level effort-sharing to address climate change have also occurred within a diverse climate ethics literature. While the CBDR-RC principle does feature in this literature, several other principles have come to dominate the discussion of countries' burden-sharing obligations (Caney, 2009a; Roser & Seidel, 2017; Shue, 2014). These include the Polluter Pays, Beneficiary Pays, Ability to Pay, Grandfathering, Equal Per Capita Emissions and Subsistence Emissions. These principles are presented and defined within Table 1 and Table 2 below.

| Financial burden-sharing principle | Conception of justice |
|---|---|
| Polluter Pays | The one responsible for causing the environmental harm should pay for its mitigation and/or remediation |
| Beneficiary Pays | The one benefitting, unjustly, from the harm should pay for its mitigation and/or remediation |
| Ability to Pay | The one with the greatest financial means to address the harm should pay |

*Table 1. Three financial burden-sharing principles and their conceptions of justice*

| Budget allocation principle | Conception of justice |
|---|---|
| Grandfathering | Future emissions rights should be based upon historical emissions or past patterns of behaviour. |
| Equal Per Capita Emissions | Emissions rights should be allocated equally, on a per capita basis, so that every person gets the same amount of rights. |
| Subsistence Emissions | Emissions rights should be allocated in a way which ensures that, at least, every person's basic needs are met. |

*Table 2. Three budget allocation principles and their conceptions of justice*

At this point, it will be helpful to distinguish between fundamental normative principles and regulative principles, also described respectively as fact-insensitive and fact-sensitive principles by Cohen (2003). Consideration will then be given to where the CBDR-RC and prominent principles from the climate ethics literature fall in relation to these.

Normative principles articulate moral ideals. These principles determine what we ought to do, irrespective of the facts about our specific situation. For instance, the normative principle of equality asserts that equality is desirable, regardless of whether we are in a position to realise it. In contrast, regulative principles require the facts of concrete situations in order to determine what ought to be done. They can be considered lower-level, action-guiding principles that descend from high-level normative principles like equality, equity and responsibility. Regulative principles take into consideration the actual circumstances of an ethical choice.

The CBDR-RC principle can be thought of as a higher-level regulative principle, which is enshrined in the international law of climate change agreements. It is fact-sensitive insofar as we must know the facts about each country's contribution to climate change, and their capabilities to respond, in order to make informed judgements about what each country owes to the collective effort to address climate change. Further, the Polluter Pays, Beneficiary Pays and Ability to Pay Principles are lower-level regulative principles which cash out or specify the CBDR-RC principle in different ways, by requiring different types of facts in its attribution of responsibility. The Polluter Pays Principle involves facts about each country's emissions, the Beneficiary Pays Principle involves facts about the advantages each country has accrued from historical emissions, and the Ability to Pay involves facts about each country's capabilities and resources. Figure 1 articulates this hierarchy of principle levels.

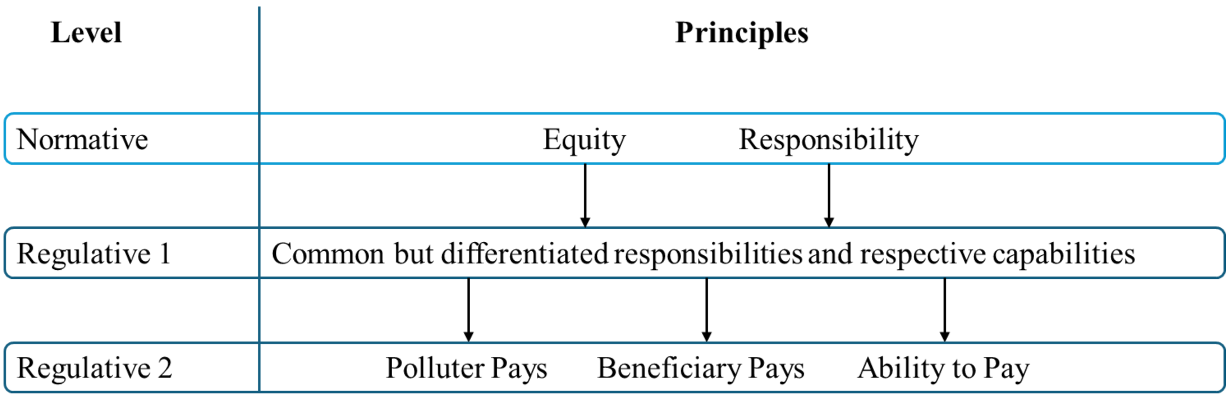


*Figure 1. Hierarchy of principle levels from normative through to regulative*

This thesis argues that, were the CBDR-RC principle to be made more specific with real-world information, it could allow the international community to test their commitments to certain conceptions of equity and responsibility. This thesis builds the case for making CBDR-RC more practically useful via applications of the Regulative 2 level principles in Figure 1 above.

An advantage of making the CBDR-RC more practically useful is that it can more helpfully guide debates about the ethical adequacy of country-level contributions towards globally agreed goals within the most recent international climate change agreement, the 2015 Paris Agreement. Under Article 2 of the Paris Agreement, countries have agreed to:

> *"Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change" (Paris Agreement, 2015, Article 2).*

These 1.5°C and 2°C targets will be referred to as Article 2 targets throughout this thesis.

The Paris Agreement has shifted away from the top-down, prescribed emissions reductions of the Kyoto Protocol era by mandating that countries put forward their own self-defined actions, called Nationally Determined Contributions (NDCs). However, despite specifying a global goal in the form of the two Article 2 targets, the Paris Agreement does not contain a mechanism for assessing the adequacy of country-level shares of the global mitigation effort from an ethical standpoint (Rajamani et al., 2021). Additionally, many countries' NDCs are not expressed in metrics which easily translate of into the globally agreed temperature targets. This lack of a mechanism for ethically reviewing countries' NDCs, combined with the discrepancy in metrics, leaves diplomats at a disadvantage in their international burden-sharing debates.

Components of the international climate regime's CBDR-RC principle and lower-level ethical principles have been applied in a range of web-based dashboard-style tools and studies, including Climate Equity Reference Calculator, Fair Mitigation Finance Explorer and Paris Equity Check (Holz et al., 2019; Pachauri et al., 2022; Robiou du Pont et al., 2017). Many of these tools have developed in the Paris Agreement's wake and seek to determine country and regional-level shares of climate mitigation finance and global carbon budgets. These assessments are analysed further in §2.6.5, where Table 6 provides a summary of these tools and their features.

While these assessments collectively capture a wide range of principles, most tend to apply components of the CBDR-RC principle and very few explicitly apply the second-order regulative principles presented in Table 1 above. The result is that currently available assessments do not delve into as much detail as they could about the different ways that responsibility might vary or be cashed out under the CBDR-RC principle. This is a current gap, given the extensive discussion of the three financial burden-sharing principles that has been done by climate ethicists in the abstract. This means there is a gap between the philosophical climate ethics literature – which discusses these principles extensively – and the applied climate ethics literature – which instead draws on the broader CBDR-RC principle that is more prevalent in the international climate regime.

Moreover, few assessments provide opportunities to consider combinations of parameters that extend across both scientific and ethical domains, including multiple climate forcers and accounting frameworks – which are concerned with assigning GHG emissions to countries – at the more finely grained country-level. Additionally, several of the studies and tools have been criticised for their untransparent methodologies and for not being explicit about the ethical principles and conceptions of fairness that underlie their analysis (Dooley et al., 2021). Some also display an assumed moral objectivism, characteristic of a positivist worldview, in their assessments. Finally, a conflation of ethical domains has arisen within several of the tools, the consequences of which are discussed further in §2.7.

The multiple gaps and limitations of other tools, described more extensively in Chapter 2, ultimately leave climate negotiators and policymakers at a disadvantage. A desire to contribute to better supporting these communities in their deliberations and decision-making has provided the motivations for this research project, discussed next in §1.2.

## §1.2 Research motivations

This research has been motivated by a real-world need to develop independent ethical assessments which assist international burden-sharing conversations about country-level efforts to address climate change.

More specifically, there was motivation to investigate how countries' ethical obligations for addressing the issue would vary under different combinations of ethical principles, accounting frameworks and scientific parameters. Since accounting frameworks have traditionally featured to a lesser extent in international negotiations, there was motivation to incorporate a range of accounting framework perspectives within the dashboard, to provide different ways of allocating GHG emissions to countries.

The intention was to build an interactive, dashboard-style tool which would help meet the research aims, listed in §1.5. Alongside meeting these aims, the dashboard would serve a more practical purpose: to help the target audiences of international climate negotiators and policymakers become better informed in their democratic deliberation and decision-making.

There was also a particular motivation to put country-level contributions to climate change into the language of the Paris Agreement's temperature change targets, by calculating countries' contributions to historical global *warming*. This could help address the Paris Agreement's absence of a mechanism for ethically evaluating country-level shares of the Article 2 targets. As climate change continues, it will be important to have independent ethical assessments to scrutinise country-level efforts for addressing the issue.

## §1.3 Research questions

The overarching research question that has guided this research is: Can an interactive dashboard shed light on country-level obligations for addressing climate change by applying regulative ethical principles in a useful way?

This broader question is tested by way of three more specific research questions (RQs), below:

- RQ1: What are countries' historical contributions to global warming?
- RQ2: How should the costs for mitigating climate change be distributed between countries?
- RQ3: How should warming rights be distributed between countries?

To provide answers to these questions, this research project included the development of a novel, dashboard-style tool – the Science and Ethics of Fair Shares (SEFS) dashboard. The dashboard is a web application which enables filtering of complex datasets to draw inferences about country-level responsibility for addressing climate change. It is publicly available and can be found at the link here: https://live-sefs-dash-app.onrender.com. The dashboard contains six pages which a user can transition between by clicking on links in the navigation pane at the top of every page.

The first page gives an overview of the dashboard and its purpose, while pages 2-4 contain the dashboard's main content. These are the pages which have helped answer the three specific RQs posed as part of this research project. In these pages, a series of dropdown boxes, buttons and checklists on each page's left-hand side allow users to generate different outputs. The outputs appear as charts on the right-hand side and swiftly update when different options are chosen by a user. A sample of these charts, as possible answers to the three RQs, are included and discussed throughout Chapter 4 of this thesis. Finally, pages 5–6 contain information about how the dashboard has been built and a list of references to datasets that have been used to create the dashboard.

Currently, the publicly available version of the dashboard does not include the Eora-26 dataset that has been used to calculate countries' consumption-based emissions. This dataset is free with an academic license but is not publicly available.

Answers to RQ1 inform answers to the RQ2 and RQ3, which are about distributive justice and effort-sharing. RQ2 is about who pays for mitigation and can be answered by drawing on the three financial burden-sharing principles in Table 1 above. RQ3 is about who has priority over future global average temperature changes, constrained by globally agreed temperature change targets like the Article 2 targets, and can be answered by way of the budget allocation principles in Table 2 above.

Of the three principles in Table 2, the Grandfathering Principle and a newly designed variant of the second Equal Per Capita Principle – Equality-over-time – have been applied within the dashboard. The Equality-over-time principle presents a novel and more sophisticated version of the Equal Per Capita Emissions Principle by explicitly taking countries' projected populations into account. A prominent third budget allocation principle – the Subsistence Emissions Principle – is discussed within this thesis, despite not having been applied within in the dashboard. This principle's prevalence in the climate ethics literature meant that the thesis would be incomplete without a discussion of it.

Both sets of principles in Table 1 and Table 2 are most commonly applied to climate mitigation, which is about preventing future GHG emissions to limit further climate change. However, the three financial burden-sharing principles can also be applied to other forms of climate action, including climate adaptation and climate compensation, where the latter is commonly referred to as "loss and damage" (Page & Heyward, 2017, p. 356). Climate adaptation describes actions which adjust and prepare for the effects of climate change, whereas loss and damage refers to actions that are taken to alleviate suffering once climate-related impacts have occurred.

There is a retribution aspect to loss and damage, where financial payments are viewed as a form of righting past wrongs or making "victims of unwarranted climatic disruptions 'whole again'" in order to address the suffering brought about by climate-related impacts (Page & Heyward, 2017, p. 356). For this reason, applications of the three financial burden-sharing principles may need to take on different forms by taking different information into account. To simplify the research, all five principles have been applied in a mitigation sense only, since definitions of each principle were found to vary across different forms of climate action (Farber, 2007; Page, 2012).

The budget allocation principles in Table 2 are commonly used to allocate rights to emit GHGs within constrained global carbon budgets – often expressed in kilotons of carbon dioxide ($CO_2$) or carbon dioxide equivalent ($CO_2e$). Carbon budgets are a concept that has received substantial attention within the climate change literature (Lahn, 2020; Matthews et al., 2021; Pan et al., 2022). However, the units of global carbon budgets and countries' NDCs differ from the Paris Agreement's Article 2 targets, which are expressed in °C. This presents a discrepancy in metrics between countries' NDCs, global carbon budgets, and the Article 2 targets.

Warming rights – a new concept introduced in this thesis – represent the level of warming that countries can be allocated as part of globally agreed temperature change targets. An advantage of expressing warming rights in terms of temperature change is that it averts the issue of placing multiple climate forcers onto the same scale using emissions metrics, discussed in §2.4.1. It also places an assessment of countries' warming contributions into the same language as the Paris Agreement. Both warming rights and emissions rights are discussed within this thesis in relation to RQ3.

## §1.4 Methodology and theoretical approach

This research works within a pragmatist-positivist paradigm which is explained more fully in §3.2. Positivism is a philosophical school of thought which prioritises the acquisition of knowledge by empiricism – from observational data or through experience – and which uses experimental methods and hypothetico-deductive reasoning to reach generalisable natural or social laws (Crook & Garratt, 2005; Park et al., 2020). Positivism has underpinned much natural science research, having successfully guided the evolution of climate science for many years.

However, positivism has faced criticism for its rigid beliefs, especially when applied to the social sciences. Several of these beliefs would restrict the level of flexibility required to handle the value pluralism or range of possible solutions that the applied ethics aspect of the research and SEFS dashboard generate. For this reason, this thesis incorporates a pragmatist perspective to withhold some of positivism's more stringent beliefs.

Pragmatism is described as an approach for doing research, which allows for the use of multiple methods in so far as they are useful (Kaushik & Walsh, 2019; Voisard & Wallimann-Helmer, 2024). Pragmatism enabled the research to be progressed using positivist methods, yet not necessarily achieve what most positivist research sets out to accomplish in terms of working towards a single unified view, theory or generalisable law.

Pragmatism's perspectives on truth and sensemaking were particularly helpful for moderating a moral objectivism that could be taken towards the ethical aspects of the thesis, under a solely positivist worldview. Where a positivist might pursue a single moral truth to each RQ, a pragmatist would recognise the inherent indeterminacy of wicked challenges like climate change and acknowledge the presence of multiple, conflicting perspectives that different ethical solutions represent.

Pragmatism also allowed for explorations of ethical principles' multiple subjective meanings and possible links between principles and accounting frameworks, which positivism on its own would have been ill-equipped to support. This research project should therefore be viewed as an exploratory endeavour, where the resulting tool is intended to prompt informed debate amongst its target audiences rather than produce determinate answers.

Within this pragmatist-positivist framework, the research draws on three methodologies or disciplines to answer the RQs: simple climate models (SCMs), industrial ecology (IE) and applied ethics. SCMs are a well-developed approach for predicting and analysing how the global climate system may respond to perturbations, including rising concentrations of GHG emissions and other radiatively active species like aerosols and indirect short-lived climate forcers (SLCFs), which alter the climate by producing precursors of direct climate forcers (Buma et al., 2025; Szopa et al., 2021).

This research builds on the approach and data from the Callahan and Mankin (2022) study, which uses the Finite Amplitude Impulse Response (FaIR) model to run modified *leave-one-country-out* experiments in order to determine countries' contributions to historical global warming from two GHG species – $CO_2$ and methane ($CH_4$) – and one indirect short-lived climate forcer (SLCF) or precursor gas: nitrogen oxides (NOx) (C. J. Smith et al., 2018).

Ideally contributions to warming from nitrous oxide ($N_2O$) – the third most important GHG behind $CO_2$ and $CH_4$ – would have been included instead of NOx. However, only NOx data was available in the dataset used by Callahan and Mankin (2022). NOx is an indirect SLCF, which indirectly affects the climate by reacting with other radiatively active species like $CH_4$, tropospheric ozone ($O_3$) and nitrate aerosols (Szopa et al., 2021). NOx enhances the radiative forcing effect of $O_3$, reduces the forcing effect of nitrate aerosols and reduces the forcing effect of $CH_4$ by producing hydroxyl radicals which alter $CH_4$'s atmospheric lifetime (Szopa et al., 2021). The modified *leave-one-country-out* experiments are a positivist method which treats countries' GHG and precursor gas emissions (and associated warming contributions) as scientific facts.

Next, the field of IE, which is underpinned by a natural ecosystem metaphor of everything being interconnected, takes a systems view of industrial and human systems in its attempts to better manage environmental problems (Lifset & Graedel, 2002; Shah et al., 2024). Environmentally extended input-output analysis (EE-IOA) is an IE technique that draws on statistical information about material and resource flows and has been employed in this research to calculate countries' consumption-based emissions (Wiedmann, 2009b). Consumption-based emissions allocate responsibility for GHG emissions to consumers rather than producers, under the consumption-based accounting (CBA) framework, and offer an alternative perspective on responsibility to the conventional production-based accounting (PBA) approach. The EE-IOA method follows a series of matrix algebra operations in order to deduce countries' consumption-based emissions. These, like countries' warming contributions, are treated as scientific facts within the research, which conforms with the positivist worldview.

Finally, an applied ethics methodology, which makes use of principlism, is used to operationalise the five aforementioned ethical distributional principles within the SEFS dashboard. Principlism is a method of applied ethics which involves top-down moral and deductive reasoning (Voisard & Wallimann-Helmer, 2024). Principlism's use of deductive reasoning therefore has affinities with positivism, which employs hypothetico-deductive reasoning to reach generalisable laws. In this way, principlism enabled a coherence across the scientific and ethical aspects of this research. However, principlism, unlike positivism, proposes that moral solutions arrived at are continuously revisable. For this reason, while using principlism to apply the five ethical principles, the pragmatist approach enabled the suspension of the positivist belief that results deduced from applying any single principle represent a form of moral law or truth.

## §1.5 Research aims and hypothesis

This research project includes five research aims and a hypothesis which will now be described.

*Aim 1: Develop a dashboard-style tool to answer the three RQs*

This research seeks to understand country-level responsibility for addressing climate change by applying a range of regulative ethical principles within a dashboard-style tool. The first aim of this research project, then, is to develop a dashboard which can help answer the three RQs.

*Aim 2: Apply lower-order regulative principles to make CBDR-RC principle more useful*

The research aims to make the CBDR-RC principle more useful by way of applying five of the regulative principles presented in Table 1 and Table 2. By grounding these principles in relevant, factual information, the CBDR-RC principle in turn can be made useable.

*Aim 3: Investigate relationships between ethical principles and accounting frameworks*

This research aims to investigate relationships between different ethical principles and accounting frameworks which have, to date, been underexplored as options for applying ethical principles.

*Aim 4: Clarify relationships between principles and distributive climate justice questions*

This research aims to clarify the relationships between different regulative principles and questions of distributive justice, so as to avoid the conceptual confusion that has occurred in existing dashboard-style tools and practical ethical assessments.

*Aim 5: Incorporate a broader range of parameters and offering a more granular analysis*

This research seeks to improve upon the shortcomings of existing studies and dashboard-style tools by incorporating a broader range of scientific and accounting framework parameters, as well as enabling a more finely grained analysis of country-level responsibility for climate change.

*Hypothesis*

It is hypothesised that large historical polluters would receive the greatest shares of responsibility for raising climate finance under the Polluter Pays Principle. However, it will depend on whether only one or multiple climate forcers are considered, how these are combined and under which accounting framework emissions were assigned. It is anticipated that large exporting countries like China will have lower emissions balances and reduced responsibility under the CBA framework when compared with the PBA framework.

## §1.6 Significance of the research

Since the SEFS dashboard has been developed with specific target audiences in mind, the results of this research are of significance to communities which extend beyond the academic audience of this thesis. It is expected that the dashboard will be of interest to a wide range of actors, including international climate negotiators, policymakers and academics, as well as the general public. By enabling top-down assessments of countries' contributions to global warming and offering a means of investigating how countries' fair shares for addressing the issue can fall short in normatively relevant ways, a wider, more practical objective of the SEFS dashboard is that it can help inform debate amongst these actors.

The actors mentioned previously would also be interested in using the SEFS dashboard, which draws upon a range of complex datasets, scientific and ethical parameters, to test their intuitions of fairness about how country-level responsibility ought to be assigned. In this way, the dashboard enables a form of technology-assisted reflective equilibrium (RE). RE is a method within moral and political philosophy which begins with sets of principles and considered judgements or one's intuitions and opinions (Knight, 2023). RE involves principles and considered judgements being scrutinised and revised in a process of mutual adjustment, so principles and considered judgements can be brought into alignment (Knight, 2017). There are two types of RE: wide and narrow (Rawls, 1999). Wide reflective equilibrium (WRE) starts with as wide a range of principles as possible; whereas narrow reflective equilibrium (NRE) is a way of ordering an agent's preconceived views (Knight, 2017; Rawls, 1999).

The SEFS dashboard's applications of regulative ethical principles can be considered a form of technology-assisted WRE. For example, it could be argued that the Grandfathering and Equality-over-time principles sit at opposite ends of a notions of justice spectrum, where Grandfathering represents a more libertarian perspective, and Equal Per Capita Emissions approaches reflect an egalitarian perspective. By including principles with very different conceptions of justice, the SEFS dashboard affords climate negotiators and policymakers an opportunity to explore a wide ethical domain as they test their ethical intuitions. This can allow them to see whether resulting distributions of climate finance and warming rights align with what they originally believed would be fair. As part of WRE, the dashboard also enables an engagement with the factual implications of these action-guiding regulative principles.

Given that a critical review by Helms (2024) found few instances of WRE being explicitly applied within the literature, the SEFS dashboard can fill a gap by offering a climate change-focussed WRE. Through operationalising ethical distributional principles with real-world empirical datasets, the dashboard sheds new light on country-level responsibility, enabling its target audiences to test their intuitions of fairness and revise them as needed. The dashboard therefore fulfils a democratic need by letting a range of different actors explore concepts of justice and fairness through different prioritisations of parameters, as countries' contributions to the issue continue changing with time.

The absence of a mechanism for ethically evaluating countries' pledges as part of the Paris Agreement raises a need for independent tools which can scrutinise the moral adequacy of countries' progress on addressing climate change. Having tools for analysing countries' changing contributions to climate change and assessing the adequacy of their efforts to address it are relevant within this Paris Agreement era, where countries pledge their own contributions to the global effort.

Additionally, as the world continues warming due to climate change, and countries work to remain beneath the Article 2 targets, a further benefit of the dashboard is that countries' historical contributions to global warming are expressed as temperature change contributions. This enables the articulation of moral responsibility in terms of warming rights, the concept introduced earlier, which is a novel contribution to the international debate. By drawing on the results of an SCM, the dashboard's ability to offer an explicit warming-centric focus aligns with the Article 2 targets and averts issues that come with using emissions metrics (discussed in §2.4.1). This puts country-level contributions into the same language as globally agreed temperature targets, making it more straightforward to analyse the world's progress as a whole.

Finally, being able to understand how countries have contributed to climate change at different points in time can inform better understandings of what countries' responsibilities ought to be for addressing the issue today and in the future. By offering an accounting framework lens on responsibility, which has historically featured less prominently in international negotiating fora, allocations of responsibility in terms of both accounting frameworks and ethical principles can help broaden the international community's perspectives on this idea. In this way, the SEFS dashboard can help clarify and demonstrate how responsibility for climate change can fall in different ways, depending on which scientific, accounting framework and ethical parameters are prioritised.

## §1.7 Thesis structure

This thesis begins by introducing climate change as an ethical issue and highlighting the prominence of equity and responsibility as concepts within international negotiating fora and the climate ethics literature. The types of principles that feature in real-world debates and practical ethical assessments are highlighted to introduce the motivations for this research. The RQs are presented, followed by the overarching pragmatist-positivist framework which guides this interdisciplinary inquiry, along with the research aims. The significance of the research is highlighted before the structure of remaining thesis chapters is outlined.

Relevant background information literatures are presented and reviewed in Chapter 2. This includes a history of scientific evidence for climate change; a history of international diplomacy efforts; emissions metrics and SCMs; different ways of assigning GHG emissions to countries (accounting frameworks); and prominent climate ethics principles – five of which feature in the SEFS dashboard. Research gaps that this research fills, as well as its unique contributions, are also explained.

How the research has been carried out – its research design, including the overarching pragmatist-positivist approach, methodologies and methods that the research employs – are described in Chapter 3. This includes details of the datasets that have been used and the pre-processing steps which transformed data into useable formats, how countries' historical warming contributions and consumption-based emissions are calculated, and the steps taken to operationalise each of the five ethical distributional principles in the dashboard. The feedback obtained from dashboard demonstrations to several climate experts in 2023 is also explained.

Samples of results from the dashboard are presented, compared with findings from similar applied ethics studies and dashboard-style tools, and discussed in Chapter 4. Relevant moral ideas and modern ethical challenges, including the repugnant conclusion, are also examined.

The penultimate chapter of this thesis (Chapter 5) critically evaluates the research by reflecting on its approach, scope and design, as well as considering the relevance of the research and method-based reflections and technical issues.

Finally, the thesis concludes by Chapter 6 summarising the research topic and its importance, outlining the main contributions and practical and theoretical implications of this research, along with limitations of the study. Recommendations for future research are then given for expanding the dashboard and improving its level of usefulness to its target audiences.

## §1.8 Chapter summary

As we move into the second quarter of the 21st century, human-induced climate change continues apace, despite scientific understanding and awareness of the issue, and nearly half a century of international efforts to address it. Central to climate negotiations have been burden-sharing questions, where the ideas of equity and responsibility, and various understandings of these, have become points of contention between countries and stumbling blocks in trying to reach agreements. The same burden-sharing questions have been prominent throughout the history of the philosophical climate ethics literature, with climate ethicists often employing a range of ethical principles to answer these in the abstract. While much of the applied climate ethics literature has focussed on applying select groups of principles to answer burden-sharing questions, few tools have provided the ability to employ a breadth of ethical principles, scientific and accounting framework parameters, in ways that avoid conflating ethical domains.

This thesis describes the development and utilisation of a tool which applies several regulative principles with real-world data to obtain possible distributions of country-level efforts for addressing climate change. The research focusses at the international level and takes nation-states as its units of analysis. Drawing on SCM outputs and methods from IE and applied ethics, the research develops a novel dashboard tool – the SEFS dashboard – to enable a data-rich applied ethics. Through its combination of scientific and ethical parameters, the tool presents a proof-of-concept for how a technology-assisted form of WRE could be enabled. The dashboard offers a way for climate change negotiators and policymakers to test their ethical intuitions, while observing how responsibility for addressing climate change falls under different operationalisations of five empirically grounded ethical principles. Ultimately, this research project and dashboard are motivated by the aim to offer practical understandings of each principle by "integrating the relevant empirical work on the matter" (Gajevic Sayegh, 2018, p. 407). This is in order to support better informed discussions amongst the dashboard's target audiences of international climate negotiators and policymakers.

# Chapter 2 Literature Review

## §2.1 Chapter overview

Chapter 2 introduces background information and reviews relevant literatures to support an understanding of the Science and Ethics of Fair Shares (SEFS) dashboard and its features. The history of climate science (§2.2) and international diplomacy efforts to address climate change (§2.3) are detailed, followed by a review of the emissions metrics and simple climate model (SCM) literatures (§2.4). Next, different ways of allocating responsibility for climate change by way of accounting frameworks are discussed in §2.5.

The six prominent ethical distributional principles presented in Table 1 and Table 2, and the debates surrounding their definitions and applications within the climate ethics literature are discussed in §2.6. An exploration of these principles' multiple meanings was allowed for by the pragmatist-positivist approach which could acknowledge the value pluralism alluded to in §1.4. Despite not featuring the SEFS dashboard, the Subsistence Emissions Principle has been evaluated and discussed because of its prevalence within the climate ethics literature.

Existing relevant dashboard-style tools are evaluated and compared in §2.6.5. A conflation of ethical domains identified in these tools motivated the design of a climate justice typology (§2.7) which brings greater conceptual clarity to the research. Finally, the chapter concludes with §2.8 reiterating key gaps the literature review exposed and the unique contributions this research makes.

## §2.2 Scientific evidence for climate change

Climate change is driven by the release of anthropogenic greenhouse gas (GHG) emissions into the atmosphere. The three main GHGs are carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$), with $CO_2$ being the largest driver of global climate change to date. In a process known as radiative forcing, GHGs absorb longwave or infrared radiation – the light that is reflected from Earth back out into space (Forster et al., 2021a). This capturing of greater amounts of infrared radiation, which then gets converted into heat energy, disrupts the energy balance of the Earth by raising the global mean surface air temperature and, in turn, altering the climate in what has become known as the "greenhouse effect" (Forster et al., 2021a, p. 971).

While a naturally occurring greenhouse effect has made the Earth's average temperature 33°C warmer than it otherwise would have been during the pre-industrial period (circa 1750–1850), rapidly rising GHG concentrations since that time are changing the atmosphere's composition, leading to higher radiative forcing and an enhanced, anthropogenic greenhouse effect (Mitchell, 1989). Since 1850, atmospheric concentrations of $CO_2$, $CH_4$ and $N_2O$ have increased by 46%, 137% and 24% respectively and radiative forcing was 2.72Wm2 higher in 2019 than in 1750, predominantly due to these increased concentrations (Forster et al., 2021a, p. 926, 2024).

The rapidly rising concentrations of GHGs in the atmosphere are attributed to human activities, which GHG emissions are byproducts of. Land and use changes and the burning of fossil fuels account for the highest proportions of human-induced $CO_2$ emissions, while the extraction and use of fossil fuels are also significant sources of anthropogenic $CH_4$ and $N_2O$ emissions (Eyring et al., 2021, p. 3; Ganesan et al., 2019; R. B. Jackson et al., 2020; Saunois et al., 2020). Rice paddies, agriculture and fertilizer use account for substantial food production-based $CH_4$ and $N_2O$ emissions, with waste being another large source of $CH_4$ emissions (Griffis et al., 2017; Kirschke et al., 2013; Kroeze, 1994).

Global annual carbon emissions have risen rapidly in recent years and in 2023, the average human-induced warming for the year was assessed to be 1.31°C above pre-industrial levels (Forster et al., 2024; Friedlingstein et al., 2022). The rate at which GHGs from anthropogenic sources are being released into the atmosphere is triggering large scale climatic changes which are pushing human and non-human life into ranges outside those to which they have adapted. The long-lived nature of some GHGs (see §2.4) will ensure that such changes persist into the future, affecting both present people and future generations (IPCC, 2018a).

It should be noted that GHG emissions are not the only radiatively active species that have an effect on the global climate. Species with net cooling effects over relatively short-term, decadal timescales are known as aerosols and aerosol precursors, and are a type of short-lived climate forcer (SLCF) (Szopa et al., 2021). The recent cooling effect of aerosols is significant; it has been estimated that nearly a third of the effect of anthropogenic warming emissions has been offset by SLCF emissions (Persad & Caldeira, 2018).

Important aerosols and aerosol precursors include sulphate ($SO_4$), nitrate ($NO_3$), sulphur dioxide ($SO_2$), nitrogen oxides (NOx), organic carbon (OC) and ammonia ($NH_3$) (Buma et al., 2025). Many aerosol precursors – like $SO_2$ and NOx – are released alongside $CO_2$ when fossil fuels are burnt and have a detrimental effect on local air quality. Efforts to improve local air quality have resulted in developed countries' aerosol emissions reducing in recent years (Y. Zheng et al., 2020). This means that the regional distributions of aerosol emissions have shifted with time and could significantly influence the size of countries' relative contributions to global warming because of their strong short-term cooling effect (Wang et al., 2015). This research has only taken emissions of the two most dominant GHGs – $CO_2$ and $CH_4$ – and the aerosol precursor – NOx – into account, in order to limit the research's scope to a more manageable size. However, the research could be extended in the future to include the emissions of other GHGs, aerosols and aerosol precursors in calculations of countries' fair shares for addressing climate change. This is discussed further in §6.5.

## §2.2.1 History of climate science

Understanding how knowledge about climate change has evolved can help inform discussions about appropriate levels of moral responsibility or culpability that actors might have for addressing the issue, discussed further in §2.6.1.1. A brief history of the development of scientific evidence for climate change will now be outlined.

The history of scientists coming to understand the greenhouse effect dates back to at least the early $19^{th}$ century when French mathematician, Jean-Baptiste Joseph Fourier, began theorising about planetary temperature in the early 1820s (Archer & Pierrehumbert, 2011; Hulme, 2009). While Fourier did not make any quantitative contributions in this regard, by surmising about factors which affect the Earth's temperature his conceptual framework laid the foundations for latter quantifications by Claude-Servais-Mathias Pouillet and Svante Arrhenius (Archer & Pierrehumbert, 2011).

As part of his theorising, Fourier conducted experiments, although they may have only been thought experiments, using a heliothermometer – an insulated wooden box, containing a thermometer and with painted black insides and a glass lid (Archer & Pierrehumbert, 2011). The idea was to prevent cool air and warm air from mixing, in order to isolate the effect of trapping light energy in the box. The effect was observed by measuring the box's interior temperature. Fourier concluded that Earth's atmosphere worked in a similar way to this so-called "hotbox" (Archer & Pierrehumbert, 2011).

One of Fourier's misconceptions was the size of the role that the temperature of space played on the Earth's temperature. Fourier estimated that the temperature of space was roughly 40 times higher than it actually was. In 1838, French physicist, Claude-Servais-Mathias Pouillet corrected this error by obtaining a more accurate measure for the Solar Constant (Archer & Pierrehumbert, 2011; Kidwell, 1981). This eliminated the need to consider the temperature of space as playing a significant role in planetary temperature. Pouillet also hypothesised that water vapour and $CO_2$ might trap infrared radiation in the atmosphere, leading to a warming of the Earth and enabling its life supporting ability (Baum Sr., 2016).

Evidence for Pouillet's hypothesis was strengthened nearly two decades later by American scientist, Eunice Newton Foote, who demonstrated in 1856 that carbonic acid and water vapour would absorb solar radiation. Foote set up experiments with glass cylinders containing different compositions of these gases and noticed that when these were placed in the sun, the air temperature in the cylinders increased. This prompted Foote to conclude that: "An atmosphere of that gas would give our Earth a high temperature" (Foote, 1856).

Three years after Foote, Irish climate scientist, John Tyndall, similarly showed that $CO_2$ and water vapour could absorb long-wave infrared radiation (Tyndall, 1859, 1861). Tyndall also demonstrated that oxygen, nitrogen and hydrogen did not absorb infrared radiation and realised that water vapour was the most important GHG in the atmosphere and was largely responsible for the hot-box effect that Fourier had observed in the 1820s (Baum Sr., 2016).

Building on the work of Fourier, Pouillet and Tyndall, in 1896, and attempting to explain the relevance of high-latitude temperatures for ice ages and interglacial periods, Swedish scientist, Svante Arrhenius, quantified Tyndall's results when he developed an energy budget model to show the effect of atmospheric $CO_2$ (Fleming, 1998). The model used moonlight absorption data that had been collected by American astronomer and physicist, Samuel P. Langley over the period of a year and indicated that if atmospheric $CO_2$ concentrations increased or decreased, temperatures would follow suit (Crawford, 1997). While not driven specifically by concerns about growing $CO_2$ emissions and associated long-term climatic implications, the results of the model led Arrhenius to predict that a doubling of atmospheric $CO_2$, from the burning of fossil fuels alone, would result in the Earth's temperature increasing by 3–4°C over a 500 year period (Arrhenius, 1896; Crawford, 1997). Arrhenius was the first person to provide a model of the greenhouse effect and conclude that anthropogenic $CO_2$ emissions from industrial activity would lead to global warming (Crawford, 1997; Rodhe et al., 1997).

For much of the early 20th century, "Arrhenius's $CO_2$ theory of climate change . . . lay largely dormant" (Hulme, 2009, p. 49). It was not until the 1930s, when the theory attracted the attention of British mechanical engineer, Guy Stewart Callendar, who performed Arrhenius's calculations, with more recent information, to determine the net absorption effect of atmospheric $CO_2$. This can be considered the first endeavour to detect and attribute large-scale climatic changes to the anthropogenic GHG emissions (Hulme, 2009). Both Arrhenius's and Callendar's findings were contentious and contested in their time. It would take another two decades before Charles David Keeling's measurements of atmospheric $CO_2$, captured at Mauna Loa Observatory in Hawaii, would lead to what many consider the point of undisputed scientific consensus for climate change (Bodansky, 2001b). From 1960 onwards, the Keeling Curve showed that atmospheric $CO_2$ was undeniably rising (Keeling, 1960). This was the point at which there was strong observational evidence for increasing emissions of $CO_2$ that were human-induced (Hulme, 2009).

Since Keeling, scientists have continued working to understand the climate and how humans are altering it. There was a renewed interest in Arrhenius' late 19th century model in the 1970s, and in the 1960s and 1970s, climatologists Syukuro Manabe and Richard Wetherald built the first climate models to simulate and predict how the climate would respond to changing concentrations of different GHGs (Manabe & Wetherald, 1967, 1975). These models formed the basis for the development of future climate models – one of which has been used in this research and is described further in §3.5.

The work of climate scientists continued throughout the 1970s–1990s, with scientific consensus on the issue being "clearly expressed in the reports of the Intergovernmental Panel on Climate Change" (Oreskes, 2004, p. 1686). However, insidious forces were also at work during this time. Deception and disinformation tactics used by fossil fuel companies from the 1970s onwards actively thwarted efforts to address the issue by stimulating public uncertainty in the science and contesting the reliability of climate models (Supran et al., 2023; Supran & Oreskes, 2017). ExxonMobil employed scientists to carry out its own research and develop climate models. The results of which, in hindsight, proved accurate in their predictions and were in line with the projections of other independent climate modellers at the time. In other words, the 1970s–1980s were a time of contradictions and confusion for the general public, for while "academic and government scientists worked to communicate what they knew to the public, ExxonMobil worked to deny it" (Supran et al., 2023, p. 7).

## §2.3 International efforts to address climate change[1]

While the history of climate science extends back 200 years, the record of international diplomacy efforts to address climate change spans a much shorter time-period of just 45 years. The first World Climate Conference in 1979 marked a point at which global-level discussions of the issue began and prompted several other conferences in the mid to late 1980s (Gupta, 2010). However, it was not until 1988 that climate change was thrust into public consciousness by a number of notable events, including the testimonies of American climate scientist James Hansen (Hulme, 2009). Hansen presented evidence of a greenhouse effect at congressional hearings in the United States, despite his colleagues' reservations about Hansen's level of confidence giving the impression of certainty for there being a detectable greenhouse effect at this time (Kerr, 1989).

In the same year, the World Meteorological Association (WMA) and United Nations Environment Programme (UNEP) founded the Intergovernmental Panel on Climate Change (IPCC), with a mandate to complete comprehensive scientific assessments on the state of the climate for policymakers (Gupta,

[1] Thank you to Dr Peter Skilling and Dr Kennedy Graham for suggesting I include a section within my thesis about the political nature of international climate negotiations and the power dynamics at play.

2010). The IPCC's First Assessment Report (FAR) in 1990 reflected the more widespread view of Hansen's colleagues in one of its major conclusions that "the unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more" (IPCC, 1990, p. 6). The FAR also suggested that in a business-as-usual scenario – which assumed "few or no steps are taken to limit emissions", with continued clearance of tropical forests and fossil fuels underpinning the energy system – the global mean temperature would likely rise by 1°C above 1990 levels by 2025 (IPCC, 1990, p. 52). By 1990, the global mean surface air temperature was found to have increased by between 0.3–0.6°C over the previous 100 years.

Since the FAR, there have been five further IPCC Assessment Reports (and many more Special Reports, which focus on particular issues); three main international climate change agreements; and annual international climate negotiations, known as the Conference of the Parties (COP). These international agreements and COPs will be the focus of the following sections. Despite international diplomacy efforts, GHG emissions have continued to rise.

Bodansky (2016b) breaks the progression of the international climate change regime (and international climate negotiations) into three phases. The first phase runs from 1990–1995, during which time the 1992 United Nations Framework Convention on Climate Change (UNFCCC) was negotiated and entered into force. The second phase includes the period from 1995–2004, when the 1997 Kyoto Protocol was negotiated, and the third phase spans the years between 2005–2015. During this time, the Kyoto Protocol entered into force; the Kyoto Protocol's first commitment period took place; and there was growing support for a more global agreement which the 2009 Copenhagen Accord set the seed for, culminating in the Paris Agreement six years later.

The following sections discuss these three phases, as well as a fourth phase running between 2015–2024. Each section will focus on the phase's key agreements; their architecture and legal force (and how agreements compare in this regard across phases); as well as notable points of disagreement between countries within the negotiations. This discussion serves to highlight three main points: how the international climate change regime has evolved over the past thirty-five years; that negotiations are highly political; and that negotiations have always been about more than the climate. The negotiations themselves are arenas where countries' competing priorities and geopolitical interests clash amidst a backdrop of power asymmetries. Having an appreciation of the political dimension of climate negotiations is relevant to this research in the sense that the SEFS dashboard has been designed to support deliberation and debate in settings where international politics plays out.

Within the constraints of this research project, a comprehensive analysis of international climate negotiations is not possible. However, discussion in the following four sections will serve to highlight key components of the negotiations and points which are most relevant to the SEFS dashboard and research aims.

### §2.3.1 Phase 1: 1990–1995 – The United Nations Framework Convention on Climate Change (UNFCCC)

The FAR's publication in 1990 coincided with the commencement of negotiations for a framework convention on climate change. Two years later, at the Rio Declaration on Environment and Development conference, the UNFCCC was adopted with its overarching aim being to ensure "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC, 1992, Article 2).

As of today, the UNFCCC currently has nearly universal participation with 196 countries and the European Union (EU) as parties to it (Kuyper et al., 2018). However, the agreement does not make clear at what point dangerous anthropogenic interference (DAI) is. Scientists have pointed out that impacts and risks of climate change will fall unevenly across communities, who have varying abilities to adapt to the level of climatic change that a universally agreed DAI represents (IPCC, 2018a; Victor, 2011). However, the IPCC cannot offer any specific definition of DAI, because of the institution's mandate to "assess climate change risks in a way that *informs*, but, importantly, does not *prescribe* the government policies necessary to avoid DAI" (Mann, 2009, p. 4065). Therefore, defining a DAI threshold could not be left to scientists alone because of the economic, political and ethical issues it presents.

Another central aspect of the UNFCCC was its promotion of key principles. These include equity; the Common But Differentiated Responsibilities and Respective Capabilities (CBDR-RC) principle; special needs of developing countries; taking a precautionary approach, subject to cost-effectiveness principle; the right to sustainable development; and an open and international economic system. The former two principles are expressed in Article 3.1: "The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities" (UNFCCC, 1992, Article 3).

Both equity and the CBDR-RC principle have been widely referenced during change negotiations, in the international climate regime, international law literatures, and climate ethics literatures (Pauw et al., 2014; Rajamani, 2011; Stone, 2004). However, these principles have proven to be contentious for several reasons. First, the CBDR-RC principle in particular established the Annex I and non-Annex I Party dichotomy, where Annex I parties included developed countries and non-Annex I parties were developing countries. Initially, the principle recognised that developed countries had contributed the most towards causing climate change and had greatest financial capacities for responding to it (Bodansky, 1993).

This meant that "Developing countries were exempt from all of the UNFCCC's obligations except to file occasional reports on their emissions and activities" (Victor, 2011, p. 206). The same Annex I/non-Annex I Party distinction would later exempt developing countries from emission reduction targets under the Kyoto Protocol. This became a point of contention for the United States in particular, which made clear its discomfort with this approach (Victor, 2011). Second, there are various interpretations of the equity and CBDR-RC principles, which have shifted with time (Pickering et al., 2012). Developing countries drew on the CBDR-RC principle to argue that they should not have to commit to prescribed emissions reductions. The CBDR-RC principle has been described within the literature as being operationalised through the Annex I and Non-Annex I Party distinction (Depledge, 2022).

In terms of international law, the UNFCCC contains elements of both hard and soft law (Bodansky, 2001a). Elements that are characteristic of a hard law approach include forcing certain duties on states; making such duties enforceable through binding, dispute resolution; and inflicting sanctions on violators (Bodansky, 2001a). A soft law approach, in contrast, would be significantly more facilitative and focus on slowly building scientific and normative consensus; as well as promoting, rather than forcing, adherence (Bodansky, 2001a). International agreements focussed on addressing global issues have tended to take a soft law approach from their outset, followed by agreements which grow in strength and demands from an international law perspective.

The UNFCCC differs from this typical approach in that it contains a mixed architecture, with both top-down elements, which define "particular policies and measures that parties must undertake"(Bodansky, 2011, p. 37), and bottom-up elements, which give countries greater autonomy and flexibility. For instance, bottom-up components of the UNFCCC are contained in Article 4.1, which requires countries to report on their progress for addressing climate change but does not prescribe the format, nor how this should be done. Concurrently, Article 4.2 establishes a top-down, non-binding commitment for developed countries to reduce their emissions to 1990 levels by 2000. At this time, countries like the United States and United Kingdom were hesitant about agreeing to specific targets which would limit their GHG emissions under the UNFCCC. As a result, they negotiated to reduce the strength of such targets by watering down language within the UNFCCC text and making such targets non-binding (Bodansky, 1993). It is for this reason that the UNFCCC, while establishing an initial international framework for addressing climate change, has been criticised for its lack of "teeth" by environmental non-governmental organisations (NGOs), which have typically subscribed to a hard law approach (Bodansky, 2001a, p. 202).

However, the process of developing UNFCCC text was a highly political one. While there was broad consensus amongst the Organization for Economic Co-operation and Development (OECD) countries with regards to the need for an agreement, Bodansky (1993) describes main axis of negotiations as taking place predominantly between European countries, which pushed for stronger measures, and the United States which opposed them. Part of why the UNFCCC has very little teeth, as mentioned previously, was due to large players like the United States requesting that the 2000 commitment be watered down. Political tensions and differences of opinion were also evident between developed and developing countries at this time, who had very different perspectives on the issue. Developing countries saw climate change as more of a development, social and political issue (Gupta, 2010). Whereas countries with a more dominant voice in negotiations, like European countries and the United States, saw climate change as an environmental issue, as well as an “economic and technological challenge” (Gupta, 2010, p. 642). The influence of these large players in the early framings of climate change as more of an environmental issue is reflected in the way that countries’ delegations of negotiators were initially “mostly composed of environment and energy ministry officials” (Bodansky, 1993; Kuyper et al., 2018, p. 352; Schroeder et al., 2012). It was not until later that developing countries began also being represented by officials from their ministries of development or foreign affairs, who were better able to articulate the importance of viewing climate change as a development issue (Bodansky, 1993). The UNFCCC entered into force in 1994.

### §2.3.2 Phase 2: 1995–2004 – Negotiating the Kyoto Protocol

In the years following the UNFCCC’s entry into force, there was a keenness to develop an additional agreement, under the UNFCCC, which would place more stringent controls on GHG emissions. Between 1995 and 1997, a new climate agreement, which would include targets and timetables, was negotiated (Victor, 2011). The result was the Kyoto Protocol, adopted in 1997 at COP3 of the UNFCCC or the first Meeting of the Parties to the Kyoto Protocol (MOP). The Kyoto Protocol was considerably more strict than the UNFCCC and has been described as having a “top-down architecture”, where binding emission reduction targets were internationally negotiated for 37 industrialised countries and Economies in Transition (EIT), also known as Annex B Parties (Bodansky, 2011, p. 704; Grubb, 2004). Collectively, these countries were required to reduce their emissions from six GHGs – $CO_2$, $CH_4$, $N_2O$, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride ($SF_6$) – reported in the carbon dioxide equivalent ($CO_2e$) emissions metric, by 5.2% below 1990 levels over the first commitment period, spanning 2008-2012 (Grubb, 2004; Gupta, 2010). These six GHGs have come to be known as the “Kyoto GHGs” and are commonly included in practical climate ethics assessments discussed in §2.6.5 (Pan et al., 2015, p. 218). The EU negotiated an overall 8% reduction target, with individual country targets ranging from a 28% reduction for Luxembourg to a 27% increase for Portugal, in order to reflect individual country circumstances (Depledge, 2022; Grubb, 2004).

The rationale for only placing GHG emission reduction targets on industrialised and EIT countries was based on the idea that they bore greater levels of historical responsibility for causing climate change. This idea is reflected in the way that only the first portion of the UNFCCC's CBDR-RC principle, concerned with responsibility, appears in the Kyoto Protocol (Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1997). At this time developing countries had pushed hard for developed countries to take the lead on efforts to address climate change and proposed ways in which historical responsibility could be measured. For instance, the 1997 Brazilian Proposal offered an elaborate methodology for a burden-sharing scheme, which used the specific indicator of contributions towards global temperature rise as a determinant of historical responsibility (La Rovere et al., 2002). However, the Brazilian Proposal was not adopted by the Kyoto Protocol because developed countries felt the methodology was biased. Within the Kyoto Protocol, industrialised countries were expected to take the lead on efforts to address climate change, with the theoretical ethical literature at the time also reflecting this belief (Bodansky, 2001a; Shue, 1994).

However, the Annex I/non-Annex I divide proved unacceptable for some countries, most notably the United States, which refused to ratify the Kyoto Protocol in 2001, following a change of government. The new George W. Bush administration justified its position by arguing that the Kyoto Protocol "fails to establish a long-term goal based on science, poses serious and unnecessary risks to the U.S. and world economies, and is ineffective in addressing climate change because it excludes major parts of the world" (Danish, 2007, p. 11). This comment showed the United States' interests and view of climate action as coming into conflict with the country's economic prosperity. It also articulated the United States' perspective on the perceived unfairness with regards to the Annex I/non-Annex I Party divide. The United States' refusal to ratify the Kyoto Protocol created a crisis situation. This was because the conditions for the Kyoto Protocol to enter into force were that at least "55 countries ratify the protocol but also that Annex I Parties represent at least 55% of those countries' total carbon emissions in 1990" (Ott, 1998, p. 44). With the United States representing 35% of global emissions at this time, other countries had to be included in the Kyoto Protocol. The EU worked hard to get Russia and Japan to be part of the agreement in the United States' absence (Gupta, 2010).

While the Kyoto Protocol was more stringent than the UNFCCC in its top-down approach of prescribing binding emission reduction targets, states were afforded freedom and flexibility with respect to how they could achieve their emissions reductions. The Kyoto Protocol's three flexible mechanisms – emissions trading, the Clean Development Mechanism (CDM) and Joint Implementation (JI) – presented alternative options for states to reach their targets (Bodansky, 2001b). Emissions trading allowed two entities which had controls on their emissions to trade part of their emission allocations, while the CDM and JI were forms of "cross-border investments" between countries (Grubb, 2004, p. 153). The CDM enabled developed countries to purchase emissions reduction credits in developing countries by funding projects that would reduce emission sources or expand emission sinks in these countries. Whereas JI enabled the same, but between developed countries. The United States was an advocate of these mechanisms, which reflected its early preference for market-based solutions that placed a price on carbon.

### §2.3.3 Phase 3: 2005–2015 – The Kyoto Protocol's first commitment period and the Copenhagen Accord

In 2005, the Kyoto Protocol entered into force. Its first commitment period ran from 2008–2012, with a first phase taking place between 2005–2007. However, only a year into this first phase, the Canadian Government announced that the country was unlikely to meet its Kyoto Protocol target (Danish, 2007). It would later end up failing to do so and would withdraw from the Kyoto Protocol towards the end of its first commitment period in 2012 (Falkner, 2016). Of the 36 countries that remained part of the agreement, nine were found to have emitted higher levels of GHG emissions than their agreed emission reduction targets under the Kyoto Protocol (Shishlov et al., 2016). However, the overcompliance of EIT countries meant that: "In the end, the Annex I countries were able collectively to comply with the treaty's provisions" (Falkner, 2016, p. 1110; Shishlov et al., 2016).

The EIT countries' overcompliance came as a result of the economic disarray within these countries, following the Soviet Union's collapse (Shishlov et al., 2016). A consequence of these countries' lower economic activity, compared with a 1990 baseline, was less GHG pollution. As part of the JI mechanism, former Soviet countries were granted more Assigned Amount Units (AAUs) than they required and were able to sell their AAUs to other developed countries. As a means of meeting their Kyoto targets, Japan, EU-member countries and New Zealand purchased many of the AAUs, which were later found to be dubious and little more than "hot air" (den Elzen et al., 2010, p. 6615). For these reasons, the Kyoto Protocol likely had little discernible impact on the trajectory of the national emissions of Russia, Australia and Canada, as well as those countries which had purchased AAUs from EIT countries.

By the beginning of the Kyoto Protocol's second commitment period, only 15% of global GHG emissions were covered by the Kyoto Protocol (Falkner, 2016). The Kyoto Protocol had also suffered from several large polluters pulling out of it. Following the United States' refusal to ratify the treaty in 2001, Canada withdrew from the Kyoto Protocol in 2012. Australia, Japan and Russia later followed suit and withdrew from the Kyoto Protocol's commitment period (Danish, 2007). However, even prior to the Kyoto Protocol's first phase, questions were being raised about would happen beyond the Kyoto Protocol and whether a new agreement should replace it (Falkner, 2016).

In 2006, China overtook the United States at the world's largest emitter of $CO_2$ and there was growing acknowledgement that developing countries, many of whose emissions had drastically increased since the 1997 Kyoto Protocol, also need to reduce their emissions if the world was to successfully curb climate change (Falkner, 2016, p. 2). The Kyoto Protocol had faced criticism for not extending "commitments to developing countries, including major emitters such as China and India, even though the emissions from developing countries are expected to surpass those of industrialized countries in the next two decades" (Danish, 2006, p. 15). However, developing countries continued to align themselves with a particular interpretation of equity based upon historical responsibility, which placed the onus of climate action on developed countries, while rejecting any emissions reductions themselves (Grubb, 2011a). This proved too restrictive an interpretation for the United States, whose issue with this narrow perspective can be encapsulated by a quote from the United States' lead negotiator at the COP17 Durban conference, Todd Stern, who said: "If equity's in, we're out" (Pickering et al., 2012, p. 423).

Attempts by the international negotiating community to build consensus for a more global agreement, which broke down the differentiation between developed and developing countries to generate greater participation, were stymied by these varying interpretations of responsibility and equity. Yet the international community were determined to resolve these issues and significant expectations were placed on the Copenhagen conference (COP15) which, it was hoped, would result in a "successor treaty to the Kyoto Protocol" (Falkner, 2016, p. 1107).

The 2009 Copenhagen Accord marked a dramatic shift away from the top-down approach of the Kyoto Protocol with its prescribed emissions reduction targets for developing countries only. Instead, with its bottom-up "pledge and review" style, the Copenhagen Accord sought to get more countries onboard (Bodansky, 2011, p. 701). While relatively brief in length, the Copenhagen Accord sought to address key issues, which would be worked through during successive COPs and eventually lead to the Paris Agreement. Notable features of the Copenhagen Accord were its aim to develop a shared vision in order to quantify the UNFCCC's objective of preventing DAI, both developed and developing country mitigation, and financial assistance (Bodansky, 2011). The shared vision included the possibility of a 2°C temperature limit for the first time, which would later make its way into the Paris Agreement. The developing/developed country divide was beginning to be broken down with an expectation that both would contribute towards mitigation efforts, with slightly more stringent expectations placed on developed countries. Finally, a climate finance goal of US$100 billion per year by 2020 was agreed to by developed countries, which would involve them sending money to developing countries for both climate mitigation and adaptation.

In terms of politics at COP15, the axis of negotiations shifted away from primarily being between the EU and the United States to the United States and China, which had now passed the United States as the largest annual polluter (Bodansky, 2010). However, the negotiations stalled when the United States and China were not able to reach an agreement and efforts were also hampered by a small coalition of countries, led by Sudan, Venezuela and Bolivia, who objected to the way in which the Copenhagen Accord had been negotiated (Bodansky, 2010). A noticeable shift was in the way several large developing countries – Brazil, South Africa, India and China – who have become known as the BASIC bloc, pledged to slow their emissions growth (Victor, 2011, p. xxvi). Bodansky (2010) describes how the BASIC group of countries began to "break the so-called fire wall between developed and developing countries [when f]or the first time, the major developing countries agreed to reflect their national emissions reduction pledges in an international instrument" (p. 240). This presented a significant shift from previous negotiating positions, like the coalition of the Group of 77 developing countries and China (G77 + China), which worked hard to avoid any emissions reductions.

In the closing days of the conference, the heads of state of 28 parties eventually drafted the Copenhagen Accord text (Bodansky, 2010; Christoff, 2010). However, instead of the Copenhagen Accord being adopted as a COP decision, under the UNFCCC, which would have held more weight as a legal agreement, it became a non-binding political agreement, that countries agreed to "take note of" (Bodansky, 2010, p. 238; Christoff, 2010). As a result, many people felt disheartened in the wake of the Copenhagen conference which was widely regarded as a failure at the time (Falkner, 2016). Yet, in hindsight, the Copenhagen Accord planted the seed for the Paris Agreement in its shift away from the Kyoto Protocol's top-down structure (Seo, 2017). Instead of prescribing emissions reduction targets, the Copenhagen Accord began paving the way towards a more global, flexible agreement with bottom-up, voluntary contributions.

The recorded suggestion of a 2°C temperature target and attempts to resolve other longstanding issues, such as the developed/developing country divide, were notable breakthroughs of the Copenhagen conference. Although the Copenhagen Accord had no legal force, it received support in the form of high participation. By the start of April the following year, 120 countries had shown their support for the Copenhagen Accord by agreeing to it (Christoff, 2010). And 77 countries, which collectively represented over 80% of global GHG emissions, had submitted pledges to limit their national GHG emissions to the UNFCCC Secretariat (Bodansky, 2010; Christoff, 2010). The renewed support for a global climate change agreement speaks to a wider theme of international agreements, where stringency must sometimes be traded off or sacrificed in order to garner greater participation.

Several climate conferences took place between the Copenhagen Accord in 2009 and the Paris Agreement in 2015. Notable decision texts were the Cancún Agreements and Durban Platform for Enhanced Action, which worked to resolve the issues that had begun to be addressed by the Copenhagen Accord (Grubb, 2011b, 2011a). The Annex I/non-Annex I or developed/developing country divide remained present and contentious during these negotiations, and differentiation took on a new form when developing countries explicitly favoured an interpretation of equity, based upon historical responsibility, which made its way into a COP decision text for the first time despite "the strong objections by some developed countries" (Grubb, 2011a, p. 848). Yet, a positive diplomatic moment occurred in 2014, when the United States and China signed a bilateral agreement on climate change which "foreshadowed their latter pledges in the run-up to the Paris summit" (Falkner, 2016, p. 1114).

China's increased prevalence as a central player within the negotiations in the period between the Copenhagen and Paris conferences was reflective of its wider geopolitical rise. As an emerging global power, China began to reformulate its identity as a more cooperative player within climate negotiations by grasping opportunities that efforts to address climate change presented for its domestic economy (Viñuales et al., 2017). Within its 12th Five Year Plan, China included energy and climate intensity targets and began to invest heavily in the development of renewable energy technologies (Falkner, 2016). These investments would help China to build greater credibility within climate negotiations but also served the country's own economic and security interests. China's more positive attitude following the Copenhagen conference, including its maturing partnership with the United States, began bringing an end to the "'you go first' relationship between the world's two highest emitters" that had troubled past negotiations (Viñuales et al., 2017, pp. 4–5).

### §2.3.4 Phase 4: 2015–2024 – The Paris Agreement

Hailed a "landmark", a "historic climate agreement" and "the world's greatest diplomatic success", the Paris Agreement was signed by 196 parties (195 countries and the EU) in December 2015 and lauded for its high participation (Davenport, 2015; Harvey, 2015; Kinley, 2017; Seo, 2017; Warrick & Mooney, 2015). Like the Copenhagen Accord, the Paris Agreement marks a substantial departure from its predecessor agreement, the Kyoto Protocol. Notable differences include a shift in architecture away from the top-down nature of the Kyoto Protocol to a more hybrid approach of "pledge and review" (Jacquet & Jamieson, 2016, p. 643). The Paris Agreement has a hybrid structure in the sense that it contains both binding and non-binding provisions (Bodansky, 2016a).

Where before, under the Kyoto Protocol, countries emissions reductions were internationally negotiated, the Paris Agreement asks countries to volunteer their own contributions to the global effort, known as Nationally Determined Contributions (NDCs) (Falkner, 2016). Often expressed as emissions reductions beneath their emissions level in some baseline year (commonly 1990), NDCs take many different forms, which are not directly comparable and vary in their level of ambition (Seo, 2017). For instance, some countries' NDCs include the land use, land-use change, and forestry (LULUCF) sector, while others do not. There are also conditional and unconditional NDCs, where conditional NDCs are often contingent upon receiving funding from other countries. The nature of countries' varying NDCs has made it difficult to determine the global level of warming that will result if countries meet their NDCs. To address this issue, a range of assessments, including by Climate Action Tracker and the UNEP, have been carried out to better understand the global implications of countries' NDCs (Climate Action Tracker, 2023; UNEP, 2024).

Other notable features of the Paris Agreement are that all Parties are now expected to contribute towards global efforts to mitigate climate change. This signifies a lessening of the Annex I and non-Annex I Party divide. However, obligations on developed countries remain stronger than those on developing countries, indicated through language, specifically the use of the terms *shall* and *should*. For instance, "Whereas developed countries 'shall continue taking the lead by undertaking economy-wide absolute emission reduction targets,' developing countries 'should continue enhancing their mitigation efforts'" (Falkner, 2016, p. 1116).

The Paris Agreement also contains the first quantification of the UNFCCC's original DAI objective, within a legal climate agreement. Drawing on the two proposed temperature targets from the Copenhagen Accord, the Paris Agreement quantifies this objective from Article 2 of the UNFCCC as: "the increase in global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (Paris Agreement, 2015, Article 2).

It is worth noting that there was no scientific basis for these specific Article 2 targets (Victor, 2011). A 2°C limit was first proposed by American economist, William Nordhaus, in the late 1970s when he warned of the effect that continued economic growth could have on global $CO_2$ emissions and, in turn, the climatic conditions that humans are accustomed to (Nordhaus, 1977). Following the Paris Agreement, the IPCC made clear in its Special Report on the Global Warming of 1.5°C in 2018 that the human impacts associated with climate change are less at 1.5°C of warming than they are at 2°C of warming (IPCC, 2018b). In other words, climatic conditions remain closer to those that current life on Earth has adapted to when there is less warming. Therefore, the less warming the better for current species and ecosystems and the temperature targets represent socially constructed focal points that the world has agreed to rally around.

Perhaps one of the most creative features of the Paris Agreement is its transparency, review and ambition mechanisms that combine in what has become known as the Global Stocktake. Described as a "global governance innovation" the stocktake acts as a review and ambition mechanism by supporting greater transparency and trust between countries, while aiming to ratchet up countries' ambition over time in five-yearly cycles (Milkoreit & Haapala, 2019, p. 103). The Global Stocktake asks countries to put forward increasingly ambitious NDCs (Kuyper et al., 2018). However, the Paris Agreement's compliance mechanism is considerably weak and relies on "the soft power of reputation" by "naming and shaming" countries that do not meet the NDCs they have put forward (Jacquet & Jamieson, 2016, p. 645; Sachs, 2019, p. 876). Scholars like Sachs (2019) are sceptical about how successful such a compliance mechanism will be without harder forms of international law like sanctions, while others have expressed the need to get non-state actors on board (Jacquet & Jamieson, 2016).

In that vein, an evolving trend throughout the international climate regime has been the growing involvement non-state actors. The Paris Agreement has been said to have "ushered in a new era of multi-actor, multi-sector, and multilevel climate governance" by making space for non-state actors – businesses, NGOs and municipal governments – who have formed coalitions to advance climate action at these varying levels of governance (Kuyper et al., 2018, p. 363). Falkner (2016) draws attention to the important role that NGOs and environmental organisations can play in monitoring country-level efforts and providing analysis to support the "naming and shaming by civil society" (p. 1122). As well as the rising importance of non-state actors, the Paris Agreement's inclusion of provisions about adaptation and finance, alongside mitigation, marked a shift away from the sole focus on emissions reductions that was present within the UNFCCC and Kyoto Protocol agreements. The rise of non-state actors and broadening of the climate action agenda to include different forms of climate action represent shifts in the international climate regime.

Despite its many accolades, the Paris Agreement has not resolved all issues. Instead it left a number crucial details to another day, to be worked out by countries at future COPs (Falkner, 2016). These include its transparency, review and ambition mechanism; and new carbon market regulations under Article 6. While developing countries did manage to include provisions about adaptation and compensation for climate-related harms in Articles 7 and 8, the carefully constructed language within these provisions rendered them with no legal force, thereby exempting developed countries from bearing legal rights or liabilities in relation to climate damages (Falkner, 2016).

Since the Paris Agreement's adoption and entry into force, annual climate change negotiations have continued, with a large focus of the following three years (2016–2018) being on finalising the so-called Paris Rulebook (Rajamani & Bodansky, 2019). The Rulebook lays out details and guidelines for operationalising components Paris Agreement (Winkler & Depledge, 2018). While efforts to finalise the Rulebook concluded at COP26 in Glasgow, issues remain with regards to rules about carbon markets and emissions trading under Article 6 (Burelli et al., 2021).

In 2018, the first review phase of the Paris Agreement took place, as a predecessor to the more formalised Global Stocktake process, and in 2020, the Paris Agreement's implementation phase began. Towards the end of 2021, the first round of the Global Stocktake process commenced with countries required to put forward more ambitious NDCs, culminating in the conclusion of the first Global Stocktake process towards the end of 2023. Analysis of countries' refreshed NDCs suggest that these will not be on track to remain beneath the Paris Agreement Article 2 temperature targets (Maslin et al., 2023).

Notable occurrences during the past three years of international climate negotiations have been the establishment of the Global Methane Pledge at COP26; explicit mentions to "phase down" and "transition away from" fossil fuels within the COP26 and COP28 decision texts; the establishment of a Loss and Damage Fund, initiated through the Glasgow Dialogue; and the United States' formal withdrawal from and re-joining of the Paris Agreement under the respective Trump and Biden presidencies in late 2020 and early 2021 (Arora, 2024, p. 109; Depledge et al., 2022, p. 149; Friedman, 2020; Stracqualursi & Kann, 2021). These developments highlight the political nature of the negotiations, which show simultaneous progress on specific issues, and regressions on others, in the case of the United States' varying degrees of alignment with global agreements.

Politically, the axis of negotiating power and potential gridlock previously sat between the United States and the EU, followed by the United States and China. However, there are signs that it may now be beginning to fall between large emerging economies, like China and India, and coalitions of "Small island states [who] are losing their patience with big polluting nations" (Wilkinson et al., 2022, para. 1). The watering down of language in the final stages of negotiating the Glasgow Climate Pact in 2021 by India and China, who could not commit to phasing out fossil fuels, is indicative of large emerging economies' and small developing countries' interests becoming less aligned than they have been historically (Harvey et al., 2021; W. Morgan, 2021).

Time will tell whether the Paris Agreement's governance innovations, including its enhanced transparency framework, flexible review and compliance mechanisms will be successful in ratcheting up countries' levels of ambition over time. What is clear is that negotiations are not becoming any less political, as the effects of climate change grow more severe and demands to address the issue, by the most vulnerable countries, take on an increasingly heighted urgency. A Pacific-led resolution was brought before the International Court of Justice (ICJ) in 2022, asking for an advisory opinion on a country's climate obligations (Peel & Nay, 2023). This shows how countries are engaging international institutions outside the international climate regime to deal with issues like litigation and loss and damage that remain unresolved within the formal UNFCCC process in the eyes of those who stand to lose the most (Wilkinson et al., 2022).

# §2.4 Emissions metrics and Simple Climate Models (SCMs)

Part of what makes climate change such a difficult challenge to address, alluded to previously, is that GHGs are by-products of many processes which serve human needs. Fossil fuel extraction and use, food production and waste all release GHGs and underpin countries' economies (Danish, 2007). Through their ability to trap longwave radiation emitted by the Earth in a process known as radiative forcing, GHGs contribute to global warming (Cubasch et al., 2013). However, not all GHGs are equal in terms of the warming effect they generate. Different GHGs exhibit different properties and behaviours. The two most important properties of GHGs from a climatic standpoint are their atmospheric residence time and radiative efficiency – that is, how strongly a GHG absorbs the Earth's outgoing longwave radiation (Myhre et al., 2013). The radiative efficiency of a GHG is predominantly influenced by its abundance in the atmosphere (Pierrehumbert, 2014).

$CH_4$ is a short-lived climate pollutant (SLCP) or short-lived climate forcer (SLCF) because it breaks down due to natural processes after around 12 years (Forster et al., 2021b). It is much less abundant in the atmosphere than $CO_2$ as it exists on a parts per billion (ppb) basis. This gives $CH_4$ a much higher radiative efficiency than $CO_2$, which is present in the atmosphere on a parts per million (ppm) scale. Recent atmospheric concentration measurements of $CO_2$ and $CH_4$ are 421.5 ppm and 1930 ppb respectively (Forster et al., 2024).

However, it is the large quantities of $CO_2$ that we emit, combined with its long-lived nature, that makes it such an effective GHG. Once released, a proportion of $CO_2$ remains in the atmosphere for millennia and continues to have a warming effect throughout this time (Eby et al., 2009; Myhre et al., 2013; Pierrehumbert, 2014).

Several relatively recent studies have quantified national- and regional-level historical contributions to global warming (Allen, Shine, et al., 2018; Callahan & Mankin, 2022; Jones et al., 2023; Skeie et al., 2017). These studies apply two different methods. The first method utilises an emissions and climate metric to calculate warming contributions in a bottom-up fashion. The second method utilises an SCM in a top-down way by running *leave-one-country-out* simulations, which explore how the world would have warmed in the absence of each country's GHG emissions over different time-periods. The following two sections (§2.4.1 and §2.4.2) review the emissions metrics and SCM literatures to evaluate these approaches as a means of generating data for the SEFS dashboard.

### §2.4.1 Emissions metrics

Emissions metrics have been developed to translate the climatic effects of different GHGs into a common currency or scale. However, reducing very different GHGs down to one number in order to represent a country's climatic effect implies a trade-off, because it removes information about how GHGs vary with respect to each other, especially in reference to time.

Two frequently employed metrics are the Global Warming Potential (GWP) and $CO_2$e. GWP, most often applied over a 100-year timeframe as $GWP_{100}$, is described as "the time-integrated radiative forcing due to a pulse emission of a given gas, over some given time horizon relative to a pulse emission of carbon dioxide" (Shine et al., 2005, p. 281). $CO_2$e uses $GWP_{100}$ values to convert quantities of different GHGs so they can be expressed as if they have the same climatic effect as $CO_2$ over a 100-year time-period.

However, a significant limitation of converting $CH_4$ emissions into $CO_2$e by using $GWP_{100}$ values is that it can misrepresent the warming effect of short-lived emissions, like $CH_4$. $GWP_{100}$ is not sensitive enough to reflect how global surface temperature will vary in response to sources of $CH_4$ emissions. For instance, $GWP_{100}$ overemphasises the effect of sustained $CH_4$ emissions by a factor of 4–5, and underestimates the effect of new $CH_4$ emission sources during the following 20 years by a factor of 3–4 (Lynch et al., 2020).

Step-pulse metrics, like Global Warming Potential Star (GWP*) and the Combined Global Temperature Change Potential (CGTP), are a relatively recent innovation (Allen et al., 2016, 2016; Allen, Shine, et al., 2018). These have been designed to better capture the behaviour of short-lived GHGs with heighted near-term warming effects, which fade substantially after 20 years (Forster et al., 2021a; Lynch et al., 2020). Step-pulse metrics avert the issue that endpoint metrics like GWP face, by combining "a step change in SLCF emissions with a pulse emission of $CO_2$" (Collins et al., 2020, p. 1). It has been argued that step-pulse metrics are a more helpful way of relating emissions of SLCFs and long-lived GHGs to long-term temperature goals (Collins et al., 2020).

Metrics have been a controversial topic amongst climate scientists, since many metrics have faced criticism for the arbitrariness of their time horizons, misleading natures, prioritising only physical measures, and ambiguities in relation to temperature (Allen et al., 2016; Cain et al., 2019; Daniel et al., 2012; Manne & Richels, 2001; Shine, 2009; S. M. Smith et al., 2012). Such criticisms often relate to the priority that metric designers afford to different parts of the "cause-effect chain" (in Figure 2 below) when designing a metric, and can also partly be explained by the aspiration to put very different gases onto an equivalent scale, which enables room for "hidden value judgements" to arise (Daniel et al., 2012, p. 247).

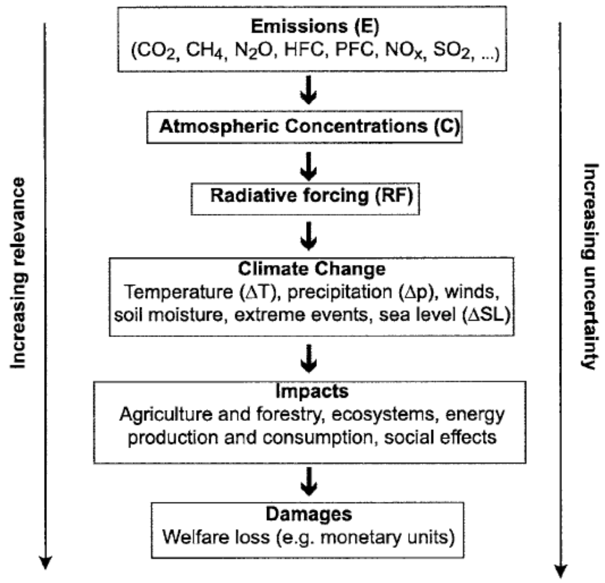


*Figure 2. Cause-effect chain (Fuglestvedt et al., 2003, p. 269)*

Decisions about how to weight different factors to take GHG properties and climate science knowledge into account will depend upon each metric designer's beliefs and priorities (Shine et al., 2007). For this reason, Pierrehumbert (2014) argues that the process of designing metrics is a normative one, with "deeply embedded value judgements" (p. 363). This goes some way to explain why metrics have been an ongoing source of debate amongst climate scientists.

Despite the criticisms that emissions metrics have faced, they have been used in recent studies along with climate metrics – which reflect characteristics of the Earth's temperature response – to calculate national contributions to climate change and changes in global average temperature (Allen, Shine, et al., 2018; Jones et al., 2023). The Jones et al. (2023) study uses what it refers to as "express formulas" to calculate the warming that results from cumulative emissions of $CO_2$ (p. 2). These formulas convert countries' $CO_2$, $CH_4$ and $N_2O$ emissions onto an equivalent scale by using the GWP* approach before calculating the associated global temperature increase by drawing on a climate metric: the transient climate response to cumulative emissions of carbon dioxide (TCRE). However, a limitation of such express formulas is that they represent "first-order approximations of a complex dynamic system", and do not capture interactions between radiatively active species (p. 20). Additionally, the TCRE assumes a linear relationship between a $CO_2$ emission and the long-term global temperature. It is not sophisticated enough to portray how temperature may vary through time and can be influenced by historical emissions and variable emission amounts. The Allen et al. (2018) study also uses the GWP* and TCRE metrics to calculate contributions to warming of several regions and large countries, like the United States, China and Russia. They conclude that this approach presents a more helpful way of putting countries' contributions in closer alignment with the long-term global temperature goals of the Paris Agreement.

SCMs, discussed next, offer an alternative approach to the express formulas of emissions and climate metrics for determining country-level contributions to global warming from individual GHGs. By including emissions from a wide range of radiatively active species, SCMs enable the climate system's complex dynamics to be incorporated.

## §2.4.2 Simple Climate Models (SCMs)

Climate scientists have developed many different types of models to investigate how the global climate system might respond to different factors, such as changing atmospheric concentrations of GHGs, volcanic forcing and cloud feedbacks. These include global circulation models (GCMs), energy balance models (EBMs), earth system models (ESMs) and SCMs. ESMs serve many functions, including providing the basis for projecting climatic changes over centuries in their "aim to simulate the evolution of the carbon sources and sinks on land and in the ocean, in addition to the physical components of the climate system" (Canadell et al., 2021, p. 730). Results of running ESMs, like the Coupled Model Intercomparison Project (CMIP), can be found throughout the IPCC's Sixth Assessment Report.

While ESMs are of a higher resolution than SCMs, they are more computationally expensive to run. SCMs or emulators, in contrast, present low-cost alternatives which "reproduce the behaviour of complex ESMs" to test how the climate system responds in much quicker and comparatively accurate ways (Arias et al., 2021, p. 49). As mentioned in §2.2.1, the first SCMs were developed in the 1960s, to emulate the Earth's climate system at the global level. Even these relatively crude, early models have been reasonable predictors of global temperature trends and climatic changes. The computational efficiency of emulators has enabled the extrapolation of insights from ESMs to explore larger sets of emissions scenarios (Arias et al., 2021).

Two modern, commonly referenced SCMs are the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) and the Finite Amplitude Impulse Response (FaIR) model. These present options for using calculating countries' historical contributions to global warming. In an approach known as *leave-one-country-out* experiments, SCMs can be run with and without countries' GHG emissions, under a range of scenarios to understand how specific GHGs from individual countries have warmed the planet. Initially, all country-level GHG emissions are included. Then, one at a time, each country's GHG emissions can be removed and the model run again, to understand how an absence of these emissions would have resulted in different amounts of warming at the global level. These differences in global warming can then be attributed to individual countries.

Unlike the MAGICC model, the FaIR model's software is open source. It can be downloaded from the online software storage and sharing platform, GitHub, and run in the free programming language, python. FaIR is the SCM that was used in this research. For a further discussion of how the FaIR model has been used, see §3.5.

An advantage of using outputs from SCMs like MAGICC and FaIR, as opposed to converting countries' GHG emissions into metric form, is that SCMs draw on historical GHG emissions and land use and land cover change (LULCC) datasets, as well as information about important forcing agents like volcanoes and aerosols to support calculations of contributions to warming at the country level. Recent studies, which consider quantities of countries' GHG emissions in isolation by using emissions metrics without taking these wider forcing agents into account, present comparatively cruder and less sophisticated approaches.

Two recent studies have used an SCM to quantify country-level information. The Skeie et al. (2017) study uses an SCM, built by Oslo's Center for International Climate and Environmental Research (CICERO), to calculate country- and regional-level warming contributions from $CO_2$, $CH_4$ and $N_2O$ emissions between 1850–2012. Results are reported for eight large countries, including the United States, Japan and India, as well as twelve groups of countries, world regions and sectors, including international shipping and aviation. The Callahan and Mankin (2022) study, in contrast, goes two steps further along the along the cause-effect chain in Figure 2 and uses the FaIR SCM to quantify national attribution for climate damages associated with 174 countries' combined $CO_2$, $CH_4$ and NOx emissions. The purpose of this study is to support loss and damage burden-sharing discussions, rather than responsibility for mitigating climate change. However, the Callahan and Mankin (2022) study's freely available code, use of the open source FaIR mode and country-level focus, meant it could be built upon to calculate countries' contributions to global warming, by focusing on the fourth step of the cause-effect chain.

By reporting warming contributions for a select few large countries and regions and combining warming contributions from multiple climate forcers in order to quantify and attribute climate damages, the two aforementioned studies are limited in that they do not offer a more granular focus of warming contributions on a per country, per gas basis. The SEFS dashboard's specific focus on country-level warming from individual climate forcers, in contrast, includes an extra layer of granularity and presents a novel contribution to the literature. The incorporation of warming from individual climate forcers can also support international policy debates concerned with how to treat short-lived and long-lived climate forcers, which is discussed in later sections (§4.4.1.1, §4.4.2.1 and §6.4) of this thesis.

### §2.4.3 Section summary

GHGs have very different properties and atmospheric residence times. The complexity of this information can be lost when GHGs are converted onto an equivalence scale by emissions metrics. While approaches which utilise emissions and climate metrics are one way of calculating countries' historical contributions to global warming that are found within the literature, SCMs offer several advantages above these more simplistic methods. First, SCMs are able to emulate the complexity of the climate system while generating faster results than more sophisticated climate models, without significantly compromising the accuracy of results. Second, in their emulation of the climate system, SCMs contain information about interactions between radiatively active species and climate forcing agents which are unaccounted for by emissions and climate metrics. Ultimately, SCMs are more sophisticated in their incorporation of global dynamics which capture the affects that radiatively active species have on one another, compared with metrics which consider countries' emissions in isolation. The FaIRv1.3 SCM is used within this research to calculate countries' historical warming contributions for the SEFS dashboard. The method is described in more detail in §3.5.

## §2.5 Accounting frameworks

Since the early 1990s, the world has become increasingly interconnected through global trade. In their analysis of trade between 113 countries, Peters et al. (2011) found that net international trade-related transfers of $CO_2$ emissions from developed to developing countries had grown fourfold between 1990–2008, from 0.4 Gt $CO_2$ to 1.6 Gt $CO_2$. This increase coincided with the trends of developed countries' $CO_2$ emissions reaching more steady levels and developing countries' $CO_2$ emissions continuing to grow. It has been suggested that the slowing of developed countries emissions was, at least in part, due to increasing imports from developing countries, known as "outsourcing" of emissions (Eckersley, 2010, p. 371). Consequently, questions such as *whose emissions are whose?* and "who is responsible for emissions?" have been raised (Afionis et al., 2017; Davis & Caldeira, 2010, p. 5687).

Accounting frameworks – which assign GHG emissions to countries in different ways – can be one way of allocating responsibility for climate change and offer varied perspectives on questions about where responsibility for GHG emissions ought to lie. Accounting frameworks have been debated theoretically, attracting much attention within scholarly and policymaking circles (Afionis & Sakai, 2022). However, they have received less attention within international negotiating fora.

Targeting specific points along the cause-effect chain when designing metrics – discussed previously in §2.4.1 – bears a resemblance to how responsibility for GHG emissions can be assigned at various positions along the value chain under different accounting frameworks (Tukker, Pollitt, et al., 2020). The green *accounting perspective* row of Figure 3 below shows four methods of accounting for GHG emissions and the value chain position that they relate to.

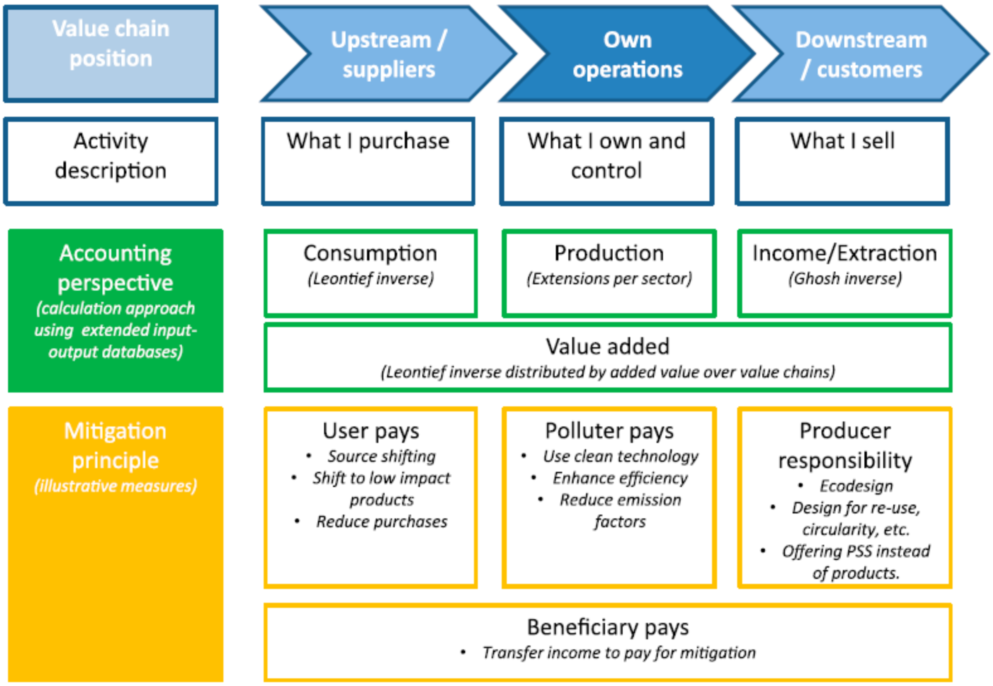


*Figure 3. Perspectives on carbon accounting and related mitigation principles (Tukker, Pollitt, et al., 2020, p. S8)*

All accounting perspectives involve implicit assumptions about where responsibility for GHG emissions ought to lie. Table 3 below outlines four of these accounting frameworks and the implicit assumptions or value judgements about responsibility that underpin them.

| Accounting framework | Implicit assumption about responsibility |
|---|---|
| Production-based | The producer releases the emissions, therefore they must take responsibility for them |
| Consumption-based | The consumer drives demand for a good or service, therefore they must take responsibility for the emissions that were associated with this |

| Accounting framework | Implicit assumption about responsibility |
|---|---|
| Income/extraction-based | The extractor enabled fossil fuels to enter the market, therefore they must take responsibility for the emissions that occur downstream as a result of this |
| Value-added | The actors who have added the greatest value per step in the value chain must bear the greatest responsibility |

*Table 3. Accounting frameworks and their implicit beliefs*

Viewing countries' responsibilities under the production-based accounting (PBA) and consumption-based accounting (CBA) perspectives in the SEFS dashboard can encourage more nuanced conversations about country responsibility for emissions and effort-sharing of climate action. The income/extraction-based and value-added accounting frameworks have not been included in the SEFS dashboard because substantially more work would have been required to calculate income-based emissions using the Ghosh model, as discussed in §5.4.2. The remainder of this section will focus on discussing the two most common methods of accounting for GHG emissions: PBA and CBA.

## §2.5.1 Production- and consumption-based accounting

PBA is the conventional "territorial" approach of allocating responsibility for GHG emissions, where responsibility for GHG pollution is assumed by the country with sovereignty over the land above which the GHGs were physically released (Steininger et al., 2018, p. 226). For instance, the PBA method of accounting underlies most conventional GHG emissions datasets, such as the UNFCCC dataset of countries' GHG inventories (Davis & Caldeira, 2010). As part of their commitment to the UNFCCC process, countries apply the PBA framework when they detail their annual GHG emissions in national GHG inventories, following IPCC 1996 or 2006 guidelines (Yona et al., 2020).

However, as the world has become more globalised since 1990, with more goods being traded between nations, inadequacies of the PBA method have been identified (Lenzen et al., 2012; Peters et al., 2011; Tukker, Pollitt, et al., 2020; Tukker, Wood, et al., 2020). Most notably, the PBA is limited by its supply-side focus since it overlooks the migration of goods and services along value chains, through to their points of final consumption.

The CBA approach offers a different perspective by calculating countries' carbon footprints through identifying those emissions "embodied in trade" (Oliveira, 2020, p. 412; Tukker, Pollitt, et al., 2020, p. S2). The CBA method challenges the PBA perspective and instead places the onus on final consumers. The underlying belief of CBA is that responsibility for GHG emissions should lie with the end-consumer, since they are the one who drives demand for a good or service (Oliveira, 2020).

Country-level warming contributions and GHG emissions under both the PBA and CBA frameworks are included in the SEFS dashboard to provide alternative perspectives for how warming could be allocated to countries. Despite the CBA approach not yet gaining significant traction within international climate negotiating fora, it remains a useful perspective to offer to policymakers and international climate change negotiators (Afionis et al., 2017). The links between trade and the potential for climate mitigation policies are becoming of increasing importance today as another means of applying pressure in an uncoordinated global regime, where the private sector also holds sway. For instance, the EU has begun implementing its Carbon Border Adjustment Mechanism (CBAM) to address the carbon intensity of imports.

The rationale for such measures is that, with greater trade occurring between nations, there is compelling evidence that GHG emissions are being outsourced or "'offshored' to other countries" (Duus-Otterström & Hjorthen, 2018, p. 868; Tukker, Wood, et al., 2020). Emissions offshoring, also known as weak leakage, "represents a type of carbon movement out of developed countries that cannot be directly attributable to new climate policies" (Eckersley, 2010, p. 371). Both weak and strong leakage will be discussed next in §2.5.2.

## §2.5.2 Emissions leakage

Leakage is the phenomenon known as offshoring of emissions. It describes the way in which reduced emissions in one jurisdiction can be offset by increased emissions in another. Since climate change is a global issue, leakage matters because if emissions are simply released elsewhere, instead of reduced overall, then the world will not be taking sufficient action to mitigate climate change.

There are two types of leakage: strong and weak (these are also sometimes characterised as direct and indirect). Strong leakage is driven by the presence of a climate policy or regulation in one jurisdiction and the absence of that policy or regulation in the other (P. Yu et al., 2021). Weak leakage, on the other hand, is a by-product of other economic conditions and general trends, such as "industry relocation to the Global South to take advantage of a range of lower factor costs (labour, environmental regulation, energy, and others)" (Eckersley, 2010, p. 371). The key distinction to make is that weak leakage is not "directly attributable to new climate policies", whereas strong leakage is (Eckersley, 2010, p. 371).

Weak leakage is evident in a study by Davis and Caldeira (2010), where 23% of global $CO_2$ emissions were found to have been traded internationally in 2004. Most of these emissions were exported from China and other emerging markets to consumers in developed countries. Figure 4, from the study, shows the interregional fluxes of emissions embodied in trade from dominant exporting countries (blue) to dominant importing countries (red) in 2004.

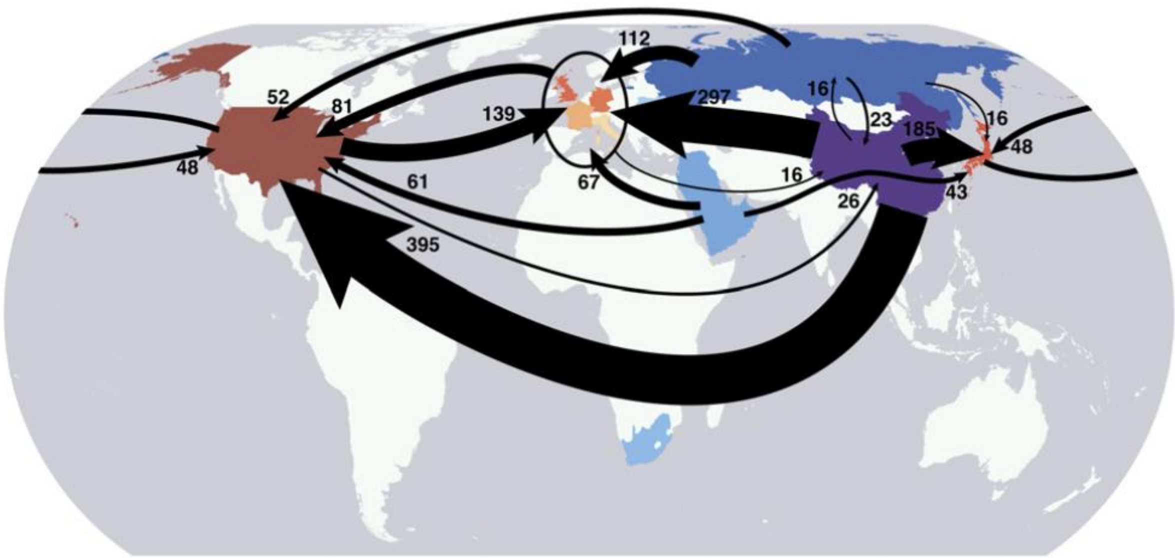


*Figure 4. Largest interregional fluxes of emissions embodied in trade (Mt $CO_2$ $y^{-1}$) (Davis & Caldeira, 2010, p. 5688)*

This trend of emissions being embodied in the exports of developing countries, to then be imported and consumed by people in developed countries, conforms with findings by Steininger et al. (2018) which "reveal that the emissions needed to sustain Austria's consumption are about 50% higher than those reported by the conventional production based accounting system" (p. 239). By carrying out input-output analysis (IOA) on a range of multi-regional input-output (MRIO) datasets, it was estimated that 34% of Austria's consumption-based emissions occurred outside the EU's region in 2011 – mainly in China, Russia and the United States (Steininger et al., 2018). Similarly, Wiedmann et al. (2010) estimated substantial growth in the United Kingdom's consumption-based $CO_2$ emissions in the ten years between 1992 and 2002. Whereas under the conventional PBA approach, the United Kingdom appears to have reduced its net GHG emissions (expressed in $CO_2e$) in 2020 to 51% below 1990 levels (Evans, 2021a).

While there is ample evidence for the occurrence of weak leakage, it has been more difficult to find evidence for strong leakage (Davis & Caldeira, 2010; Peters & Hertwich, 2008). Several studies find no sign that strong leakage has taken place yet (Dechezleprêtre et al., 2022; Franzen & Mader, 2018). However, there is concern about the potential for strong leakage to happen in the future as countries strengthen economic policy instruments and environmental regulations to achieve climate goals (Jakob, 2021). For instance, rising emissions prices, whether by emissions trading schemes (ETSs) or carbon taxes, pose a risk that certain industries may move to locations where production costs are lower (Borghesi et al., 2020; Koch & Mama, 2019). Until now, the price of emissions under these instruments has likely been too low to drive this change (Antoci et al., 2021).

Not only can leakage undermine the effectiveness of local climate policies and global mitigation efforts, but it also has wider ethical ramifications, especially concerning the distribution of perceived responsibility for causing climate change (Cosbey et al., 2019). If the PBA framework is the only lens applied, leakage will impose greater climate action responsibilities on those countries to whom emissions are outsourced. Therefore, the CBA perspective is an important lens as it corrects for emissions leakage by considering the role of final consumers.

### §2.5.3 Accounting frameworks and responsibility for emissions

While the CBA approach is compelling, some would not advocate that all responsibility for GHG emissions be absolved from producers and pushed onto final consumers. Duus-Otterström and Hjorthen (2018) find agreement with Roser and Tomlinson (2014) when they conclude that "consumers and producers are jointly causally responsible for emissions that occur" (p. 873). Jakob et al. (2021) provide a practical application of this point by proposing an Economic Benefit Shared Responsibility (EBSR) scheme: a hybrid approach between PBA and CBA for attributing trade-related GHG emissions. They argue that this approach overcomes the limitations of PBA and CBA by recognising benefits that accrue to both producers and consumers throughout the value chain. A conceptualisation of this approach from Jakob et al. (2021) is shown in Figure 5 below.

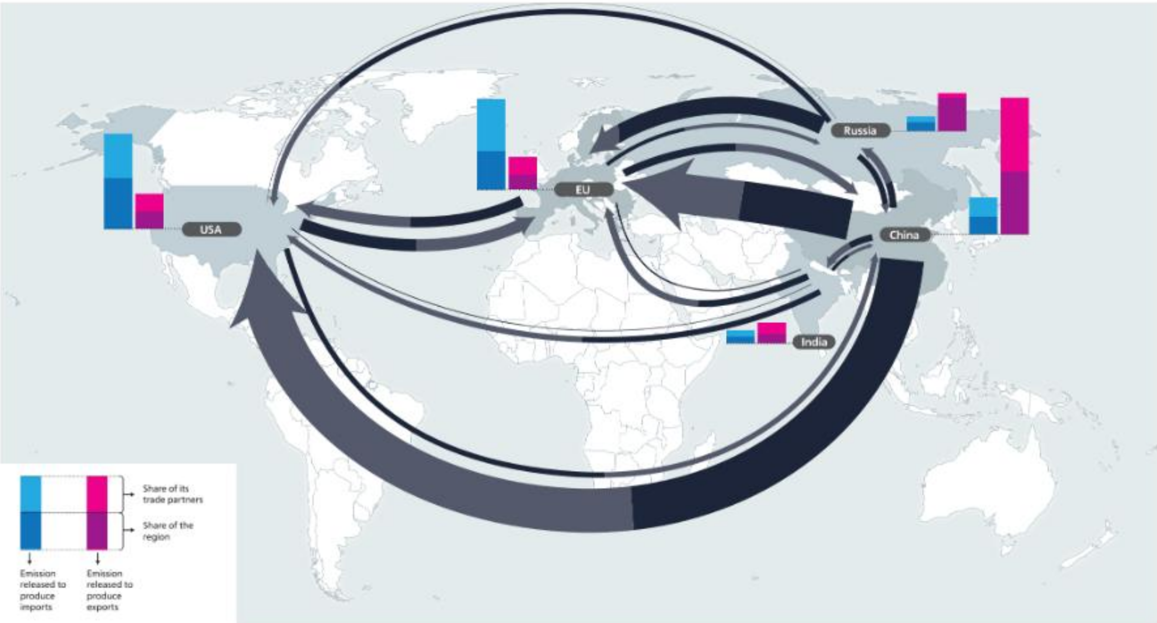


*Figure 5. Responsibility for trade-related GHG emissions under the EBSR scheme (Jakob et al., 2021, p. 4)*

In a similar vein, Oliveira (2020) challenges the producer-consumer dichotomy and argues for justice parameters being included in the development of footprinting methods. She believes that such an approach will generate fairer and more meaningful results, which move away from assigning responsibility for GHG emissions to a single agent.

Rather than recognising a joint producer-consumer responsibility, other studies acknowledge a difference in how emissions ought to be accounted for by selecting different accounting frameworks for different time-periods (Hickel, 2020; Matthews, 2016). Hickel (2020) uses production-based GHG emissions data between 1850–1969 and consumption-based data from 1970–2015. The choice to use consumption-based data for the most recent time-period shows a preference for an accounting lens which recognises a more globalised world.

Combinations of multiple accounting frameworks and ethical principles are considered in a further two studies (Pan et al., 2022; Steininger et al., 2016). The Steininger et al. (2016) study compares countries' Equal Per Capita Emissions under four different accounting lenses, while the Pan et al. (2022) calculates countries' shares of national emissions budgets based an application of the Equal Cumulative Per Capita Emissions (ECPCE) Principle, using both consumption-based and production-based emissions. Both of these studies consider a single ethical principle and more than one accounting framework to highlight that people have varying views about how responsibility for emissions ought to be assigned to countries, and the implications that different accounting frameworks have for countries. However, where multiple GHGs are included, these are combined using the $CO_2e$ metric rather than offering the opportunity to isolate the effect of individual GHGs.

While the PBA framework has become the conventional way that countries report their GHG emissions under the UNFCCC, this does not mean it is the right, nor most appropriate framework to use. Nor does it provide the clearest picture of a country's true contributions to global warming and level of responsibility for climate change, especially as the world has become more interconnected through global trade. The design choices and prioritisation of each accounting framework and the way in which it imposes responsibility can result in countries inadvertently becoming winners or losers in a responsibility-sense.

For instance, the thirteen members of the Organization of the Petroleum Exporting Countries (OPEC) will not have emissions falling on their balance sheet under either the production- or consumption-based frameworks, despite collectively supplying nearly 38% of the world's crude oil in 2021 (OPEC, 2021). There is something ethically contestable about Saudi Arabia producing nearly 10 million barrels of oil a day in 2021, yet not being accountable for the downstream emissions that this action enables (OPEC, 2021). This is where additional accounting perspectives, such as the income- or extraction-based approach (included in Figure 3) can offer alternative, beneficial lenses for designing climate policies, as well as allocating responsibilities (Davis et al., 2011; Liang et al., 2017).

Additionally, Liang et al. (2017) points out the way countries' emissions profiles can vary substantially under different accounting frameworks. For instance, New Zealand is often described as having a unique emissions profile for a developed nation, owing to a high proportion of $CH_4$ and $N_2O$ emissions from its large agricultural sector and a relatively lower share of $CO_2$ emissions due to its high supply of renewable electricity (Ministry for the Environment, 2022). Yet many of the products associated with New Zealand's $CH_4$ and $N_2O$ emissions are supplied to overseas consumers. 94% of New Zealand's sheep meat and 87% of its beef meat are exported to other countries, with China being the largest importer of these products (Beef + Lamb New Zealand, 2024; Hancock, 2021). This raises the question of whether the $CH_4$ and $N_2O$ emissions associated with the production of New Zealand's meat and dairy ought to be relocated onto the balance sheet of consumer countries like China, the United Kingdom and the United States.

Chandrakumar et al. (2020) studied how New Zealand's production- and consumption-based accounts compared for the year 2012. They found New Zealand's production-based emissions were 20Mt $CO_2e$ higher than its consumption-based emissions – a 27% difference. This means New Zealand is a net exporter of emissions and consequently carries a higher responsibility for emissions under the conventional PBA framework, as opposed to the CBA.

## §2.5.4 Emissions intensities of products

Another point to consider when looking at a global emission reduction strategy is the emission intensity of the same products in different locations. New Zealand accounted for just 0.2% of the world's total aluminium supply in 2019 (Hasanbeigi et al., 2022). However, it is one of the cleanest producers of this product because the Tiwai Point smelter is powered by a large nearby source of renewable hydroelectricity (Reeve et al., 2019). Similarly, New Zealand farmers are regarded as some of the most efficient agricultural producers in the world (Saunders & Barber, 2007). This is in large part due to New Zealand's temperate climate providing favourable conditions for grass growth. Rather than receiving emission-intensive feeds, livestock are predominantly pasture-fed and can live outdoors year-round instead of in barns (Flysjö et al., 2011; Ilyas et al., 2019; O'Brien et al., 2012).

Assuming demand for aluminium, meat and dairy products remains constant or grows into the future, there is a risk that emissions pricing measures could force these local industries to become less competitive in the global market. This could induce strong leakage where existing or new competitors, who are less energy efficient, grow their market share, resulting in increased emissions overall. The idea of needing to consider variable emissions intensities between countries is summarised by Peters and Hertwich (2008) who say: "the challenge for policy is to ensure that countries that specialize in pollution-intensive exports do so with clean technology, rather than moving production elsewhere (assuming production can be relocated)" (p. 1405).

This section (§2.5.4) and the previous three (§2.5.1–§2.5.3) have built the case for including multiple accounting lenses on responsibility within the SEFS dashboard, given the globalised nature of the world's economy, evidence for weak emissions leakage, and the potential for strong leakage. The next section provides information about how consumption-based emissions can be calculated.

## §2.5.5 Multi-regional input-output (MRIO) tables for calculating consumption-based emissions

While existing data sources like the Global Carbon Project (GCP) contain pre-calculated, country-level consumption-based emissions for 119 countries over the 1990–2022 time-period, they are limited in that they only contain information about countries' $CO_2$ emissions. A review of the accounting frameworks literature identified studies which use MRIO tables to calculate country-level consumption-based emissions (Steininger et al., 2018; Wiedmann et al., 2010). The MRIO table approach was investigated further, and it was found that MRIO tables offer a way to calculate consumption-based emissions, on a per gas basis, where emissions from individual GHGs can be isolated.

Countries' consumption-based emissions can be calculated using a technique from industrial ecology (IE) called environmentally extended input-output analysis (EE-IOA). This technique builds on the simpler input-output analysis (IOA) method – discussed in more detail in §3.6.2 – by using environmental-related information to extend IOA to environmental problems (Wiedmann, 2009a). EE-IOA can be applied to environmentally extended multi-regional input-output (MRIO) tables or global multi-regional input-output (GMRIO) tables, by performing a series of matrix algebra operations on these tables (Kitzes, 2013).

The terms MRIO and GMRIO are often used interchangeably within the IE literature and refer to large databases, compiled from countries' import and export information, and other trade-related data (Kitzes, 2013; Tukker, Wood, et al., 2020). Environmentally extended MRIO tables include satellite accounts, which contain information about environmental and social resources associated with the production of goods and services (Lenzen et al., 2012). It is these satellite accounts that enable the EE-IOA method to be carried out.

MRIO tables began being developed in the late 1990s. By the early 2010s, advancements in computing capabilities enabled the development of more comprehensive MRIO tables (Wiedmann, 2009a). With increasing availability of these tables and improved computing power, it has become possible to apply the EE-IOA method to these tables. Table 4 below summarises and compares the features of six GMRIO databases which have been developed by researchers at universities and international organisations.

| Database | Full Eora | Eora-26 | Global Trade Analysis Project (GTAP) | OECD Inter-Country Input-Output (ICIO) Tables | EXIOBASE | World Input-Output Database (WIOD) |
|---|---|---|---|---|---|---|
| **Developed by** | Researchers at the University of Sydney and University of Ballarat<br>Now owned and maintained by KGM & Associates Pty. Ltd. | Researchers at the University of Sydney and University of Ballarat<br>Now owned and maintained by KGM & Associates Pty. Ltd. | Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University<br>GTAP Consortium | The Organisation for Economic Cooperation and Development | Norwegian University of Science and Technology (NTNU), Netherlands Organization for Applied Scientific Research (TNO), The Sustainable Europe Research Institute (SERI), Universiteit Leiden / The Institute of Environmental Science (CML), Vienna University of Economics and Business / Institute for Ecological Economics (WU) 2.-0 LCA Consultants | Developed by 12 European research institutes, headed by the University of Groningen in the Netherlands<br>Was financially supported by the European Commission, Research Directorate and the Dutch Science Foundation |
| **Country coverage** | 189 + Rest of the World | 189 + Rest of the World | 160 | 76 + Rest of the World | 44 + 5 Rest of the World regions | 43 + Rest of the World |
| **Sector coverage** | 15,909 | 26 | 65 | 45 | 200 products<br>163 industries | 56 |
| **Time series** | 1990–2017 (academic license)<br>1990–2022 (commercial license) | 1990–2017 (academic license)<br>1990–2022 (commercial license) | 5 reference years | 1995–2020 | 1995–2011 | 2000–2014 |
| **Literature** | Lenzen et al. (2012)<br>Lenzen et al. (2013) | Lenzen et al. (2012)<br>Lenzen et al. (2013) | Aguiar et al. (2016) | Yamano & Ahmad (2006) | Tukker et al. (2009)<br>Tukker et al. (2013)<br>Wood et al. (2015) | Dietzenbacher et al. (2013)<br>Timmer et al. (2015) |
| **Studies that use database to calculate consumption-based emissions** | Chandrakumar et al. (2020) | Steininger et al. (2016)<br>Pan et al. (2022) | Peters & Hertwich (2008)<br>Hertwich & Peters (2009)<br>Wilting & Vringer (2009)<br>Davis & Caldeira (2010)<br>Peters et al. (2011a)<br>Steininger et al. (2018) | Ahmad & Wyckoff (2003)<br>Wiebe et al. (2012a)<br>Wiebe et al. (2012b) | Steininger et al. (2018) | Chen et al. (2019) |
| **Link for further information** | https://worldmrio.com/ | https://worldmrio.com/ | www.gtap.org/databases/v11/ | http://oe.cd/icio | https://www.exiobase.eu/index.php | www.wiod.org |

*Table 4. Review of the main GMRIO databases, adapted from Tukker and Dietzenbacher (2013, p. 12)*

These different GMRIO databases have varying country and sectoral coverage, cover different time-periods and aggregate data in different ways. Many use data from countries' National Statistics Offices (NSOs) which adhere to reporting standards, such as the United Nations Systems of National Accounts (UNSNAs). In fact, the IOA method prompted development of the UNSNAs – an internationally agreed set of standards which countries follow to compile their measures of national economic activity (ten Raa, 2017).

Both the Global Trade Analysis Project (GTAP) and EXIOBASE databases are heavily focussed on the EU economies and aggregate sectors from the Rest of the World (RoW). In contrast, the Full Eora global supply chain database is the most comprehensive GMRIO database with 189 countries and nearly 16,000 sectors (Lenzen et al., 2012, 2013). The Eora-26 database – a simplified 26-sector version of the Full Eora database – was chosen above other GMRIO databases for calculating countries' consumption-based emissions for the SEFS dashboard. It was chosen for its extensive country and sectoral coverage, and because the 26-sector format allowed for EE-IOA to be carried out following a relatively straightforward industry-by-industry approach. While the Full Eora dataset could have been used to carry out a commodity-by-industry approach, which can offer a more finely grained analysis of GHG emissions at the commodity level, this would have involved different mathematics and is more often applied to understand regional flows within a country, by regionalising countries' national commodity accounts (R. W. Jackson, 1998; R. W. Jackson & Schwarm, 2011). Thus, the industry-by-industry approach, with its consistent 26-sectors for every country, was deemed sufficient for the purposes of this research project.

Additionally, as mentioned in §2.5.3, the Pan et al. (2022) and Steininger et al. (2016) studies have respectively drawn on the Eora database to apply the ECPCE Principle and consider links between multiple accounting frameworks and fair climate policies. These studies gave confidence that the Eora database would be a suitable information source for this research project. The steps taken to calculate consumption-based emissions for the SEFS dashboard are outlined in §3.6.

### §2.5.6 Section summary

Accounting frameworks are a means of assigning responsibility for GHG emissions, or climate change, to different countries. Sitting behind each accounting framework are unstated assumptions about where responsibility for emissions ought to lie. The conventional PBA approach was designed in the context of a less globalised world, where it was assumed that a country which physically released emissions should take responsibility for them. However, growth in international trade has led to emissions offshoring or weak leakage, which an alternative CBA perspective can correct for. Both weak and strong leakage must be kept in mind as countries work towards their climate goals because "[s]tudying carbon leakage is vital . . . to the fair sharing of international emission reduction responsibilities" (B. Yu et al., 2021).

EE-IOA is a technique which can be applied to environmentally extended MRIO tables to calculate countries' consumption-based emissions. Several GMRIO databases were compared in Table 4 and the Eora-26 database was chosen to be included in the SEFS dashboard, due to its comprehensiveness and use in relevant studies which also combine and discuss multiple accounting frameworks and ethical principles.

Some have suggested that combining different GHG accounting methods with "schemes for producer and consumer responsibility in dashboards . . . could help to establish a comprehensive picture of the responsibility for trade-related emissions" (Jakob et al., 2021, p. 6). The SEFS dashboard meets this demand by enabling users to compare countries' GHG emissions balances under the PBA and CBA frameworks. This enables the dashboard to highlight how prioritising different accounting approaches can paint vastly different pictures of countries' emissions profiles, contributions to global warming and their perceived responsibilities for climate change.

Ultimately, people will have different perspectives about where responsibility for emissions ought to lie. The SEFS dashboard's ability to provide users with a means to view country-level emissions allocated under two accounting lenses will support responsibility-related discussions. It could also promote consideration of emission reduction opportunities that might exist through global trade. The next section (§2.6) reviews the climate ethics literature and considers how responsibility for addressing climate change can be considered by way of several ethical principles.

## §2.6 Ethical distributional principles

Since the late 1980s, moral and political philosophers have contributed to a vast climate ethics literature, which contemplates important ethical questions that climate change raises. Prominent topics of debate include the allocation of responsibility at various levels (individual, local or municipal, institutional, governmental, corporate, sectoral, regional, provincial, state, federal or national, etc); climate change as a human rights issue; and a focus on climate change's inter-temporal and inter-spatial dimensions (Caney, 2010; Gardiner et al., 2010). These overlapping ethical considerations are highly complex. Philosopher Stephen Gardiner has used the analogy of the Andrea Gail fishing ship, entering a confluence of multiple storms to conceive of climate change as a "perfect moral storm . . . [which] . . . threaten[s] our ability to behave ethically" (Gardiner, 2006, 2011).

The three storms that Gardiner presents are global, inter-generational and theoretical. The global storm describes inequities that exist between nation-states. The inter-generational storm describes inequities that exist between generations where, through their actions, past and present people hold significant power and influence over the type of world future people will inhabit. Finally, the theoretical storm reflects a perspective that humanity's current theoretical frameworks and understandings are ill-equipped to address long-term challenges like climate change.

While grappling with how to address climate change at some of the aforementioned levels, ethicists have highlighted the insufficiency of conventional moral principles, like *do no harm*, to argue that global warming is not any single individual's fault (Sinnott-Armstrong, 2005). Or they have suggested that by adopting green virtues, such as humility, temperance and mindfulness, individuals could help address environmental challenges (Jamieson, 2007). Some moral and political philosophers have concluded that the nature of climate change challenges our common sense morality, and conceptions of fairness (Jamieson, 2014); while others say we just need new approaches for combining the values we already have in creative ways (Page, 2006). This demonstrates the varied perspectives that ethicists hold and the complexities of analysing climate change from an ethical standpoint.

A large and consistent focus within the climate ethics literature has been on the questions of distributive justice that arise, where burdens and benefits fall unequally, both intra-generationally between countries as well as inter-generationally across generations (Agarwal & Narain, 1991; Caney, 2009a; Shue, 1993). Questions of distributive justice have often been described broadly as "the allocation question" (Baer et al., 2010, pp. 216–217) or "burden-sharing question" (Duus-Otterström & Jagers, 2012, p. 746), and can be distinguished on the basis of whether they are focussed on allocating *costs* (assumed to be financial in nature) for addressing climate change or *rights* to emit GHGs within fixed emissions budgets.

This thesis is not focussed primarily on contributing to these normative debates. Instead, it focusses on applying ethical considerations to the facts of global GHG emissions. In this sense, the SEFS dashboard attempts to make Gardiner's *perfect moral storm* more tractable, by enabling decision makers to more easily test their ethical theories or intuitions against country-level emissions data.

The SEFS dashboard's international focus – at the level of nation-states – engages with the global storm, while the Equality-over-time Principle engages with the inter-generational storm by capturing how to distribute warming rights over multiple generations. Finally, the technology-assisted form of reflective equilibrium (RE) which the dashboard enables engages with the theoretical storm by allowing users to better understand conceptions of fairness that underpin different allocations of nation-state responsibility. By engaging with multiple dimensions of the perfect moral storm, the dashboard helps to navigate some of the complexity of climate change, and its ethical nature, in an applied way.

Table 5 below gives a sample of these allocation or burden-sharing questions as they appear in the literature, whether they focus on costs, rights or both, and the source where they can be found.

To help answer such questions, a range of ethical distributional principles (sometimes called burden-sharing or effort-sharing principles) are often drawn upon. This thesis focuses on the six principles introduced in Table 1 and Table 2 which are:

- Polluter Pays
- Beneficiary Pays
- Ability to Pay
- Grandfathering
- Equal Per Capita Emissions
- Subsistence Emissions

Gaining an understanding of each principle was necessary before they could be applied within the dashboard to answer the second and third research questions (RQs). Within this thesis, the first three principles will be referred to as *financial burden-sharing principles* (discussed next in §2.6.1) and the last three as *budget allocation principles* (discussed in §2.6.2).

The next section takes an in-depth look at the three *financial burden-sharing* principles: how they have been defined and understood by climate ethicists, their theoretical strengths, weaknesses, and ease of application.

| Question | Costs/Rights | Source (literature) |
|---|---|---|
| How should this 300 btC global carbon emissions budget (over period 1986-2100) ought to be shared? | Rights | (Agarwal & Narain, 1991, p. 15) |
| What is a fair allocation of the costs of preventing the global warming that is still avoidable?<br>What is a fair allocation of the costs of coping with the social consequences of the global warming that will not in fact be avoided?<br>What is a fair allocation of emissions of greenhouse gases (a) over the long term and (b) during the transition to the long-term allocation? | Costs<br>Costs<br>Rights | (Shue, 1993, p. 40) |
| Who should pay for the costs of global climate change? | Costs | (Caney, 2005, p. 748) |
| How the permission to emit greenhouse gases should be distributed and among whom?<br>What, then, would be a fair way of distributing rights to emit greenhouse gases? | Rights<br>Rights | (Caney, 2009, p. 125) |
| Who should bear the burdens of dealing with climate change? | Costs | (Caney, 2010, p. 203) |
| How much are these burdens likely to cost to discharge? Which agents should cover these costs and why? How great a burden can each of these agents reasonably be asked to bear? | Costs | (Page, 2011, p. 412) |
| How should the right to emit greenhouse gases be distributed?<br>Given that there is a fixed limit on the volume of green house gases that may be permissibly emitted, how should rights to emit greenhouse gases be distributed? | Rights<br>Rights | (Caney, 2012, p. 255)<br>(Caney, 2012, p. 256) |
| What are the burdens associated with climate change and policies for its management? (the 'burden identification' question)<br>Which type(s) of agent should bear these burdens? (the 'level of agency' question)<br>How should the burdens identified in (i) be shared amongst tokens of the agent type identified in (ii)? (the 'burden-sharing' question) | Costs | (Page, 2012, p. 302) |
| *Who* must do what exactly? Which contributions must individual countries make and which costs must they bear? How should these duties be distributed? | Both | (Roser & Seidel, 2017, p. 4) |

*Table 5. Distributive justice questions from the climate ethics literature*

## §2.6.1 Financial burden-sharing principles

Addressing climate change requires financial resources. International climate finance commonly refers to the dedication of financial resources towards two different forms of climate action: climate mitigation and climate adaptation (Weikmans & Roberts, 2019). As mentioned in §1.3, climate mitigation involves limiting GHG emissions to prevent further climate change, whereas climate adaptation includes measures which involve adjusting to the effects of climate change. A third type of climate action – loss and damage – refers to financial redress or compensation for climate-related harms and is becoming increasingly important as climate impacts intensify (McNamara & Jackson, 2019).

Efforts to mobilise climate finance have featured throughout climate negotiations. At COP15 in 2009, Annex I Parties pledged to raise $100 billion of climate finance by 2020. This goal was met for the first time two years later in 2022, according to OECD assessments (OECD, 2022). COP27 in 2022 marked the establishment of a Loss and Damage fund to provide financial assistance to vulnerable countries (Wyns, 2023). More recently, last year's COP29 – referred to as the *finance COP* – established two new climate finance pledges, known as the New Collective Quantified Goal (NCQG) on climate finance. These were that:

- Developed countries raise US$300 billion annually for developing countries by 2035; and
- All actors (both nation-state and non-state) raise US$1.3 trillion annually by 2035

This second pledge is reflective of a broadening international climate regime, under the Paris Agreement, where a growing influence and engagement by non-state actors – including NGOs, businesses, and regional and municipal-level governments – has been observed.

In the case of the 2009 US$100 billion climate finance pledge, there was little discussion of how countries' pledges could be assessed in terms of fairness. Cases were made about how much different countries should contribute, but without clear links to scientific facts. Immediate questions which follow the more recent NCQG are: How much money should each actor contribute? And what should the rationale be for this?

To better inform these real-world discussions, the three financial burden-sharing principles in Table 1 – the Polluter Pays, Beneficiary Pays and Ability to Pay – can be drawn upon. These principles are widely discussed in the climate ethics literature and present options for determining fair distributions of climate finance amounts. The use of the term *pays* in the names of these three principles reflects their concern with distributing *costs*; in particular, how the costs of different forms of climate action ought to be shared. As explained in §1.3, only the financial costs for climate mitigation are the focus within this thesis.

The SEFS dashboard offers users the opportunity to see how the costs of climate change for nation-states vary when each of these different principles, with different metrics, are applied. These principles and the SEFS dashboard can help answer (RQ2) how should the costs for mitigating climate change be distributed between countries?

Conceptions of justice of each financial burden-sharing principle were summarised in Table 1. All three principles relate to the UNFCCC's overarching expression of equity: the CBDR-RC principle. The Polluter Pays and Beneficiary Pays Principles are distinct ways of articulating the *differentiated responsibilities* element of the CBDR-RC principle, which stem from different interpretations of responsibility – from contributions to the problem (Polluter Pays) and benefitting from actions that have caused the problem (Beneficiary Pays). Meanwhile, the Ability to Pay Principle relates to the *respective capabilities* element of the CBDR-RC principle, which stems from an interpretation of responsibility as based on one's capability or available resources.

Discussions of these principles within the climate ethics literature, including criticisms against them, have highlighted the need for a pluralist approach – defended in §2.6.3 – where one principle can compensate for the shortcomings of another. This also explains why the SEFS dashboard has been designed to incorporate multiple principles, with wide ranging conceptions of fairness, and why the following sections investigate and carefully articulate the strengths and limitations of each principle.

The following three sections (§2.6.1.1–§2.6.1.3) discuss each financial burden-sharing principle in depth, including their interpretations and formulations and how they are understood and debated within the climate ethics literature. Since this research is concerned with carrying out applied ethics, the technically feasibility of applying each principle, based on available data and suitable metrics, will also be discussed.

#### *§2.6.1.1 The Polluter Pays Principle*

The Polluter Pays Principle, also referred to as the Contributor Pays or Contribution to Problem Principles and historical responsibility within the climate ethics literature, is an ethical principle which assigns responsibility for climate action to those who have *caused* climate change (Heyward, 2021; Page, 2012). The principle's intuitive conception of responsibility appeals to the common sense morality "that one must take responsibility for one's own actions" (Roser & Seidel, 2017, p. 118). In other words, if someone makes a mess, that same someone should clean it up. The principle is described as "backward-looking" because it focusses on pollution that has occurred in the past (Shue, 2014, p. 205). In this way it follows a "responsibility-centred justice", whereby duties to act are based on previous contributions to the problem (Page, 2011, p. 414).

Five prominent philosophical objections have been raised against the Polluter Pays Principle. These include the disappearing perpetrators problem, moral unfairness, excusable ignorance, insensitivity to the needs of the most vulnerable, and how to deal with non-harmful emissions. Each of these objections will be described and explained in turn.

The first objection against the Polluter Pays Principle – disappearing perpetrators – relates to applying the principle at the level of individual persons, where holding past polluters accountable may be impossible if they are no longer alive (Caney, 2018; Page, 2011). Caney (2010) argues that, for this reason, the Polluter Pays Principle is incomplete and must be supplemented by other principles. However, the objection of disappearing perpetrators is not relevant where "a collectivist approach to moral responsibility and accountability", involving collectives of individuals – like businesses and countries – are taken as moral agents instead (Tan, 2023, p. 3). By taking countries as its unit of analysis, the SEFS dashboard circumvents the disappearing perpetrators objection since, with the exception of several notable border changes mentioned in §5.2.3, countries have, for the most part, maintained a continuous existence over time (Moellendorf, 2014).

It has also been argued – the second philosophical objection – that the Polluter Pays Principle suffers from an inherent unfairness because of the way it holds recent generations responsible for the past actions of their ancestors, which they had no control over or ability to prevent. Page (2011) argues that this cuts against the ethos of the Polluter Pays Principle, which "presupposes that only agents that actually caused an environmentally adverse outcome can be held responsible" (p. 415). One way this objection is addressed within the climate ethics literature is by arguing that just as rights and benefits pass down through generations, so too can debts in relation to harmful past actions (Gardiner, 2010). In other words, while current and future generations cannot necessarily be blamed for the emissions-generating activities of their ancestors, they should at least bear some level of responsibility for the harmful impacts of their ancestors' actions.

A third philosophical objection to the Polluter Pays Principle is excusable ignorance. Excusable ignorance occurs "where agents are unaware of any potential for harm at the time that they engage in the harmful action and so are excused from fault for the resulting outcome" (Vanderheiden, 2016, p. 300). In a climate change sense, excusable ignorance describes a lack of knowledge about the detrimental impacts associated with emissions-generating activities (Gosseries, 2004; Mittiga, 2019; Moellendorf, 2014; Tan, 2023).

A related concept – inexcusable negligence – describes a continued inaction to address climate change, despite knowledge of its ill-effects (Vanderheiden, 2004). In other words, inexcusable negligence marks a point in time at which countries were no longer excusably ignorant and became *morally* responsible for their unabated GHG emissions. However, determining countries' inexcusable negligence when it comes to anthropogenic climate change is difficult, where "once-innocuous actions begin to cause harm at some point, once thresholds are crossed and further GHG emissions accumulate in the atmosphere and begin to cause harm" (Vanderheiden, 2008, p. 187).

While certain countries are more obviously historically responsible for climate change than others, there are varying views on which point in time countries ought to be held morally responsible. Vanderheiden (2004) summarises this point when he asks: "[b]y what standard should an agent be held morally responsible for an effect for which they are causally responsible?" (p. 145). For this reason, excusable ignorance raises questions – with no immediately clear answers – about what point in time countries should be culpable for their emissions.

Various climate ethicists have proposed a "cut-off date" after which time it would not be possible for states to claim excusable ignorance (Mittiga, 2019, p. 165). There are a range of such cut-off date possibilities which have implications for perceived country-level responsibility (Bodansky, 2001b; Caney, 2010; Gosseries, 2004; Neumayer, 2000). Offering a range of time-periods over which emissions are accounted for within the SEFS dashboard is one way of facilitating such debates without presupposing an ethical correctness of a particular date.

One way that the previous two objections – moral unfairness and excusable ignorance – have been addressed within the climate ethics literature is by appealing to the legal concept of strict liability (Gardiner, 2004; Neumayer, 2000; Shue, 1999). Strict liability "holds agents responsible if they caused the problem, regardless of whether they acted with knowledge" (Moellendorf, 2012, p. 135). It is usually applied in situations where there is concern about particular actions being highly dangerous or in situations "where a high standard of care is warranted" (p. 136). The concept is permitted within United States tort law and has been endorsed in environmental cases, setting a legal precedent for it (Gardiner, 2004). However, appealing to strict liability has proven controversial, with some ethicists arguing that it asks too much of duty-bearers (Caney, 2005). Instead they advocate for a form of limited liability, which would make polluters liable for climate-related costs associated with their emissions-generating activities, provided the costs do not outweigh the benefits they have gained from those activities (Bell, 2011). Potential unfairness objections to the Polluter Pays Principle can also be averted by the unjust enrichment version of the Beneficiary Pays Principle, discussed next in §2.6.1.2, which is itself a form of limited liability.

A fourth objection to the Polluter Pays Principle is the way that attributing emissions to countries at the national level can result in a lack of sensitivity towards legitimate emissions of the disadvantaged. For instance, China overtook the United States as the largest annual emitter of $CO_2$ in 2006. Applying the Polluter Pays Principle at the country-level and over recent time-periods could result in large countries with high populations at significantly lower standards of living being expected to pay more than countries in more affluent positions, like the United States.

Finally, the principle also faces the practical challenge of determining the amount of harm that has been caused by anthropogenic climate change, as discussed in Caney (2010). This is because some formulations of the Polluter Pays Principle focus specifically on the harm that has been caused, rather than contributions to the problem. Within the SEFS dashboard, this challenge has been averted by basing applications of the Polluter Pays Principle solely upon GHG emissions datasets, rather than on downstream harms that have already occurred, and might occur in the future.

Despite the aforementioned philosophical objections and practical challenges, the Polluter Pays Principle is one of the most technically feasible of the three financial burden-sharing principles to apply in the SEFS dashboard because of its focus on GHG pollution being the primary driver of climate change. There are many publicly available country-level GHG emissions datasets (see §3.4.2) which can be used to operationalise the Polluter Pays Principle. However, a point worth drawing attention to is that there are varying perspectives about who the polluter is in today's globalised world. This will be discussed further in §2.6.1.4, which draws links between accounting frameworks, the Polluter Pays and Beneficiary Pays Principles and their perspectives on responsibility.

### *§2.6.1.2 The Beneficiary Pays Principle*

Rather than placing responsibility on those who have *caused* climate change, the Beneficiary Pays Principle argues that those "benefiting most from activities that cause climate change should bear the greatest burden in terms of the costs of preventing dangerous climate change" (Page, 2012, p. 300). Here, the focus is on the *benefit* that has been derived from acts, as opposed to the *harmful act* of polluting itself. There will be some overlap between polluters and beneficiaries, since the same actors that cause climate change (polluters) may also profit from it as beneficiaries. A helpful distinction can be made between entities that cause climate change because they *must* and entities which own resources, supply chains or technologies that produce emissions. For instance, the oil-importing nation or the daily commuter would be polluters, whereas oil-exporting nations, petrol companies and citizens who use public infrastructure which is funded by oil export earnings would be beneficiaries.

The Beneficiary Pays Principle is characterised by Page (2012) as having both forward-looking and backward-looking elements. This "hybrid structure" gives it advantages over other principles, like the Polluter Pays and the Ability to Pay Principles, which are either solely focussed on the past or the present (Page, 2012, p. 307). The hybrid form is advantageous because it allows the Beneficiary Pays Principle to explain *why* (mostly) developed states ought to pay for climate change, rather than assuming the wealthier developed states should pay purely because they have the ability to (Page, 2008).

Several versions of the Beneficiary Pays Principle have been developed, which vary across not only the type of climate action, but also the grounds for placing onus on a beneficiary within climate mitigation (Farber, 2007; Heyd, 2017; Page, 2012). In a climate adaptation setting, a beneficiary is the one who benefits from climate adaptation measures. In a climate mitigation setting, a beneficiary is the one who benefits from actions that caused climate change. However, in the climate mitigation setting, it is difficult to argue that beneficiaries have benefitted from *wrongful* actions. This is because while widespread fossil fuel use has been the primary driver of climate change to date, it can be difficult to argue that fossil fuels themselves are fundamentally wrong, since they have also brought a range of benefits. Page (2012) terms the version he finds most convincing the "unjust enrichment BPP" (p. 313). This form of Beneficiary Pays Principle focusses on "climate change-linked benefits" that states have gained (p. 313). By focussing solely on benefits, the unjust enrichment Beneficiary Pays Principle averts debate about whether acts that benefits were derived from were wrongful or not. This is the particular version of the Beneficiary Pays Principle that has been operationalised in the SEFS dashboard, and which will be considered in this thesis.

The Beneficiary Pays Principle offers an alternative to the Polluter Pays Principle because it focusses on the benefits that have been derived from unjust harms (or unjust enrichment) which are then passed onto generations alive today, rather than the particular agents who caused the harm: "[i]n this way the BPP finesses the problem of disappearing perpetrators, excusable ignorance, and nonharmful emissions" (Page, 2011, p. 421). However, the Beneficiary Pays Principle faces several philosophical objections of its own. These include chronological unfairness, the non-identity problem and the disaggregation problem. Each of these objections will be defined and discussed in turn, starting with chronological unfairness.

Caney (2006) argues that the Beneficiary Pays Principle may suffer from a chronological unfairness, where beneficiaries who are alive today could be expected to pay for benefits which have accumulated across previous generations. However, this argument is dismissed by Page (2012) who argues that the "unjust enrichment BPP is naturally interpreted to embrace a 'net benefit' proviso … [and] … a 'no debilitating cost proviso'" (p. 318). This means that states would only be expected to surrender the benefits they have obtained after adverse costs they have experienced due to climate change are considered. Additionally, the surrendering of states' benefits must not cause harm to citizens or democratic structures within states.

The non-identity problem, a challenging problem in population ethics, describes the way in which a different set of past actions or circumstances could result in different people being alive today. It has been argued that the Beneficiary Pays Principle suffers from this challenge because "the activities that contributed to the emergence of climate change also played a minor, but necessary role, in the coming into existence of the current citizens of all states such that none of these citizens would have been born in the absence of industrialization" (Page, 2012, p. 319). This raises the question of whether it is reasonable to hold people accountable for benefits they have derived from past activities that their coming into existence was contingent upon. Page (2012) highlights that the non-identity problem objection to the Beneficiary Pays Principle is not so relevant when the principle's application is at the nation-state level. This is because countries' identities are less vulnerable to a reshuffling, based upon historical events, than an individual person's are.

Finally, the disaggregation problem refers to the challenge of distinguishing between direct and indirect benefits that are associated with activities which have contributed to climate change, making it difficult to quantify the size of such benefits. Page (2012) contrasts this challenge that the Beneficiary Pays Principle faces with the way in which burden-sharing frameworks, based upon the Contributors Pays and Ability to Pay Principles, can draw upon GHG emissions or national income datasets to calculate shares of global climate efforts which are more reflective of their understandings of fairness. The disaggregation problem foreshadows the challenge of operationalising the Beneficiary Pays Principle, especially in a globalised world where benefits associated with GHG emissions can accrue along value chains. This is discussed further in §2.6.1.4.

The Beneficiary Pays Principle, by comparison to the Polluter Pays Principle, is much more difficult to apply because it is challenging to "calculate the economic value of national and global wealth that can be uniquely linked to the activities that cause climate change" (Page, 2012, p. 322). When applying the principle in a practical way, an immediate challenge is to identify to what degree countries have obtained benefit from actions which have caused the harm that is climate change. Put another way, how would one determine the degree to which countries have profited from actions that have contributed towards climate change?

This challenge could explain why there are so few studies in the climate ethics literature which consider how the costs of climate change ought to be distributed between states according to the Beneficiary Pays Principle. It seems the most difficult issue the Beneficiary Pays Principle faces, then, is in its practical application. In theory, the Beneficiary Pays Principle involves quantifying all public and private revenues from fossil fuels and from GHG emitting sectors, like agriculture, and then tracing how those revenues translate into private and public gains – commercial profits and investment in infrastructure and other welfare enhancing systems, like health and education.

While this is theoretically conceivable, in practice is it difficult to find how much fossil fuel revenue was invested in a health system, in comparison with tax revenue, for instance. Articulating this challenge of linking revenue flows and associated gains has highlighted a distributional complexity, where some people will benefit to greater degrees than others, such as recipients of private profits or communities with political power to obtain greater shares of public spending. One approach for applying the Beneficiary Pays Principle takes "national wealth as a proxy for accumulated unjust climatic benefit" (p. 323). Total national wealth is the proxy metric that has been used to apply the principle in the SEFS dashboard.

### *§2.6.1.3 The Ability to Pay Principle*

In contrast to the Polluter Pays and Beneficiary Pays Principles, the Ability to Pay Principle is described as "forward-looking" and ahistorical, since it distributes burdens for climate change irrespective of what has taken place historically (Page, 2011, p. 418). It regards both the *causation of,* and *benefits derived from* climate change as irrelevant and focusses instead on the level of ability an actor has to pay for the costs of climate change. For this reason it is dubbed a "no-fault" principle (Shue, 2014, p. 60).

Roser and Seidel (2017) distinguish between two formulations of the Ability to Pay Principle. The first is that *all* actors should bear the costs of climate change in proportion to their level of capability in economic terms. The implication is that everyone, even those with very limited economic capability, ought to bear the costs of addressing climate change. However, a second reading of the principle would exempt those with few financial resources from bearing any costs. This second reading has synergies with the Subsistence Emissions Principle (discussed in §2.6.2.3), which seeks to safeguard the vital interests of the most destitute. The SEFS dashboard gives users the opportunity to only apply the first version of the Ability to Pay Principle. This first version was chosen for its ease of application since further information would be required to exempt certain demographics of a country from paying for climate mitigation.

Several philosophical objections have been expressed against the Ability to Pay Principle in Caney (2010). These relate to the principle's forward-looking, ahistorical, and non-fault nature. Objections include a counter-intuitiveness of ignoring the historical record, the questionable approach of making someone pay who is not at fault, and the possibility of unfair penalties arising for those who have become wealthy without contributing to climate change. Each of these objections will be defined and discussed in turn.

By ignoring the past – a morally relevant dimension, given climate change's long-term timescales and intergenerational impacts – the Ability to Pay Principle essentially deems actors' contributions to the issue irrelevant (Caney, 2010). In this way, the principle's conception of justice has a contrasting temporal orientation to the Polluter Pays Principle, which has an explicit focus on historical contributions to the issue. A proponent of historical responsibility might question why what has taken place in the past should not inform how to distribute financial costs in the future. However, the fact that two principles point in opposite directions does not provide sufficient rationale to disregard a principle. Principles are expected to reflect different perspectives on equity and justice. Moreover, the Ability to Pay Principle's conception of fairness can be seen in other contexts which involve debates about fairness, such as tax policy. The principle underpins progressive tax schemes, where those with higher incomes pay more (Buehler, 1946; Kendrick, 1939).

A second objection to the Ability to Pay is in relation to the principle's no-fault nature. Why, if an actor is not at fault for contributing to climate change, should that actor pay to address the issue simply because they can? Caney (2010) distinguishes between two possible groups who could be expected to pay: the advantaged and the poor. A third option would be to carry on with the status quo, where no particular group is identified as having a duty to bear costs. By default, option three would impose burdens on people for something that was not their fault anyway, especially future generations who have not yet contributed to climate change but will suffer from its effects. Reflecting on this three option scenario, the most advantaged – those "most able to pay the price without sacrificing any reasonable interests" – are under a duty to bear costs (p. 214).

A third philosophical objection to the Ability to Pay Principle is that focussing solely on actors' financial capacities could result in the principle unfairly penalising those who have increased their wealth in ways which have not contributed climate change. Caney (2010) argues that it does not matter how groups came to acquire their wealth. Positive duties can fall on those who have the ability to help, provided it does not become excessively demanding and contravene their own interests. For this reason, even countries which acquire wealth in a climate-friendly fashion may obtain positive duties to commit financial resources towards addressing the issue and its impacts.

The second and third objections to the Ability to Pay Principle show that countries can inherit positive duties for bearing climate-related burdens simply because they can afford to bear costs without worsening their situations, rather than because they contributed to the issue.

The Ability to Pay Principle also faces several challenges in terms of its application. Within the climate ethics literature, the *Capability* and *Capacity* Principles capture similar notions of justice as the Ability to Pay Principle (Dooley et al., 2021; Rajamani et al., 2021). This research reviewed approaches which apply the Ability to Pay, Capability and Capacity Principles and found that these often rely on indicators or *proxy* metrics like Gross Domestic Product (GDP) Per Capita and the Human Development Index (HDI). In Winkler et al. (2002), countries' ability to pay for emissions reductions is "measured by the proxy of GDP Per Capita" (p. 307). van den Berg et al. (2020) also use the GDP Per Capita metric to operationalise the Ability to Pay Principle. Alongside the GDP Per Capita and HDI indicators, three other proxy metrics are used to apply the principle in the SEFS dashboard: GDP, Gross National Income (GNI) and GNI Per Capita.

### *§2.6.1.4 Responsibility, the Polluter Pays and Beneficiary Pays Principles*

As alluded to in §2.6.1.1 and §2.6.1.2, the Polluter Pays and the Beneficiary Pays Principles have been identified by scholars as having connections with accounting frameworks. It is important to discuss these links because GHG emissions data, reported under different accounting frameworks, presented one means by which both principles could be operationalised in the SEFS dashboard.

The decision to investigate the possibility of using accounting frameworks to apply these principles was influenced by the discovery of several recent articles which consider relationships between accounting frameworks and ethical principles (Duus-Otterström & Hjorthen, 2018; Steininger et al., 2016; Sun et al., 2019; Tukker, Wood, et al., 2020). These articles take different views on who the polluter, beneficiary, producer and consumer are. For instance, Steininger et al. (2016) explain that the Polluter Pays Principle allocates responsibility "to the wrongful emitter" while the Beneficiary Pays Principle allocates responsibility "to the beneficiary of wrongful emissions" (p. 35). Sun et al. (2019) reference these comments and take them a step further when they argue that the "the 'polluter pays' principle allocates emissions to producers, while the 'beneficiary pays' principle consigns emissions to consumers" (p. 363).

Explicit links are also drawn between ethical principles and accounting frameworks in Tukker, Pollitt, et al. (2020). These can be found in the *Accounting perspective* and *Mitigation principle* rows of Figure 3. Tukker, Pollitt, et al. (2020) agree with Sun et al. (2019) in terms of drawing a link between the Polluter Pays Principle and producers or the PBA perspective. However, instead of positioning the Beneficiary Pays Principle beneath the CBA perspective, Tukker, Pollitt, et al. (2020) position it in line with the value-added perspective. This reflects a more sophisticated view of the Beneficiary Pays Principle, since it acknowledges that benefits from activities contributing to climate change are spread amongst actors along value chains.

In contrast, Duus-Otterström and Hjorthen (2018) take a very different approach. They draw on the Polluter Pays, Beneficiary Pays and Ability to Pay Principles, their characteristics and particular views of justice, to present a normative debate about which accounting framework – whether consumption-based or production-based – is more just. In this way, they keep the principles and their conceptions of justice separate to accounting frameworks. The traditional notion that producers are polluters is challenged when they argue that: "Consuming goods and services that embody emissions is one interpretation of what is means to be a 'polluter'" (p. 872). This relates to how the consumption-based perspective offers an alternate view of who the so-called polluter might be in a globalised world.

These debates about who ought to be considered the polluter mark a shift towards an interpretivist paradigm, which will be discussed in §5.2.1, and which the pragmatist-positivist approach has allowed for. While the research primarily employs positivist methods and treats particular interpretations of each principle as fixed within the SEFS dashboard, the pragmatist-positivist approach allowed for an exploration of these normative, interpretive arguments which reveal why single principles are insufficient and why – in theory and in practice – principles overlap. This in turn builds the case for the ethical pluralism which the SEFS dashboard reveals – and the importance of taking a pluralist approach, defended in §2.6.3 – by enabling applications of diverse principles, representing different conceptions of justice.

#### *§2.6.1.5 Section summary*

Fair distributions of international collective climate finance goals are anticipated to be an ongoing focus of international negotiations as countries work to address climate change. The three financial burden-sharing principles, which can inform such debates, adhere to different conceptions of fairness, face various philosophical objections and technical feasibility challenges.

Given the applied nature of this research, each principle's ease of application was assessed, where a lack of suitable data was found to have constrained principle applications in practice. This was particularly the case for the Beneficiary Pays and Ability to Pay Principles, which commonly draw on proxy metrics. This finding uncovered a challenge that applied ethicists face when seeking to connect principles with appropriate datasets: they are limited by what data has been collected and is currently available. Theoretical ethicists do not face the same challenge. Instead, they can develop moral arguments by theorising about what is right wrong in the abstract, tend to write on general issues and advance defensible positions, as opposed to make issues more specific and data constrained. For this reason, the approach of applying ethical principles, which the SEFS dashboard follows, will inevitably open up new fronts for contestation.

A lack of suitable datasets for applying the Beneficiary Pays Principle, in particular, prompted consideration of the nexus between accounting frameworks and ethical principles. This raised philosophical questions about distinctions between polluters and consumers and their relationships to ethical principles. Accounting frameworks present possible warming-dependent approximations of the Beneficiary Pays Principle.

Applied ethics assessments also focus on allocating rights to emit GHGs within a constrained carbon budget by way of three prominent budget allocation principles. The next section discusses several budget allocation principles as possible options for answering RQ3.

### §2.6.2 Budget allocation principles

The Paris Agreement's Article 2 temperature targets are globally agreed temperature increases, above pre-industrial levels, that countries have agreed to not surpass. However, these targets alone do not provide guidance about the proportion of temperature increase which each country should be able to use or consume.

Carbon budgets are a relevant concept which link cumulative $CO_2$ emissions to resulting temperature increases in a linear way, through the transient climate response to cumulative emissions of $CO_2$ (TCRE) (Rogelj et al., 2019). Rather than placing a limit on global temperatures that will result from emissions, carbon budgets reflect a limit on emissions themselves. They are usually expressed in $GtCO_2$ or atmospheric concentrations – in ppm – and represent a ceiling on allowable $CO_2$ emissions.

Carbon budgets can be total or remaining; total carbon budgets commence from the pre-industrial period, whereas a remaining carbon budget (RCB) starts from more recent dates (Arias et al., 2021). Carbon budgets also vary in their level of application: global, national or local. In its Sixth Assessment Report, the IPCC estimated the global RCB to be $500GtCO_2$ for a 50% chance of remaining beneath the 1.5°C Article 2 temperature target (Canadell et al., 2021). A more recent estimate is $200GtCO_2$ (Forster et al., 2024). Given current annual rates of $CO_2$ emissions, it is possible that this budget will be exhausted by 2029.

The carbon budget concept traverses many parts of the climate change literature from the science through to the policy and ethics (Lahn, 2020). A section of the literature has been concerned with distributing RCBs between actors, usually nation-states (Fanning & O'Neil, 2016; Matthews et al., 2021; McMullin et al., 2020; Pan et al., 2022). Most often, assessments are restricted to $CO_2$ emissions only, in part because of the complexities that come with placing different GHGs onto an equivalent scale. However, recent studies have sought to calculate combined budgets which include other GHGs, like $CH_4$ (Jenkins et al., 2021). This work is important, given that contributions of non-$CO_2$ GHGs have the potential to affect RCB estimates, in line with the Article 2 temperature targets, by up to $220GtCO_2$ (Canadell et al., 2021; Rogelj & Lamboll, 2024).

There are varied perspectives about how to distribute a carbon budget. Arguments have been made for everyone to have equal access to the global atmospheric commons, following the likes of the United Nations' Convention on the Law of the Sea (Baer et al., 2000). Other scholars have suggested the atmosphere be apportioned to countries based on the size of countries' jurisdictional land area below (Westing et al., 2001). Bearing in mind that GHGs warm the world differently, as discussed in §2.4, the carbon budget concept can be extended to become an emissions or climate budget. The warming-related dataset that has been used in the SEFS dashboard also makes it possible to distribute a warming budget in line with the globally agreed Article 2 temperature targets. The idea of a warming budget, and associated warming rights, are novel concepts that have not yet been seen within the climate ethics literature.

To better inform discussion about how a warming budget might be distributed at the international level, the three budget allocation principles in Table 2 – Grandfathering, Equal Per Capita Emissions and Subsistence Emissions – can be drawn upon. These principles are widely discussed in the climate ethics literature and present options for fair distributions of warming rights within constrained warming budgets, under the Article 2 temperature targets.

The SEFS dashboard offers users the opportunity to see how possible shares of rights to emit GHGs and rights to warm the planet, within fixed carbon and warming budgets, vary for individual nation-states when both the Grandfathering Principle and a more sophisticated version of the Equal Per Capita Emissions Principle – Equality-over-time – are applied. These principles and the SEFS dashboard can help answer (RQ3) how should warming rights be distributed between countries?

Each budget allocation principle, how it has been understood and debated within the climate ethics literature – including its features, various versions and interpretations, as well as philosophical objections to each principle – will be discussed in the following three sections (§2.6.2.1–§2.6.2.3). Additionally, since this research is concerned with carrying out applied ethics, the technical feasibility of applying each principle, based on available data and suitable metrics, will also be discussed.

While the Subsistence Emissions Principle does not feature in the SEFS dashboard, a discussion of budget allocation principles would have been incomplete without it, given the principle's prominence within the climate ethics literature. The rationale for not including this principle is also discussed. Each of these principles and the discourse surrounding them within the climate ethics literature will now be discussed, starting with the Grandfathering Principle.

#### *§2.6.2.1 The Grandfathering Principle*

Grandfathering is a principle which takes the past as its starting or reference point for allocating future rights. In other words, rights are inherited or acquired, based upon an established custom or prior practice. The principle's origins can be traced to various "Grandfathering Clauses" in the United States' legislation (Schmidt Jr., 1982, p. 846). These clauses excluded nearly all African Americans from having the right to vote by granting rights only to American citizens, whose fathers or grandfathers had "voted anywhere before the onset of Congressional Reconstruction in 1867" (Riser, 2006, p. 248).

In a climate change context, a Grandfathering Principle commonly takes actors' prior emission levels as a starting point for distributing rights to emit in the future (Knight, 2013). Several climate agreements and policy instruments represent real-world applications of the Grandfathering Principle. For instance, expressing countries' Kyoto Protocol emission reduction targets in reference to 1990 emissions levels reflected a "partial commitment to grandfathering" (Caney, 2009a, p. 128). Similarly, allocations of European Union Emissions Trading System (EU ETS) allowances have been classified as instances of "moderate grandfathering" because allowances were based on countries' previous emissions levels (Caney, 2009a; Knight, 2013, p. 412). Finally, the forms of countries' NDCs often follow implicit commitments to a Grandfathering Principle by being percentage reductions beneath historic emissions levels (Williges et al., 2022).

Despite these real-world instances of the Grandfathering Principle, it has garnered much criticism from prominent climate ethicists who regard it as an unfair emission allocation method and dismiss it as ethically indefensible (Caney, 2009a; Jamieson, 2010; Page, 2013a; Roser & Seidel, 2017). Several of the philosophical objections against a Grandfathering Principle will now be discussed.

Described by Roser and Seidel (2017) as stipulating "equal relative reduction obligations", the Grandfathering Principle would maintain the distribution of historical emissions in some baseline year (p. 120). The first objection to this principle is that it would preserve the status quo and exempt developing countries from being able to raise their standard of living while other countries, with long records of pollution, continue to pollute in the same proportions to how they have previously. In other words, the principle endorses historical distributions of emissions without considering what they necessarily ought to be (Roser & Seidel, 2017). In this way, Page (2013) argues that the principle applies "an implausible weight to the normative relevance of historic usage of the capacity of the atmosphere to assimilate greenhouse gas" (p. 233). Similarly, Jamieson (2010) describes the principle as ethically problematic because " [t]he existing pattern of emissions primarily reflects temporal priority in the development process, rather than any moral entitlement" (Jamieson, 2010, p. 272).

The effect is that a Grandfathering Principle upholds the existing world order, where those who had taken up atmospheric space first would continue being granted the same relative proportions of this space. Ultimately, the Grandfathering Principle "privileges today's high-emitting countries" (Kartha et al., 2018, p. 348).

A second, related objection is that the Grandfathering Principle does not consider people's needs and would contravene developing countries' right to development (Caney, 2009a). The principle's operation on an equal relative reduction basis means that large developing countries, like China and India, would be allocated "radically fewer emissions rights per capita than North American, Japanese and European citizens, and as such would thwart the former's legitimate interests in development and the realisation of fundamental human rights to meet basic needs" (Caney, 2009b, p. 128). Because fossil fuels remain essential for providing energy security to individuals in many countries, a Grandfathering Principle would breach other important ethical concerns like human rights.

As well as "guarantee[ing] existing advantages for the wealthy and in practice den[ying] the vulnerable the resources to meet their basic needs", the Grandfathering Principle has been criticised for coming into conflict with other widely accepted principles of climate justice, including historical responsibility and the Polluter Pays Principle (Caney, 2009a; Dooley et al., 2021, p. 302).

Dooley et al. (2021) argue that:

> *"Grandfathering of emissions, in particular, should not be included in equity assessments of global climate action; it is not a defensible general principle of equity. Grandfathering undermines the foundations of climate equity reasoning by contradicting principles that aim to protect the vulnerable and promote sustainable development. It allows polluters to evade paying their due and discourages ambition" (p. 303).*

However, this third criticism is not sufficient on its own to disregard the Grandfathering Principle, since principles often have very different conceptions of justice and can be expected to point in opposing directions. For instance, the Ability to Pay Principle is ahistorical and determines responsibility on the basis of capability that actors might have for addressing an issue, irrespective of how culpable or responsible they are for causing it.

Caney (2009) and Roser and Seidel (2017) acknowledge several justification strategies and arguments in favour of the principle and then build cases against these. The strategies and arguments include customary rights-based defences, legitimate expectations, the longhaul argument and the priority argument. In brief, the customary rights-based defence – where "the de facto and unchallenged use of a good gives rise to a kind of 'customary right' to continue to use it accordingly" (Roser & Seidel, 2017, p. 122) – is dismissed because the conditions for legitimate appropriation were not satisfied, since the atmospheric appropriation was neither beneficial to others, nor leaves them in as good a position as they otherwise would have been. The legitimate expectations defence – which would endorse emissions-intensive lifestyles of individuals in developed countries – is disregarded because once the consequences of climate change were known, it would have been morally questionable for individuals in developed countries to continue living so decadently. Finally, both the longhaul and priority arguments are based on the political palatability of granting large emitters grandfathered rights, so that they engage with global climate mitigation efforts. These arguments are both dismissed by Caney (2009) because they argue for catering to existing power imbalances and succumb to the practical appeal that these are merely the "price to pay" for getting large emitters on board, rather than because they would result in a fair distribution of GHG emissions (p. 129). In a similar vein, Damon et al. (2019) mention how "grandfathering is just a polite word for caving in to politically powerful polluters . . . [where] they may need to be 'paid to play'" (p. 28).

Despite receiving heavy criticism from several climate ethicists, a range of moral arguments have been made in defence of the principle by moral and political philosophers, including Luc Bovens, Carl Knight and Rudolf Schuessler. These scholars have criticised quick dismissals of the principle's use in climate-related contexts and instead argue for temporary forms of a Grandfathering Principle. These temporary forms would give historical emitters more time to reduce their emissions without granting permanent rights for them to emit more than developing countries. Their moral arguments for the principle, along with a customary rights-based defence, will now be discussed.

The Grandfathering Principle is applied in the real world to allocate common pool resources by appealing to a first-in first-served basis or "customary right" (Roser & Seidel, 2017, p. 112). For instance, the Marine and Coastal Area Act 2011 is an example of national legislation which identifies two categories of customary interests that New Zealand's Indigenous tribes have in the marine and coastal area: protected customary rights and customary marine title (Finlayson & Christmas, 2021). Given proof of an undisrupted, exclusive use of a resource and area since 1840, customary marine title has been granted under this Act to recognise a tribes' rights and ancestral connections to resources within particular areas.

A further property rights-based defence of the principle can be found in Bovens (2011), which develops a "Lockean defense of grandfathering emission rights" (p. 1). This approach acknowledges countries' differential investments in GHG emitting activities and ways of life up until the point at which the Lockean condition of leaving "enough and as good for others" is clearly breached (p. 10). The enough-and-as-good condition marks the point where a common resource can no longer be taken without leaving others worse off than they otherwise might have been. For GHG emissions, the enough-and-as-good condition would be breached once emissions surpassed an innocuous level.

However, determining such a level with certainty would be a challenge. Moreover, would all countries want to return to a level of no anthropogenic warming and pre-industrial revolution climates? This seems unlikely, given that some level of warming may have resulted in more favourable climates and growing conditions for some countries and regions. Bovens (2011) suggests that emissions rights could be allocated based upon prior usage up until the time that the enough-and-as-good condition was violated.

A third, consequentialist defence of the Grandfathering Principle is what Knight (2014) refers to as "moderate emissions grandfathering" (p. 571). This argues that the higher costs faced by high historical emitters when transitioning to lower emissions are greater than those faced by lower historical emitters. For this reason, and by appealing to a range of political philosophies – including utilitarianism, egalitarianism, prioritarianism and sufficientarianism – the higher emitters should be provided with greater resources, including emissions entitlements, to help them transition. In this regard, the Grandfathering Principle is viewed as a possible approach for allocating emissions entitlements amongst countries.

Finally, Schuessler (2017) argues for a temporary, "luck-based moral defence of grandfathering" (p. 141). Luck egalitarianism is a theory of justice concerned with equalising the spread of unearned gains and welfare losses. The central claim of this theory is that no one should be at an undeserved advantage or disadvantage. However, emissions reductions will result in some agents experiencing unnecessary hardship, which was not of their own doing, as they transition to greener ways of living. This hardship, he argues, "ought to be buffered by a community that possess the necessary means to do so" (p. 141). This would mean that both rich and poor are entitled to help over a time-period of reducing their emissions.

This temporary form of grandfathering resembles the Contraction & Convergence (C&C) proposal, put forward by the Global Commons Institute in the late 1990s. The C&C approach argued for developed countries' emissions contracting so as to give developing countries the ability to increase their emissions, with the intention being that developed and developing countries' emissions would converge at a point in the future (A. Meyer, 2000, 2007). Under this temporary form of grandfathering, developed countries' emissions would contract in a gradual way, while developing countries' emissions would increase, so that both converge at similar levels in the future.

Like the Polluter Pays Principle, the Grandfathering Principle is a relatively straightforward principle to apply since it requires information about countries' historical GHG emissions at a particular point in time. There are many country-level GHG emissions datasets that can be used to calculate countries' future emission rights under a Grandfathering Principle.

Implicit applications of the Grandfathering Principle appear in studies which reference staged approaches, a constant emissions ratio, the inertia principle and sovereignty-principled reduction approaches (Peters et al., 2015; Raupach et al., 2014; Robiou du Pont et al., 2017; Robiou du Pont & Meinshausen, 2018; Williges et al., 2022). Dooley et al. (2021) bring attention to these implicit applications in their review of sixteen influential climate-related effort-sharing assessments, where several of these combine the Grandfathering Principle with others to create a composite index. Such approaches can be misleading when they claim value-neutrality because they seemingly imply there is one ethically determinate way for the world to reduce emissions, when in fact there are many.

Despite its criticisms and philosophical objections, the Grandfathering Principle has been included in the SEFS dashboard, owing to its real-world presence and prevalence in climate ethics assessments. However, the principle's inclusion should not be interpreted as a loyalty to the Grandfathering Principle, or an expression of ethical endorsement. To be clear, its inclusion does not imply that it is the correct distributive principle to choose.

Because the SEFS dashboard enables its target audiences to test their intuitions by applying a range of ethical principles, it is sensible to include those principles which are actively applied within the real world, even if their ethical foundations have been challenged. Viewing allocations of emissions and warming rights amongst countries according to the Grandfathering Principle can broaden the spectrum of principles being considered to support the enablement of a wide reflective equilibrium (WRE). The Grandfathering Principle's inclusion might also corroborate criticisms of the principle if many users judge the distributions to be unjust. Additionally, the occurrence of studies which have not always explicitly named this principle in their assessments, or combined it with other principles, motivated a decision to be clear about the principle's inclusion in the SEFS dashboard.

Finally, some may disagree with the language of referring to Grandfathering as an ethical principle, given the strong arguments that have been mounted by climate ethicists against it. However, the principle can be considered ethical in the sense that it is action-guiding, not that it is necessarily morally right. Moreover, compelling moral defences of the principle show the importance of including it in this analysis which is open to ethical pluralism. In other words, criticisms of grandfathering have not provided sufficient grounds for excluding this action-guiding principle from this analysis.

#### *§2.6.2.2 The Equal Per Capita Emissions Principle*

The second budget allocation principle – Equal Per Capita Emissions – assumes an egalitarian notion of justice, whereby everyone ought to be allocated the same amount of emissions, regardless of where they live in the world and irrespective of historical emitting behaviour. The principle is also known within the climate ethics literature as *Emissions Egalitarianism* (Roser & Seidel, 2017; Schulan et al., 2023).

A philosophical objection to this principle is that it is not clear why emissions, as a specific form of good, ought to be distributed equally amongst people when other goods or common pool global resources are not divided in this way (Caney, 2012). This had led to the principle being criticised because it demands an insensitivity to the real-world fact that: "[p]eople have unequal needs" and require different amounts of emissions to meet these (p. 264; Gardiner, 2010; Moellendorf, 2015).

A further, related, philosophical objection to the Equal Per Capita Emissions Principle is that it focusses on the wrong thing. Moellendorf (2015) argues the principle should be concerned with persons or their well-being, rather than focusing on emissions. He also argues that the principle is implausibly indifferent to past emissions. By distributing permissible emissions amounts on an equal per capita basis at some point in time, past emission distributions are not factored into how many emissions people might receive in the future, despite historical emissions having an unequal distribution.

In contrast to the previous philosophical objections, one of the strongest arguments for allocating emissions on a per capita basis is that it is simple (Baer et al., 2000). Calculations for applying the principle are straightforward because only two pieces of information are required: population information for each country and a figure for the RCB. The principle's ease of application, due to its simplicity, can explain its application in many assessments which seek to quantify national historical responsibility for climate change by way of dividing carbon budgets, and studies which provide equitable effort-sharing approaches (Fanning & O'Neil, 2016; Gignac & Matthews, 2015; Hickel, 2020; Matthews, 2016; Robiou du Pont & Meinshausen, 2018). Results of the Matthews (2016) study found many large developed countries to be in carbon and climate debt. Climate debt is a concept which broadly articulates the moral responsibility that highly polluting countries have to compensate less polluting countries, given these differences in countries' contributions to climate change (Haas, 2025; Pickering & Barry, 2012).

Scholars have, however, described their applications of the principle as starting points to be built upon and made more sophisticated in the future (Matthews, 2016). The ECPCE Principle is a more sophisticated version that has emerged (Pan et al., 2022; Robiou du Pont et al., 2017). The ECPCE Principle differs from its simpler predecessor by incorporating anticipated future populations, as well as historical population figures and historical emissions estimates. Some applications of the ECPCE approach also include discount rates, whereby historical emissions are given a lower weighting to reflect the energy efficiency improvements that have occurred since (van den Berg et al., 2020). The discount rate formulation of the principle circumvents the philosophical objection of the Equal Per Capita Emissions Principle being implausibly indifferent to past emissions that was raised in Moellendorf (2015).

A new version of the Equal Per Capita Emissions Principle – Equality-over-time – is developed within this thesis and applied in the SEFS dashboard. This principle builds upon the ECPCE approach by distributing a carbon budget across historical as well as future populations. By incorporating a temporal dimension, the Equality-over-time Principle explicitly takes future generations into account. Historical warming estimates and future permissible warming, constrained by Article 2 targets, are distributed across historical and projected populations, based on a range of future scenarios. This is something that none of the financial burden-sharing, nor the other budget allocation principles were found to do. As such, it is an example of a principle addressing the inter-generational component of climate change. The temporal element of the Equality-over-time principle also renders it more similar to the C&C approach.

#### *§2.6.2.3 The Subsistence Emissions Principle*

The Subsistence Emissions Principle has evolved from an approach of distinguishing the "'survival emissions' of the poor, from the 'luxury emissions' of the rich" (Agarwal & Narain, 1991, p. 3). Shue (1993) elaborated on this idea by coining the term "subsistence emissions" (p. 57). Later, Caney (2009) proposed: "The Subsistence Emissions Principle: Each person is entitled to that level of emissions required for them to attain a minimal decent standard of living" (p. 138). In other words, a Subsistence Emissions Principle would allocate rights to emit GHGs in such a way that people's most basic needs are met.

The Subsistence Emissions Principle is synonymous with "sufficientarianism" and "emissions sufficientarianism" principles, where a proponent of sufficientarianism would believe in a minimally decent standard of living beneath which no one should fall (L. H. Meyer & Roser, 2009, p. 219; Schulan et al., 2023, p. 1).

Strong cases have been made in favour of the Subsistence Emissions Principle. The principle's focus on improving the lives of the most worst off has a strong moral significance, based on the idea that everyone is entitled to a basic standard of living which will require GHG emissions to achieve (Caney, 2009a; Vanderheiden, 2008). The principle also acknowledges that people have different needs. In this way it does not suffer from the same insensitivity that the Equal Per Capita Emissions Principle suffers from (Caney, 2012). However, while the Subsistence Emissions Principle does contain an egalitarian element in so far as it requires that everyone "at least reach the same threshold of sufficiency", it does not require that everyone have the same number of emissions to achieve this like an Equal Per Capita Emissions Principle would (Schulan et al., 2023, p. 5).

Several criticisms of the principle have been raised. These include the challenge of distinguishing between luxury and subsistence emissions, the application challenges involved with this and the exemption claim. These will be discussed in turn, followed by consideration of whether the principle can provide a full account of justice on its own.

One of the greatest obstacles the Subsistence Emission Principle faces is in being able to clearly distinguish subsistence from luxury emissions. This also affects the principle's technical feasibility making it difficult to apply the principle in practice, especially at the level of nation-states. Scholars like Drennen (1993) have suggested possible industrial-related and biological (non-industrial-related) distinctions. Shue (1993) related this approach to equity concerns by implying that industrial emissions could be a proxy for luxury emissions and non-industrial-related ones a proxy for subsistence emissions. However, blanket categorisations of emissions on an activity-basis showed a lack of sensitivity to the fact that: "Just as the methane emissions from beef feedlots are in service of the desires of the wealthy, many of the $CO_2$ emissions in China and India *could* be . . . in service of the needs of the poor. Some agricultural methane emissions are a luxury, and some industrial $CO_2$ emissions are a necessity" (p. 57).

In another attempt to differentiate between luxury and subsistence emissions, Rao and Baer (2012) developed a conceptual framework for calculating what they termed "decent living emissions" (p. 657). The framework focussed on identifying energy requirements of different countries across ten essential activities to calculate emissions entitlements. As part of this, *development emissions* – those which would allow countries to improve their infrastructure and lift their standard of living – were differentiated from *maintenance emissions*: the annual emissions required to support a decent standard of living. However, the framework highlights the complexity in translating a universal standard of decent living to the national level, since countries' energy use requirements are highly context specific.

A criticism levelled at the decent living emissions framework is the exemption of mitigation burdens for those who fall beneath a decent standard of living threshold. Duus-Otterström (2021) terms this the "exemption claim" (p. 103). He goes on to argue that being granted subsistence emissions should not absolve one from moral duties to remedy the harmful effects of those emissions, even in cases where people have few resources. In short, with rights to emit come responsibilities. Granting an actor rights to emit GHGs does not alleviate that actor from obligations to, in the future, correct for the harms associated with those emissions.

The Subsistence Emissions Principle also raises the question of whether it can provide a full account of justice on its own. Two cases can illustrate this point. In the first case – where a RCB has not yet been exhausted – once subsistence emissions have been distributed it is not clear how remaining rights to emit ought to be distributed. In the second case – where a RCB has been exhausted – there may not be enough emissions rights left for everyone to meet their basic needs. These cases raise the possibility that the principle is insufficient on its own and additional principles may be required for allocating carbon budgets.

Despite the Subsistence Emissions Principle's prominence in the climate ethics literature, its aforementioned criticisms and application challenges have resulted in it being difficult to apply on a country-level basis (Duus-Otterström, 2021; Shue, 1993, 2019). In particular, the challenge of defining and separating subsistence from luxury emissions for nation-states – where individuals within a country will have wide-ranging requirements for rights to emit – is why the principle has not been included within the SEFS dashboard.

#### *§2.6.2.4 Section summary*

The importance of remaining beneath globally agreed temperature targets raises questions of distributive justice which the three budget allocation principles discussed in §2.6.2 can have a role in providing guidance on. These principles have all faced philosophical objections, as well as limitations in terms their technical ease of application.

Despite the Grandfathering Principle being disregarded by many climate ethicists, it appeals to the widely accepted concept of customary rights which is applied in many contexts, including the rights of Indigenous peoples to territories and resources with which they have ancestral connections. The principle also features in international climate agreements and policy instruments in the real world and recent moral defences of it have warranted its further consideration. It is for these reasons that the Grandfathering Principle has been included within the SEFS dashboard.

The Equal Per Capita Emissions approach on the other hand faces philosophical objections to its simplicity and has been strongly dismissed for not being sensitive to individuals' wide-ranging needs. Awareness of these issues motivated the development of a more sophisticated version of the principle to be applied within the SEFS dashboard: Equality-over-time. This principle has been influenced by the ECPCE Principle and bears a resemblance to the C&C approach. The Equality-over-time Principle is one of few principles which explicitly take future generations into account – an important consideration, given the inter-generational implications of climate change.

While strong cases have been made in favour of the Subsistence Emissions Principle in the climate ethics literature, it has not been included within the SEFS dashboard because of difficulties involved with applying it at the country-level. Yet a review of the climate ethics literature would have been insufficient without a discussion of it.

## §2.6.3 Combining climate ethics principles

Due to the aforementioned philosophical objections and limitations that climate ethics principles face, climate ethicists have advocated for combining such principles (Caney, 2010; Dooley et al., 2021). In this way, the strengths of one principle can be used to address the shortcomings of another (Roser & Seidel, 2017). The combining of ethical principles presents one way of offering more holistic perspectives on responsibility and fairness.

For instance, Caney (2010) puts forward a strong case for combining the Polluter Pays and Ability to Pay Principles in a Poverty-Sensitive Polluter Pays Principle. He asserts that the Polluter Pays

Principle "must be supplemented with an additional principle (or set of principles) . . . to deal with what we might term the Remainder" (p. 213). The Remainder would include various types of historical emissions that the Polluter Pays Principle has been less equipped to deal with, such as the emissions of previous generations, emissions from non-human-induced climate change and the legitimate emissions of the disadvantaged. He argues that the Remainder could be distributed according to the Ability to Pay Principle in an approach he terms the "Hybrid View" (p. 221). Similarly, Dooley et al. (2021) suggest that "[b]ecause capacity is an exclusively forward-looking indicator of equity, capacity should be utilized along with others that, like responsibility, are partly backward-looking" (p. 301).

Climate ethicists have also argued for combining the Subsistence Emissions and Equal Per Capita Emissions Principles. For instance, Vanderheiden (2008) proposes a "modified equal shares model", which would distribute survival emissions first to ensure everyone's basic needs are met, and then remaining luxury emissions on an equal per capita basis (p. 226). Page (2006) refers to such combinations of principles as "pluralist theories" (p. 172). As an example, he refers to "those that apply a sufficiency principle when at least some are below the threshold and a priority principle when all are above it" (p. 172). Such pluralist theories take a similar approach to Caney's Hybrid View by enabling a more sophisticated treatment of the so-called Remainder. While the SEFS dashboard does not yet support such pluralist theories by allowing users to combine and weight different climate ethics principles, it could support this in the future and is discussed in §6.6.

### §2.6.4 Other principles and theories of distributive justice

Many additional principles have featured in climate-related research and international negotiations and are of relevance to the type of distributive justice questions considered in this thesis. In its Fifth Assessment Report, the IPCC mention four main equity principles: responsibility, capability, right to development and equality (IPCC, 2014, p. 287). These IPCC principles are high-level, normative principles. As mentioned in §1.1.1, such normative principles do not provide sufficient guidance about what ought to happen. A principle of equality, for instance, does not specifically advise how equality might be achieved.

In contrast, the five principles which feature in the SEFS dashboard operate at the second-order regulative level in Figure 1 and offer a way to make the IPCC's normative principles action-guiding. For instance, all three financial burden-sharing principles take factual information into account by applying the normative principle of responsibility to real-world circumstances. Similarly, the

Subsistence Emissions Principle could be employed to provide action guidance to the normative principle of right to development.

Two other prominent principles which have not been reviewed in detail here, but which have featured strongly in global climate policy debates alongside equity and fairness principles, are efficiency and effectiveness (Pickering et al., 2009; Zhou & Wang, 2016).

The efficiency principle is often discussed in terms of the most efficient use of emissions or a minimisation of abatement costs (Manne & Stephan, 2005). Applied to the situation of distributing $CO_2$ emissions, an efficiency principle would allocate these inversely to countries' emissions intensities (Zhou & Wang, 2016). This would reward countries for their emission reduction efforts as they shift towards more low emission practices and could favour developed countries which have begun undergoing their low-carbon transition earlier than developing countries.

The effectiveness principle, in contrast, prioritises approaches and allocation methods which achieve the most effective real-world outcome, by enabling the greatest emissions reductions (Pickering et al., 2009; Wiegandt, 2001). Often, the effectiveness principle has been used alongside fairness criteria to evaluate the effectiveness of international climate agreements and policies (Pickering et al., 2012; Wiegandt, 2001). For instance, scholars have argued that effectiveness is related to fairness in the sense that "ineffective policies fail to prevent climate change and thus fail to bring about justice towards future generations" (Roser & Tomlinson, 2014, p. 226).

Both the efficiency and effectiveness principles have historically been favoured by developed countries, in contrast to the equity principles that developing countries advocate for and which have come to dominate the climate ethics literature (Pickering et al., 2009). For this reason, the efficiency and effectiveness principles are more sensitive to the means by which countries collaborate on climate-related goals and efforts to address the issue in the real world, rather than ideal end states articulated by equity principles.

Alongside these other principles, scholars have argued that theories of distributive justice are relevant to the types of questions considered in this thesis. Davidson (2021) has argued that carbon budget principles, as well as principles associated with sharing costs for different types of climate action, relate to different theories of justice or political schools of thought, including different types of libertarianism, cosmopolitan liberal-egalitarianism and utilitarianism. For instance, a right-libertarianism theory might distribute a carbon budget on the basis of a Grandfathering Principle, while a left-libertarianism theory might distribute a carbon budget on the basis of an Equal Per Capita Emissions Principle. In contrast, the cosmopolitan liberal-egalitarianism and utilitarianism theories would distribute a carbon budget in such a way that the least advantaged have the greatest benefit which would align with a Subsistence Emissions Principle.

Prioritarianism is another theory of distributive justice which can be viewed "as a kind of utilitarianism with a bias towards equality" (L. H. Meyer & Roser, 2006, p. 238). Broome (2012) explains that a prioritarian would prioritise raising the well-being of those most worse off. Applied to RQ3 – which is concerned with fair allocations of warming rights – this could translate into worse off people being allocated more warming rights than better off people. In this way, prioritarianism would encourage a shift towards equality (Broome, 2012; L. H. Meyer & Roser, 2006).

It is not within the scope of this research to link relevant theories to each of the ethical principles, nor to consider how different theories might rank each of the principles. This would be a difficult task because such theories are complex in nature and have complicated relationships to the applied principles and what priority they accord to them. The main point to note is that theories will prioritise the applied principles in different ways. For instance, a libertarian might put a lot of emphasis on the Polluter Pays Principle, but nothing on a Subsistence Emissions Principle. Whereas an egalitarian might insist upon the inverse priority. Either way, the SEFS dashboard accommodates a theoretical diversity and allows people to express their preferences in the way that they use the tool to better see the resulting real-world implications. The research's relevance to International Relations (IR) theories is similarly considered in §5.3.1.

## §2.6.5 Relevant dashboard tools

A number of dashboard tools have been developed since the 2000s. Table 6 categorises seven of these tools, which have been built by researchers from a range of institutes, universities, foundations and think tanks. Several of these, like the Climate Equity Reference Calculator (§2.6.5.2), have been particularly influential and cited in key reports, including the IPCC's Special Report on Global Warming of 1.5°C and the Paris Agreement has been a clear motivator for the development of tools like Paris Equity Check (§2.6.5.7) (IPCC, 2018a). All tools serve a similar purpose to the SEFS dashboard by providing possible equitable effort-sharing approaches for addressing climate change. Each of these seven tools will now be discussed in turn.

### *§2.6.5.1 Greenhouse Development Rights*

One of the earliest tools to emerge which sought to confront the burden-sharing questions that climate change raises was the Greenhouse Development Rights framework (Baer et al., 2009). Developed by researchers from EcoEquity and the Stockholm Environment Institute, the framework provides a means of distributing emissions reductions and adaptation to climate change between countries. It uses the capacity or the Ability to Pay Principle and responsibility in terms of Contribution to the Problem which, as mentioned in §2.6.1.1, is another name that the Polluter Pays Principle goes by. The Greenhouse Development Rights framework also contains a sufficientarianism aspect to it in that a development threshold is used to safeguard emissions rights for those countries which would otherwise fall beneath their development needs without them. In this way, the Greenhouse Development Rights framework includes a formulation of the Ability to Pay principle which is slightly different to that which has been included in the SEFS dashboard, as mentioned in §2.6.1.3.

#### *§2.6.5.2 Climate Equity Reference Calculator*

The Climate Equity Reference Calculator is the successor to the Greenhouse Development Rights framework, which focusses on allocating emissions rights aligned with budgets of an overall global effort (Holz et al., 2019). It includes a Responsibility-capacity-indicator, which enables users to apply different weightings to countries' levels of historical responsibility and their capacity for addressing the issue. The calculator draws on a core database of information, including historical GHG emissions datasets. The Climate Equity Reference Project used the calculator to assess the adequacy of countries' Intended Nationally Determined Contributions (INDCs) and establish equity criteria. This approach was highly regarded by scholars for the democratic process by which the equity criteria were reached (Dooley et al., 2021). While the calculator includes all six Kyoto GHGs: $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs and $SF_6$, the $CO_2e$ emissions metric is used to combine these different GHGs, which has been problematic for the way it misrepresents the warming effect of short-lived emissions over short time-frames as outlined in section §2.4.1. Moreover, the calculator does not provide an additional lens on responsibility by offering multiple accounting framework perspectives. Like its Greenhouse Development Rights framework predecessor, the Climate Equity Reference Calculator enables a focus on both mitigation and adaptation (Holz et al., 2019).

#### *§2.6.5.3 Fair Mitigation Finance Explorer*

Fair Mitigation Finance Explorer has been developed by researchers from the International Institute for Applied Systems Analysis – an international research body with member organisations in Africa, the Americas, Asia and Europe. The explorer's purpose is to present possible allocations of climate finance, for climate mitigation efforts only, across ten world regions: South-east Asia and Developing Pacific, Middle East, Asia-Pacific Developed, Africa, Southern Asia, Latin America and Caribbean, Eastern Europe and West-Central Asia, Eastern Asia, Europe and North America. The explorer enables applications of three of high-level equity principles – responsibility, capability and need – that are argued for in Dooley et al. (2021). Like Climate Equity Reference Calculator, the explorer provides the ability to combine different principles by giving each a weighting, where all three principles’ weightings must sum to 100. The tool utilises many datasets, including historical cumulative gross anthropogenic fossil fuel and industry $CO_2$ emissions between 1850–2019 from the IPCC Sixth Assessment Report’s Summary for Policymakers; indicators like GDP Per Capita and Capital stock Per Capita from the World Bank Indicators dataset; as well as estimates from academic articles (Pachauri et al., 2022). Two indicators can be used to apply each of the three principles, where each principle (and either of its two indicators) can also be applied on their own. However, Fair Mitigation Finance Explorer does not allow possible finance distributions to be based upon multiple GHGs, nor to be influenced by allocations of responsibility under different accounting frameworks. It also has a less granular focus, by including data at the world-region level, rather than at the country level.

#### *§2.6.5.4 Climate Equity Monitor*

Developed by researchers from India’s National Institute of Advanced Studies and the M. S. Swaminathan Research Foundation, the Climate Equity Monitor has been touted the “first-of-its-kind” equity assessment to emerge from the Global South (MSSRF, 2022, para. 1). The tool uses population figures from the World Bank and country-level emissions from the Potsdam Realtime Integrated Model for probabilistic Assessment of emissions Paths (PRIMAP) historical timeseries for all six Kyoto GHGs under the IPCC’s Fourth Assessment Report and the corresponding GWP values to calculate $CO_2$e emission figures. The equity approach is based upon cumulative historical emissions over the 1850–2019 period, expressed in $CO_2$e, being allocated between countries’ populations in 2019. Possible carbon budgets, as defined in the IPCC’s Sixth Assessment Report, are drawn on to determine the extent to which countries have exceeded or fallen within their fair shares of emission rights. The distribution of emission rights is displayed on a map, where shades of red indicate industrialised countries’ varying levels of carbon debt, while developing countries’ varying levels of carbon credit are indicated by shades of blue. It is the only tool of the seven dashboards considered here that refers to the Annex I/non-Annex I distinction, which can be used to toggle between these groups of countries on the map. While the monitor relies on an equal per capita distribution of emissions rights, the calculation is relatively static in that only countries’ populations in a single year (2019) are used. The conception of fairness under this principle does not capture how countries’ populations have varied in the past, nor how they might change in the future. The monitor is also limited in that it presupposes only one perspective for fair distributions of carbon budgets by reflecting countries' emissions under the $CO_2$e metric, without options to also select start years post-1850, and consider additional principles as well as the static per capita one.

### *§2.6.5.5 Climate Action Tracker*

Perhaps one of the most widely recognised and often quoted assessments of countries' progress towards reaching the Paris Agreement's Article 2 targets is the Climate Action Tracker. Developed by researchers at New Climate Institute and Climate Analytics, Climate Action Tracker seeks to assess the adequacy of country-level efforts against the Paris Agreement's Article 2 targets to determine countries' fair shares. Its rating system ranks countries' efforts from *Critically Insufficient* to *1.5°C Paris Agreement Compatible*. The Climate Action Tracker assessment take a broad view of countries' climate change mitigation efforts by considering national-level policies, as well as countries' historical emissions from the PRIMAP-hist dataset between 1990–2022. Countries' NDCs and other targets are also incorporated into the assessment.

However, the Climate Action Tracker only offers assessments for a select group of 42 countries and has been criticised by scholars for its untransparent methodology which does not clearly explain how different information is weighted and which specific ethical principles are drawn on and to what degree (Dooley et al., 2021). The Climate Action Tracker's lack of transparency is not conducive to encouraging deliberation and debate amongst its users. Despite these limitations, Climate Action Tracker has become an influential tool, commonly referred to in reports and by the media as evidence that countries must ramp up their efforts to reach Paris Agreement goals (Chen & Asgarian, 2024; Kirk, 2023).

### *§2.6.5.6 Eth Climate Calculator*

The Eth Climate Calculator, developed by academics at the ETH Zürich in Switzerland, is focussed on distributing a global $CO_2$ budget out to 2050 (Bretschger, 2013; Bretschger & Mollet, 2015). The calculator provides users with options to vary the size of this budget, include different numbers of countries, base the budget on four equity principles, and vary the degree of historic responsibility. The budget allocations are based upon a combination of four principles, a global carbon tax, and equal per capita emissions. The Eth Climate Calculator builds on the work of the Climate Equity Reference

Calculator, by using the same emissions, GDP and population datasets. It also includes a fuel price dataset which is treated as a proxy for the global carbon tax budget allocation.

Out of the seven dashboards discussed in §2.6.5, the Eth Climate Calculator and the Greenhouse Development Rights framework are the only two tools which explicitly apply the Ability to Pay principle. The other equity principles that the Eth Climate Calculator applies are cost sharing, technical contribution and technical development, where the cost sharing principle is related to the costs associated with addressing climate change for a country. The technical contribution principle reflects the size of a country's historical contribution towards developing carbon-efficient technologies and the technical development principle makes greater allowances for earlier emissions when less carbon-efficient technologies were available. These last three principles could be considered similar to the efficiency and effectiveness principles, discussed in §2.6.4, in their focus on the means rather than the ends of reaching climate goals. The inclusion of these principles distinguishes the Eth Climate Calculator from the other dashboards, which tend to draw on more commonly discussed high-level ethical principles like responsibility, capability and need. The Paris Agreement's entry into force and the announcement of countries' INDCs was a clear motivator for the development of the Eth Climate Calculator.

#### *§2.6.5.7 Paris Equity Check*

Paris Equity Check is the result of collaborative efforts between the Australian-German Climate & Energy College, The University of Melbourne and The Potsdam Institute. Paris Equity Check uses what it describes as "cost-optimal" mitigation scenarios to assess the global adequacy of countries' NDCs and fair shares of a remaining emissions budget (Robiou du Pont et al., 2017, p. 1; Robiou du Pont & Meinshausen, 2018). The budget is assigned according to five equity categories: capability, equal per capita, Greenhouse Development Rights, equal cumulative per capita and a constant emissions ratio. As mentioned in §2.6.2.1, a constant emissions ratio is another name for the Grandfathering Principle. Paris Equity check draws on results from the MAGICC SCM and, like the Climate Equity Reference Calculator, combines historical estimates of all six Kyoto GHGs for countries, according to the $CO_2e$ emissions metric. However, rather than letting users toggle between these equity categories to understand how country-level fair shares might vary according to each equity category or weightings of each, Paris Equity Check combines all categories to arrive at average values for each country or group of countries. This approach, which frames resulting distributions as "Equitably Determined Contributions", is criticised by Dooley et al. (2021) for claiming objectivity through combining multiple equity principles into a composite index.

Assessments like Paris Equity Check, in their pursuit of equitably determined contributions, appear to believe that a single moral or equitable truth can be arrived at. This is symptomatic of the moral objectivism that a positivist would presuppose. Arguments against Paris Equity Check by Dooley et al. (2021) reinforce the importance and usefulness of this research's pragmatist-positivist approach for enabling interpretivist explorations of principles' multiple meanings and supporting the SEFS dashboard's ethical pluralism.

| Tool | Greenhouse Development Rights | Climate Equity Reference Calculator | Fair Mitigation Finance Explorer | Climate Equity Monitor | Climate Action Tracker | Eth Climate Calculator | Paris Equity Check | Science and Ethics of Fair Shares |
|---|---|---|---|---|---|---|---|---|
| **Area of concern** | Mitigation, adaptation | Mitigation gaps | Mitigation finance | Carbon budgets,<br>Carbon debts and credits | Overall assessment of how countries are tracking in reference to Paris Agreement goals | Distributing a global $CO_2$ budget out to 2050 | Adequacy of NDCs to meet Paris Goals<br>Mitigation gaps<br>Emission allocations | Mitigation finance<br>Warming rights |
| **RQ relevance** | 2, 3 | 3 | 2 | 2, 3 | 2, 3 (not so clear) | 2, 3 | 2, 3 | 1, 2, 3 |
| **Principles operationalised** | | | | | | | | |
| Ability to Pay | Yes | | | | | Yes | | Yes |
| Beneficiary Pays | | | | | | | | Yes |
| Capability | | | Yes | | Yes | | Yes | |
| Capacity | Yes | Yes | | | | | | |
| Equal Cumulative Per Capita | | | | Yes | Yes | | Yes | |
| Equal Per Capita | | | | | | | Yes | |
| Equality-over-time | | | | | | | | Yes |
| Grandfathering / staged approaches / constant emissions ratio | | | | | Yes | | Yes | Yes |
| Greenhouse Development Rights | | | | | | | Yes | |
| Need | | | Yes | | Yes | | | |
| Polluter Pays / Contribution to Problem | Yes | | | | | | | Yes |
| Responsibility | Yes | Yes | Yes | | Yes | | | |
| Sufficientarianism / Subsistence Emissions | Yes | Yes | | | | | | |
| **Link to tool** | http://gdrights.org/ | https://calculator.climateequityreference.org/ | https://data.ece.iiasa.ac.at/faimitigation/ | https://climateequitymonitor.in/pari | https://climateactiontracker.org/ | http://www.ccalc.ethz.ch/ | https://paris-equity-check.org/ | https://live-sefs-dash-app.onrender.com |
| **Literature** | Baer et al. (2008)<br>Baer et al. (2010) | Holz et al. (2018)<br>Holz et al. (2019)<br>Kemp-Benedict et al. (2019) | Pachauri et al. (2022) | Kanitkar & Jayaraman (2019) | Climate Action Tracker (2023) | Bretschger (2013)<br>Bretschger & Mollet (2015) | Robiou du Pont (2016)<br>Robiou du Pont (2017)<br>Robiou du Pont (2018) | |
| **Focus: past or future** | **Future:** Emission reduction/mitigation obligations and climate finance obligations over 2010–2020 and 2020–2030 | **Future:** Global mitigation requirements and mitigation and adaptation costs between1990–2035 | **Future:** Sharing of annual mitigation investment needs in the decade from 2020–2030 | **Past:** Historical emissions over 1850–2019 to determine carbon debts and credits | **Future:** Emission allowances in the years 2025, 2030 and 2050 | **Future:** Global $CO_2$ budget out to 2050 | **Future:** Emissions budgets out 2050 and 2100 | **Past & Future:** Current climate mitigation finance obligations and remaining warming rights |
| **Greenhouse gases** | $CO_2$ from fossil fuel consumption | $CO_2$ (excluding emissions from LULUCF)<br>All other non-$CO_2$ in $CO_2e$, using $GWP_{100}$ values from IPCC AR4 | $CO_2$ from fossil fuel and industry | Six Kyoto GHGs: $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$ (in $CO_2e$). Excludes emissions from LULUCF, international shipping and aviation emissions | Six Kyoto GHGs: $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$ (using $GWP_{100}$ values from IPCC AR4) | $CO_2$, excludes emissions from land use and reforestation | Six Kyoto GHGs: $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$ (in $CO_2e$, using $GWP_{100}$ values from IPCC SAR). Excludes emissions from LULUCF, international shipping and aviation emissions | Emissions and warming amounts from $CO_2$, $CH_4$, $N_2O$ and NOx |
| **Organisations, affiliations** | EcoEquity<br>Stockholm Environment Institute | EcoEquity<br>Stockholm Environment Institute | Shonali Pachauri (lead author) works at the International Institute for Applied Systems Analysis | National Institute of Advanced Studies, Bengaluru, India<br>M.S. Swaminathan Research Foundation, Chennai, India | New Climate Institute<br>Climate Analytics | ETH Zürich University | Australian-German Climate & Energy Collage, The University of Melbourne<br>Potsdam Institute | Auckland University of Technology |

*Table 6. Dashboard tools*

## §2.6.6 Section summary

The climate ethics literature is diverse and from its outset has considered the types of distributive justice questions which this research project focusses on. The abstract, ethical debates surrounding six prominent ethical distributional principles – Polluter Pays, Beneficiary Pays, Ability to Pay, Grandfathering, Equal Per Capita Emissions and Subsistence Emissions – have been reviewed and it was found that each principle has unique strengths and weaknesses from a philosophical standpoint and can be applied with varying degrees of ease, depending on what data is available. Given the principles' advantages and limitations, climate ethicists have argued for multiple principles being combined in a pluralistic manner, to better capture a diversity of perspectives on fairness.

The dashboards discussed above and presented in Table 6 all seek to answer burden-sharing questions similar to those that have been raised throughout the history of international climate negotiations and the climate ethics literature. The number of ethical principles considered by these tools is vast; across all seven tools, thirteen different ethical principles are either implicitly or explicitly referenced and operationalised. The most common of these being components of the UNFCCC's CBDR-RC principle. While the tools vary in their focus, most are concerned with climate mitigation – whether this be emissions reductions, mitigation finance or assessing the adequacy of countries' NDCs. The tools' variable focuses have made it difficult to directly compare results from the SEFS dashboard with these tools, as will be discussed in Chapter 4.

These dashboards also have a number of shortcomings, including untransparent methodologies of fair shares approaches, in the case of Climate Action Tracker; a belief that equitable effort-sharing approaches can carried out in an objective way and produce determinate answers, in the case of Paris Equity Check; and an unintentional conflation of ethical domains, where a mixture of financial burden-sharing and budget allocation principles are used. The conflation of ethical domains will be discussed further in §2.7. The dashboards also neglect key principles like the Polluter Pays and Beneficiary Pays Principles, despite significant portions of the climate ethics literature being devoted to discussing these.

While many of the dashboards do include multiple GHGs in their equity assessments, these are often combined using the $CO_2$e metric, which has been problematic for the reasons outlined in §2.4.1. Additionally, none of the dashboards offer multiple accounting frameworks as options for distributing responsibility. Instead, they assume a production-based paradigm of responsibility. The SEFS dashboard addresses these gaps and overcomes these limitations by enabling an analysis of country-level contributions to global warming so that five ethical principles can be applied using a range of scientific, accounting framework and ethical parameters. The SEFS dashboard's specific use of countries' contributions as a temperature increase also puts country-level shares in line with the Paris Agreement's Article 2 temperature targets.

## §2.7 Climate justice typology

As mentioned at the beginning of §2.6, questions of distributive justice have consistently been raised within the climate ethics literature and a range of ethical principles are drawn on to answer these. Distinctions can be made between two types of distributive justice question, commonly referred to as the *allocation question*: the sharing of financial costs for addressing the climate change and the sharing of rights to emit GHGs within fixed carbon budgets.

Several existing tools that were reviewed in §2.6.5 displayed a conflation of these separate distributive justice concerns. Most commonly, financial burden-sharing principles were employed to answer questions which focus on distributing carbon or emissions budgets, which budget allocation principles are more suitable for answering. For instance, both the ETH Climate Calculator and Paris Equity Check slide across these distinct ethical domains by employing both financial burden-sharing and budget allocation principles within their assessments.

Taking the ETH Climate Calculator as an initial example, the aim of the calculator is to determine fair shares of a $CO_2$ budget out to 2050. The calculator provides carbon budget allocations according to three different approaches based on equity principles, a global carbon tax, and equal per capita emissions. However, the inclusion of the Ability to Pay Principle – a financial burden-sharing principle – within the equity principle approach for allocating $CO_2$ budgets – which budget allocation principles are more suitable for answering – represents a conflation of ethical domains.

Similarly, Paris Equity Check employs five very different distributive criteria within its hybrid assessment. These include a Capability principle (another name for the Ability to Pay Principle, a financial burden-sharing principle) and a Constant emissions ratio principle (another name for the Grandfathering Principle, a budget allocation principle). These occurrences of conceptual confusion suggest misunderstandings about the purpose of financial burden-sharing principles and budget allocation principles, and the types of questions they are most suitable for answering. This highlights a need to clearly distinguish between different types of questions and principles, which motivated the development of a climate justice typology for this thesis, presented below in Figure 6.

Figure 6 formalises how the three financial burden-sharing principles – Polluter Pays, Beneficiary Pays and Ability to Pay – are used to answer financial cost-related questions, whereas the three budget allocation principles – Grandfathering, Equal Per Capita Emissions and Subsistence Emissions – are used to answer rights to emit questions.

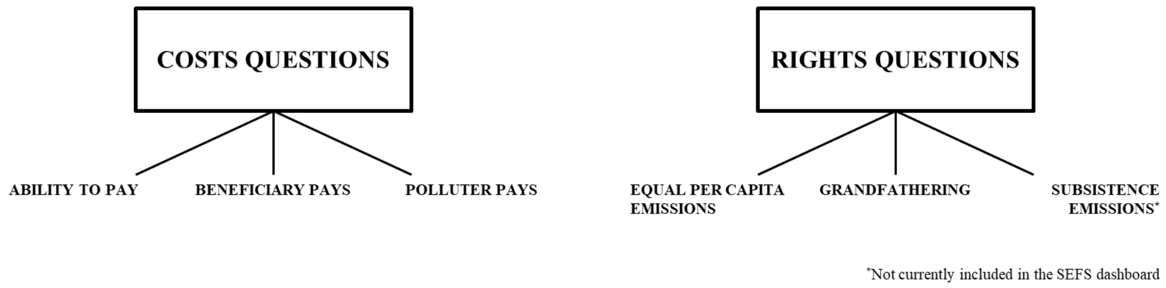


*Figure 6. Climate justice typology of questions and related ethical principles*

By clearly separating these two related, but distinct, ethical domains, the climate justice typology brings greater conceptual clarity to this research inquiry. It also follows the advice of several scholars, who have stressed the importance of keeping the sharing of financial costs and allocations of carbon budgets separate (Duus-Otterström, 2023; Grubb, 1995; Pickering et al., 2012; Shue, 1993).

## §2.7.1 Possible explanations for this conceptual confusion

A possible explanation for how such conceptual confusion may have arisen is that the climate ethics literature has developed in a relatively organic way, with many sources of influence. For instance, real-world influences on the literature can be found in the way that the 1997 Brazilian Proposal articulated a methodology for calculating countries' historical contributions to global warming, as a measure of their responsibility for the issue (La Rovere et al., 2002). This prompted studies in the early 2000s to consider indicators and measures that would assist international conversations about the various ways in which warming could be calculated and assigned to countries (Blanchard, 2002; den Elzen et al., 2005; Höhne & Blok, 2005).

Several prominent climate ethicists and moral and political philosophers have also had an influence on the climate ethics literature by theorising and debating such principles in the abstract (Gardiner et al., 2010; Page, 2006; Shue, 2014). While these philosophers' understandings of the principles have grown with time, confusion can arise for researchers in this field when different principles, with apparently similar understandings of fairness, are used to answer both costs- and rights-related questions within the same assessment.

Caney (2009), for instance, presents three different principles for distributing rights to emit: equality, grandfathering and historical responsibility, where the latter acts as a budget allocation principle. However, in other articles by Caney and Derek Bell, historical responsibility can also be used to mean the Polluter Pays Principle (Bell, 2011; Caney, 2005, 2010).

This can create confusion because the Polluter Pays Principle tends to be concerned with distributing climate-related costs, rather than rights to emit, as seen in Table 5. While Caney's higher-level philosophising of historical responsibility serves its purpose within moral and political philosophy, to researchers seeking to apply ethical principles to data, such discussions can generate misunderstandings by seeming to slide over an important distinction between climate-related costs and GHG emission rights.

The typology in Figure 6 presents one way of better organising concepts within the distributive climate justice literature and provided clarity about which type of question each principle relates to, during the research process. There are, however, many ways to categorise different ethical principles and the questions they are suited to answering. For instance, the Polluter Pays and Grandfathering Principles are different principles which both share a concern with what has happened in the past. However, their purposes vary in the way they distribute different types of goods: financial resources and emissions rights. Therefore, they must be employed to answer different questions to each other. Yet both principles could fall within the same category of being historically focussed principles.

By connecting costs- and rights-related questions with the most appropriate ethical principles, the typology presents a novel contribution to the climate ethics literature that could aid future researchers trying to make sense of the domain as they seek to operationalise principles. The next section summarises this chapter.

## §2.8 Chapter summary

Despite increasing scientific evidence for climate change and climate negotiators' efforts to address the issue by way of international agreements over the past thirty-five years, countries' GHG emissions have continued rising. As a result, calls to address the challenge are growing increasingly urgent, especially from those who stand to lose the most. The need for independent assessments which evaluate equitable effort-sharing approaches is of particular relevance within this Paris Agreement era, where countries voluntarily specify their national contribution to the global effort.

To inform their ethical effort-sharing discussions, climate change negotiators have tended to draw on high-level regulative principles enshrined in international law, like the CBDR-RC principle. However, without facts to apply such principles at the country-level, the CBDR-RC principle is not conducive for fostering well-informed debate about possible distributions.

Within the climate ethics literature, the CBDR-RC principle is often made more specific by way of lower-level regulative principles, like the three financial burden-sharing principles presented in Table 1: the Polluter Pays, Beneficiary Pays and Ability to Pay. However, this literature review has found few instances of these financial burden-sharing principles being explicitly applied within practical climate ethics assessments and dashboard-style tools. The CBDR-RC principle and other high-level regulative principles feature more commonly in contrast.

An absence of these lower-level regulative principles has limited opportunities for international climate negotiators and policymakers to become better informed about what the CBDR-RC might mean at an individual country level, by being made more specific. Ultimately, this leaves these actors in a sub-optimal position, which is undesirable when the Paris Agreement contains no mechanism for assessing the ethical adequacy of countries' proposed shares.

Empirically grounding lower-level regulative principles, then, with real-world information presents a way of making the CBDR-RC principle more practically useful. International negotiators and policymakers would stand to benefit from tools which present equitable effort-sharing approaches for climate change along the lines of the lower-level regulative principles which are made more useful by facts. Such principles offer opportunities to better guide climate action, while producing possible answers to burden-sharing questions that climate negotiators face in the real world.

For this reason, tools which can utilise scientific and ethical information to conduct top-down, independent ethical assessments of countries' responsibilities for addressing climate change are important for assisting civil society efforts to scale up nation-state contributions over time. While several such tools – discussed in §2.6.5 – do exist, some have a less granular, regional-level focus and do not cover a wide range of scientific and ethical parameters. Two of the tools also suffer from untransparent methodologies and display a form of moral objectivism which is misleading and does not reflect the ethical pluralism of the climate ethics literature.

Instances of conceptual confusion arising within the same dashboard-style tools motivated the development of a climate justice typology, presented in §2.7. The typology supports a clear distinction between costs- and rights-based questions, by connecting financial burden-sharing principles with the former and using budget allocation principles to answer the latter. This has been important for providing greater clarity during the research process when answering RQ2 and RQ3.

This review has exposed the issues these tools suffer from and identified a number of gaps in this literature that this research seeks to fill. The SEFS dashboard addresses these gaps by presenting a novel method for people to investigate the results of operationalising multiple ethical principles using a wide range of country-level information. Despite not featuring in the SEFS dashboard, the Subsistence Emissions Principle was discussed in §2.6.2.3 due to its prominence in the climate ethics literature.

Chapter 2 has also drawn attention to underlying beliefs of parameters, including accounting frameworks and ethical principles, which feature within the SEFS dashboard. Offering users a range of parameters (and choices) within the SEFS dashboard is one way that underlying judgments and beliefs can be made apparent and questioned, as opposed to being implicitly – perhaps unknowingly – taken for granted or assumed. In this way, users gain an opportunity to see how their choices result in varied distributions of financial shares for climate mitigation and rights to emit GHGs.

The literature review has highlighted seven gaps that this research fills:

1. calculating historical warming from multiple climate forcers at the country level, over multiple time-periods;
2. calculating countries' consumption-based emissions on a per gas basis;
3. explicitly operationalising regulative ethical principles from the philosophical climate ethics literature, like the Polluter Pays, Beneficiary Pays and Ability to Pay Principles;
4. explicitly applying forms of the Grandfathering Principle on its own;
5. applying sophisticated versions of the Equal Per Capita Emissions approach which take future generations into account when allocating GHG emissions budgets;
6. dashboard-style tools which integrate a range of real-world datasets, scientific and ethical parameters to answer the questions of distributive justice that are raised in the climate ethics literature; and
7. tools within the climate ethics literature which help to prevent a conflation of ethical domains in applied ethics studies and dashboard-style tools.

Specific contributions from this research, which fill the seven gaps listed above are:

1. using an SCM to calculate countries' historical warming contributions from three climate forcers, over multiple time-periods;
2. using an environmentally extended MRIO to calculate countries' consumption-based emissions on a per gas basis;
3. carrying out calculations to explicitly operationalise the Polluter Pays, the Beneficiary Pays and the Ability to Pay Principles;
4. explicitly applying forms of the Grandfathering Principle on its own;
5. developing and operationalising a more sophisticated version of the Equal Per Capita Emissions approach, the Equality-over-time Principle;
6. building a novel dashboard which integrates scientific and ethical information to answer the RQs; and

7. developing a climate justice typology to clearly distinguish between financial burden-sharing principles and budget allocation principles, so as to avoid a conflation of ethical domains.

By detailing brief histories of scientific evidence for climate change and international climate negotiations, reviewing a range of literatures to articulate gaps within the applied ethics literature, and expressing the unique contributions of this research, Chapter 2 has built the case for the importance of using dashboard-style tools to serve the democratic need of allowing the international community to explore their value differences. The next chapter describes the process of building the SEFS dashboard, including the overall research design and methods that were used to develop and calculate its key components.

# Chapter 3 Research design, methodology and methods

## §3.1 Chapter overview

The applied aspect of this research involves building and demonstrating the Science and Ethics of Fair Shares (SEFS) dashboard, which supports the filtering and interrogation of large country-level datasets and information to help answer the three research questions (RQs). Chapter 3 begins by overviewing the research design, including the pragmatist-positivist approach, methodology and methods for carrying out the research (§3.2).

Next, to help the reader appreciate the SEFS dashboard's layout, examples of two dashboard pages are shown and described in §3.3. In §3.4, the secondary data sources displayed in the dashboard are described, including the assumptions, uncertainties and caveats that sit behind them, and the pre-processing steps which were used to transform data into more useable formats for the dashboard.

The procedure for calculating countries' historical contributions to global warming from three climate forcers by drawing on a simple climate model (SCM) to run modified *leave-one-country-out* experiments is outlined in §3.5. How the environmentally extended input-output analysis (EE-IOA) method was used to calculate countries' consumption-based emissions is described in §3.6.

The approach for applying five ethical distributional principles – Polluter Pays, Beneficiary Pays, Ability to Pay, Grandfathering and Equality-over-time – is articulated in §3.7. Feedback obtained while demonstrating the dashboard to several climate experts throughout July–September 2023 is explained in §3.8, along with a description of how this expert input influenced the dashboard's design. The chapter is summarised in §3.9.

## §3.2 Research design

All research operates within a particular paradigm that shapes the objectives and decisions of the research. Guba and Lincoln (1994) define a research paradigm as "the basic belief system or worldview that guides the investigator, not only in choices of method, but in ontologically and epistemologically fundamental ways" (p. 105). Underpinning each paradigm are fundamental beliefs about the nature of reality (ontology) and how knowledge is created (epistemology) (Crotty, 1998; Grix, 2004). The paradigm guides the research approach, the plan or strategy that will be taken (methodology), and specific procedures that will be followed (methods) (Crotty, 1998). Each of these elements and how they relate to this research project are shown in Figure 7 below and will be discussed in turn.

### §3.2.1 Positivism

This research predominantly functions within a positivist paradigm. While there are diverse forms and understandings of positivism, it is commonly considered a theory of knowledge which presupposes a foundationalist ontology which rests upon justified beliefs, and an objectivist epistemology which means that meaning about the world lies in objects and it is the role of the researcher to discover this meaning (Crotty, 1998; Halfpenny, 2015; Hasan & Fumerton, 2022; Ryan, 2015). Two distinct forms of positivism illustrate how the paradigm has evolved over time.

Comtean positivism, which developed in the early 19th century, emphasised the existence of "invariable natural laws" and believed that legitimate knowledge is either based upon observation or must be obtained through experience and empirical evidence (Halfpenny, 2015, p. 14). By using such scientific methods, Comtean positivism aimed to discover generalisable laws and unify the sciences – both natural and social – into one integrated system where social knowledge could be acquired in a similar way to the natural sciences (Crotty, 1998; Halfpenny, 2015; Pollins, 2007).

Later, in the 1930s, logical positivism – a renewed form of positivism which emerged out of the Vienna Circle, where it was developed by a group of natural scientists turned philosophers – placed importance on logical reasoning and analysis and introduced the verification principle or principle of verifiability (Drakopoulos, 2024; Khanday et al., 2024). According to this principle, "no statement is meaningful unless it is capable of being verified", where a process of verification would involve the statement being tested by observation and experiments (Crotty, 1998, p. 25; Goff, 2024). Like Comtean positivism, logical positivism also sought to unify the sciences, albeit in terms of a common language and logic in the way that mathematics has a common language and logic (Halfpenny, 2015).

While these different forms of positivism diverge in their orientations and what they emphasise, they both contain key tenets which connect them with the positivist paradigm (Crook & Garratt, 2005). Common to both forms of positivism is a focus on identifying causal relationships to understand outcomes that are observed and a belief that knowledge must be arrived at in an objective manner, where logical positivism is more stringent about maintaining "[a] clear disjunction . . . between fact and value" (Crotty, 1998, p. 26; William, 2024).

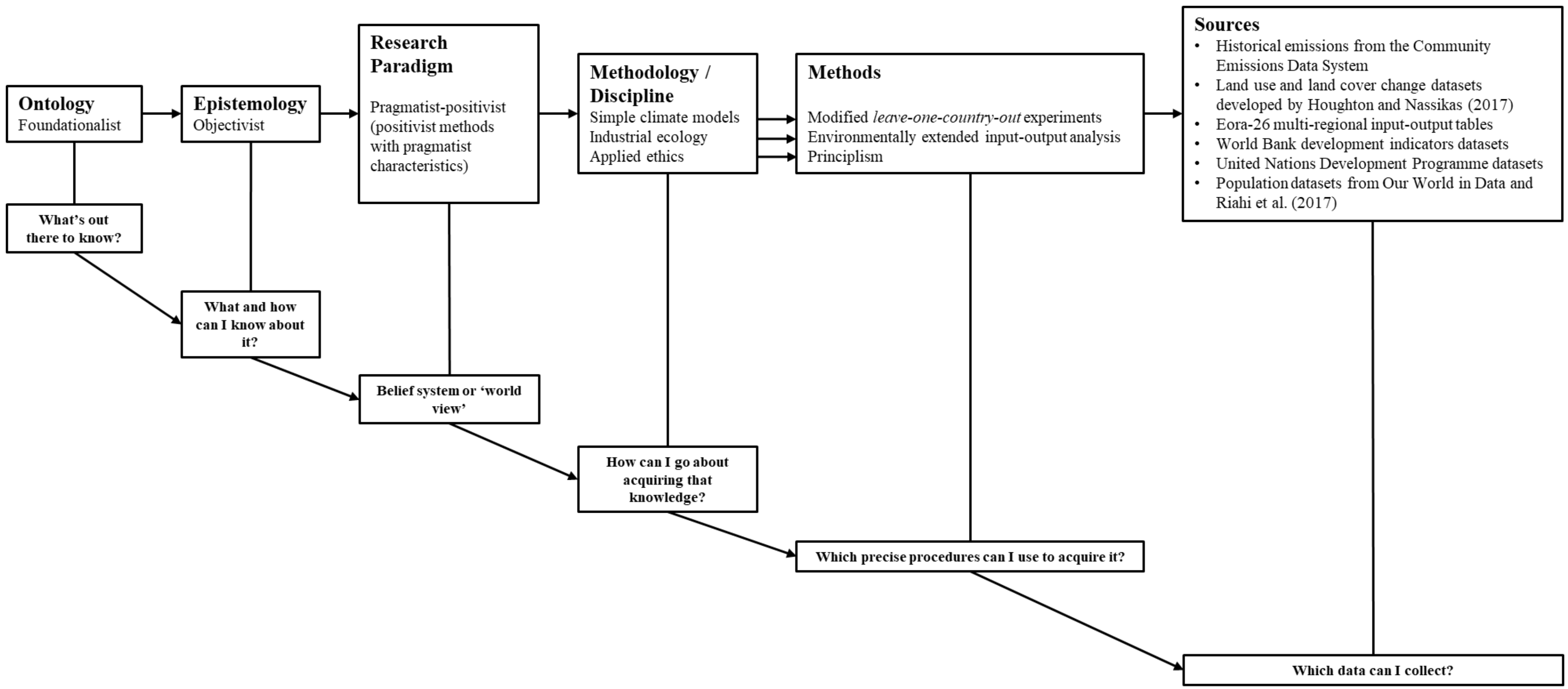


*Figure 7. "The building blocks of research" as defined in Grix (2004), adapted to this research*

To summarise, the main tenets of positivism are: that knowledge is obtained through empirical evidence – either observational data or by experience; that a single, tangible reality exists; relationships are causal; and there is a clear fact-value distinction (Halfpenny, 2015). Additionally, applying a positivist paradigm involves hypothetico-deductive reasoning, whereby the researcher forms a hypothesis and then tests, through experimentation, whether or not this is supported by data (Park et al., 2020; Ryan, 2015; William, 2024).

The research approach in this thesis is practically consistent with positivism in several ways. First, its use of mathematical and engineering-related methods applied to quantitative data adheres with an empirical approach, where country-level information for applying different ethical principles within the dashboard are treated as scientific facts. Second, in its use of secondary data sources, the research assumes a separation between the researcher and the data, so the researcher can adopt the position of a "disinterested scientist" (Guba & Lincoln, 1994, p. 112). According to the positivist worldview, this enables the research to be carried out in an objective manner, with a clear distinction between the objective facts of country-level greenhouse gas (GHG) emissions and the subjective values that inform different views on how we practically ought to respond to the issue.

Third, there are affinities between the principlist method to ethics used in this research (discussed further in §3.2.3.3) and the deductivist reasoning that characterises positivism. Similar to how positivism forms scientific hypotheses by working back deductively from natural laws, a principlist approach to ethics involves deducing determinate answers to ethical questions by applying normative principles to the real-world circumstances of an ethical dilemma. Both involve deductive reasoning, albeit one in the domain of facts (positivism), the other in the domain of values (principlism).

Despite the positivist paradigm having successfully progressed much scientific research and what is commonly referred to today as "evidence-based" research, it has faced considerable criticism, especially when applied to the social sciences and in its aim to determine generalisable laws (Khanday et al., 2024, p. 535). Positivism's emphasis on objectivity does not consider the social context in which research is carried out and how knowledge is not generalisable to multiple cultures and places, but rather "socially situated" (Harding, 1992, p. 438; William, 2024). Additionally, the importance that positivism places on empirically verified knowledge makes an ability to explore subjective beliefs and interpretations out of scope (Khanday et al., 2024). These criticisms of positivism have implications for this research.

First, under a purely positivist approach, the ethical principles in this research would be considered universal laws or inviolable moral truths within a positivist paradigm, instead of regarded as commonly used principles which inform deliberation and collective decision-making in the climate policy community. This could lead to a form of moral objectivism, such as that observed in existing climate ethics assessments like Paris Equity Check, as explained in §2.6.5.7. Second, by taking laws and principles as given, positivism would inhibit an interpretivist approach to the ethical principles used in this research and an exploration of their multiple meanings.

For these reasons, the positivist approach of this thesis is complemented by pragmatist commitments, discussed in §3.2.2. This enables the research to progress in a positivist manner, with mostly positivist methods, but without a strong commitment to the existence of generalisable laws and the fact-value distinction that characterises both forms of positivism – Comtean and logical. The incorporation of pragmatism, as discussed in the next section, has allowed such ontological commitments to be suspended or withheld.

## §3.2.2 Pragmatism

Pragmatism is often not considered a doctrine or philosophical paradigm on its own, but is rather an approach for doing research, "characterised by its method of inquiry … [which] … unfolds as an interdisciplinary practice that structures our analysis of problems in the world" (Voisard & Wallimann-Helmer, 2024, p. 9). Pragmatism is open to considering multiple theories and perspectives on the basis of whether they provide useful insights, rather than whether they absolutely capture the nature of reality and have been arrived at in an empirical way.

According to classical pragmatist, William James, a pragmatist takes the view that "no theory is absolutely a transcript of reality, but that any one of them may from some point of view be useful" (James, 1906, as cited in McDermott, 1977). Expanding on this notion, Hilary Putnam has argued that: "They [the classical pragmatists] held that we should recognize that there are many different descriptions of the world, to be evaluated by how far they are useful in achieving specific ends, there being no description of the world available apart from that from some particular standpoint" (Putnam, 1987, p. 70). In this way, pragmatism will endorse a theory, method or way of looking at the world provided it serves a useful function. It is agnostic about truth in an objective sense, but treats useful theories and principles as closely associated with truth, because their usefulness in practice is a reliable indicator of their truthfulness. For example, a theory's capacity to generate successful predictions, or an ethical principle's capacity to guide practical decisions in a way that consistently produces positive outcomes or social approval are useful. This is in contrast to the more rigid tenets of positivism which assumes that true knowledge can be acquired by the application of rigorous scientific methods.

As well as its concern to be useful, pragmatist research is also often characterised as having a mixed methods design, being motivated by real-world problems, having a purpose-orientated inquiry, and ultimately being hopeful that it can have an influence on addressing real-world problems (Johnson & Onwuegbuzie, 2004; Kaushik & Walsh, 2019; D. L. Morgan, 2014a, 2014b).

This research project therefore aligns with pragmatism through its multi-method strategy, focus on the wicked challenge of climate change, and aim to develop a tool that will be useful in the real world by supporting deliberation and debate amongst the tool's target audiences. Pragmatism's perspectives on truth and sensemaking have also been particularly helpful in freeing the research from some of positivism's more stringent beliefs, discussed previously in §3.2.1.

For instance, pragmatism's view of truth contrasts with the moral objectivism that positivism might pursue, where a logical positivist might view the application of an ethical principle as a single moral truth. This can be partly explained by pragmatism's anti-foundationalist nature being antithetical to logical positivism which "was foundational and believed in a single method for finding a single truth" (Baker & Schaltegger, 2015, p. 266). As Baker and Schaltegger (2015) point out, "Pragmatism maintains a challenging, albeit liberating, view of truth, wherein the "truth" value of a statement resides not in how accurately it represents the external world but rather in how useful it is for enacting change" (p. 265). In this regard, pragmatism was an appropriate perspective for handling the multiplicity of results that can be obtained from the dashboard, by applying diverse ethical principles.

Taking a pragmatist view also moderated the more stringent positivist belief that a single answer for how much responsibility countries ought to take for addressing climate change could be arrived at, akin to a generalisable natural law. Rather than seeing the pursuit of knowledge as being governed by the aim to identify true laws of nature by mirroring reality, pragmatists emphasise how truths can shift with time, and are sensitive to the particular time and context in which individuals find themselves (Barnes, 2008). This was a helpful perspective to take when analysing the results of applying the ethical principles and the way in which countries' contributions to climate change and the normative assumptions which underpin what constitutes a reasonable level of moral responsibility are continuously shifting. Such a perspective has supported the principlist belief that rather than arriving at a single solution, there many views of distributional fairness which are continuously revisable.

Related to its notion of truth, pragmatism is also concerned with the concept of sensemaking, which describes how individuals come to view and "make sense of" the world around them (Baker & Schaltegger, 2015, p. 263). John Dewey encouraged a form of practical sensemaking, when his theory of education argued for a "learning by doing" approach, where learning is inherently practical and informed by one's experiences (Sikandar, 2015, p. 195). This experiential form of learning is evident, both in the process of developing the dashboard, as well as in how its target audiences are encouraged to engage with it. The research's experimental design of developing a practical tool, while being continuously guided by ideas from a range of literatures is reflective of a learning-by-doing approach. Additionally, the dashboard can encourage a secondary, experimental learning-by-doing in its target audiences as they interact with the dashboard. The practical way in which the tool’s target audiences can conduct their own experiments will allow them to make better sense of what ethical principles can mean in practice when they are applied with real-world data.

Finally, pragmatism’s intrinsic hopefulness is exemplified through the research’s motivation to be useful and applicable to the real-world challenge of global climate change. Within their philosophies, John Dewey and John Rawls both stressed the important role that democratic deliberation and debate have for advancing knowledge (Festenstein, 2023; Saward, 2002). By developing a tool which supports ethical analysis, and which can be used to encourage discussions amongst the communities of international negotiators and policymakers, greater understandings of nation-states’ moral responsibilities for climate change can be built in the hope that useful insights for addressing the issue might be uncovered by these communities.

Ultimately, pragmatism informs the approach to positivism. A range of positivist methods have been used, in so far as they are useful, for progressing the research and to provide evidence-based information which will strengthen collective decision-making. However, by taking a pragmatist perspective, critical distance is preserved towards the hard positivist assumptions of there being generalisable natural laws and truly objective knowledge through a strong fact-value distinction. In this way, the paradigm that guides this research is positivism with pragmatist characteristics.

## §3.2.3 Methodology and methods

The three main methodologies or disciplines that this research draws on are SCMs, industrial ecology (IE) and applied ethics. Each of these methodologies and the specific techniques (methods) that are used to carry out the research will be discussed in turn, starting with SCMs and modified *leave-one-country-out* experiments.

### *§3.2.3.1 Simple Climate Models (SCMs) and modified leave-one-country-out experiments*

SCMs (discussed in §2.4.2) are well-established approaches for simulating the Earth’s climate system, which enable climate scientists to reconstruct the past climate or predict how the climate might change in the future. The specific type of climate model that has been employed in this research is the Finite Amplitude Impulse Response (FaIR) model (C. J. Smith et al., 2018). By using this model to run modified *leave-one-country-out* experiments, where emissions of three climate forcers for each country are excluded and then included within the model, estimates of countries' historical contributions to global warming on a per gas basis can be calculated (Callahan & Mankin, 2022). The specifics of how code which interacts with the FaIR model has been adapted to support the aims of this research are described in §3.5.

#### *§3.2.3.2 Industrial Ecology (IE) and environmentally extended input-output analysis (EE-IOA)*

IE, also referred to as "the science of sustainability", is a discipline concerned with studying relationships between industrial processes and the natural environment, within economies (Allenby, 1998; Kapur & Graedel, 2004, p. 373). The discipline cuts across the fields of science, engineering, ecology and economics, and arose in the late 1990s when motivations to better understand the environmental impacts of industrial processes and concerns about unsustainable practices were growing (Ehrenfeld, 2000).

To study the flow of natural resources throughout an economy, IE uses a range of analytical techniques (Shah et al., 2024). One of these – EEOIA – can be used to calculate countries' consumption-based emissions (Wiedmann, 2009b). Consumption-based accounting (CBA) offers a different perspective on allocating responsibility for addressing climate change compared with the conventional production-based accounting (PBA) approach, discussed in §2.5.1. The specific matrix algebra steps that have been used as part of EE-IOA are outlined in §3.6.2.

#### *§3.2.3.3 Applied ethics and principlism*

The final methodology in this research is applied ethics. Also known as "practical ethics", applied ethics is a branch of moral philosophy which seeks to apply ethical principles to practical problems (Fitzpatrick, 2008, p. 4). The discipline emerged out of a need to address ethical dilemmas in the real world. Prominent contributions from medical ethics and bioethics in the 1960s paved the way for other specialisations of applied ethics (Tham, 2016). Environmental ethics is one such specialisation and climate ethics is a growing area of research within environmental ethics (Gardiner et al., 2010).

Principlism, which surfaced as principlist theory in the 1970s when there was motivation to make ethics more practically useful, is one way of carrying out applied ethics (Beauchamp & Childress, 2019). Principlism refers "to any account of ethics comprising a plurality of potentially conflicting prima facie principles" (p. 428). The method has been used within biomedical contexts, including to apply the four principles of biomedical ethics discussed in Beauchamp and Childress (1979): autonomy, non-maleficence, beneficence and justice. Principlism, commonly described as following a top-down manner of moral reasoning, takes a framework or set of ethical principles as its starting point and uses deductive reasoning or deduction to reach a logical conclusion (Voisard & Wallimann-Helmer, 2024). The processes of further specification and balancing judgements make principles more context-specific and resolve conflicts between principles which might be "pointing in opposite directions" (Beauchamp & DeGrazia, 2004, p. 61; Beauchamp & Rauprich, 2016).

While principlism is used as a method in this research, it is underpinned by a number of assumptions or beliefs, characteristic of a paradigm. For instance, principlism assumes that the core set of principles constitute "the common morality" in the sense that these transcend cultures and act as moral norms (Beauchamp & DeGrazia, 2004, p. 58). Put another way, the common morality is viewed "as a universal morality that is not relative to cultures, individuals, religions, or professional associations" (Beauchamp & Childress, 2019, p. 428).

Principlism also holds that sets of principles, rather than one supreme principle, are required, where all principles are initially given equal moral weighting (Beauchamp & Rauprich, 2016). This is because "morally relevant aspects of many real-world situations cannot be reduced to a single, supreme moral principle but need to be captured by a plurality of irreducible principles" (p. 3). Finally, principlism does also not believe that a single solution will be arrived at, because of the way that norms shift with time. In this way, principlism views possible solutions as dynamic and continuously revisable.

This research uses principlism to apply five ethical distributional principles, four of which have been widely discussed in the climate ethics literature: the Polluter Pays, Beneficiary Pays, Ability to Pay and Grandfathering (Caney, 2005; Duus-Otterström & Hjorthen, 2018; Roser & Seidel, 2017). These principles are treated as social facts within the realm of climate diplomacy and international law, which negotiators will benefit from applying to answer ethical burden-sharing questions concerned with whom ought to bear responsibility for addressing climate change.

Principlism's use of deductive reasoning has affinities with a positivist approach, which makes use of hypothetico-deductive reasoning. Where positivism uses hypothetico-deductive reasoning to form a hypothesis and then test by way of experiments whether this is supported by data, principlism's use of deductive reasoning provides a structured way of analysing ethical dilemmas. In this way, principlism creates a coherence across the ethical and scientific aspects of the thesis by enabling a deductivist approach across those elements.

As well as its affinities with positivism, principlism may also – depending on how it is interpreted – have affinities with pragmatism. This would be the case if the principles are assumed to be pluralistic and change over time. In this way principlism shares similarities with both positivism and pragmatism, reminiscent of how this overall research project connects these two paradigms.

## §3.3 SEFS dashboard layout

The three pages of the SEFS dashboard, which are associated with answering each of the RQs, follow the same general layout displayed in Figure 8 and Figure 9 below.

The navigation panel (indicated by a yellow border) sits at the top of each page and provides links to each of the other pages. The RQ that each of the middle three pages of the dashboard are concerned with answering is on the top left-hand side of the dashboard, indicated by a red border. This enables users to understand which RQ the page is focussed on helping them answer. Finally, the selection pane (green border) includes a range of options which users can choose to answer the RQs in different ways. Users do this by selecting different combinations of parameters. Parameter choices are offered by dropdown boxes, buttons and range sliders.

Finally, the output section (within the purple border) on the right-hand side of the dashboard includes charts which help answer the RQ of interest. The dashboard's layout is similar to several other dashboard-style tools, including Fair Mitigation Finance Explorer, in the way that the RQ and selection pane are on the left-hand side of the page, while outputs – based on user selections – are displayed as charts on the right.

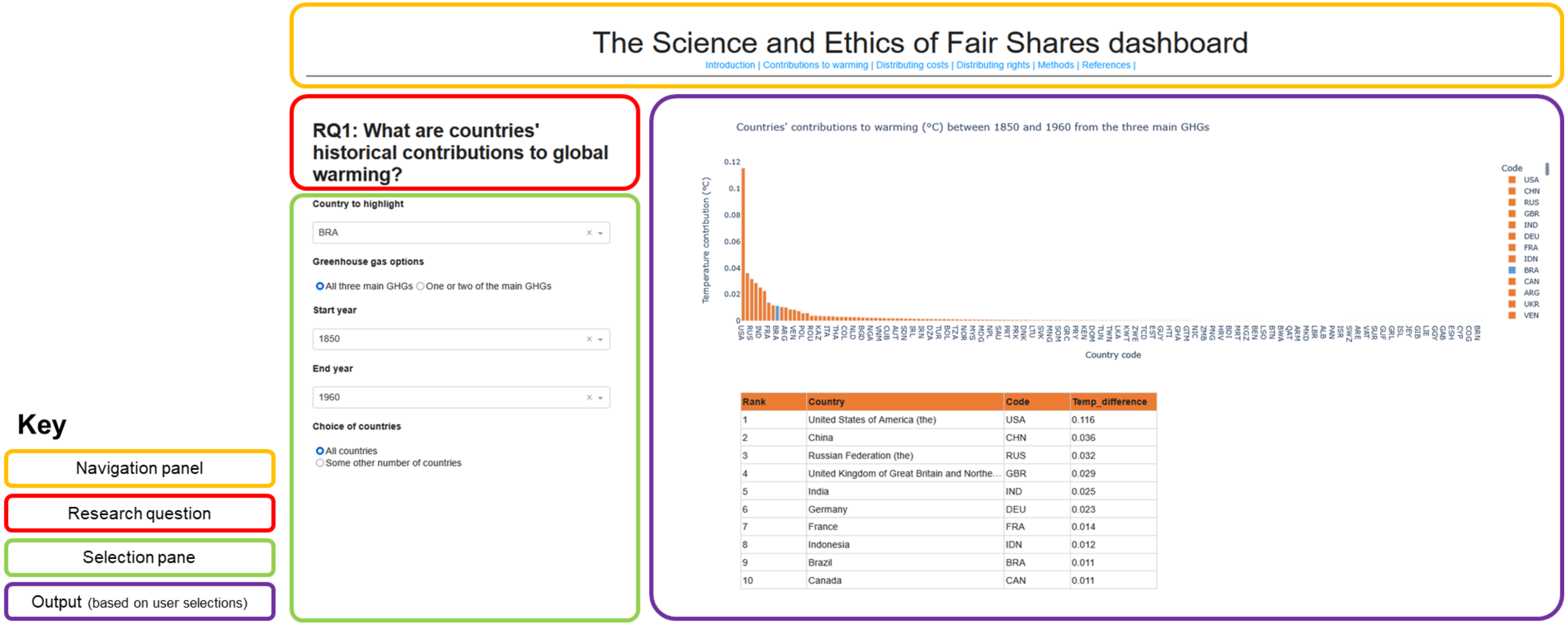


*Figure 8. Dashboard page layout for RQ1*

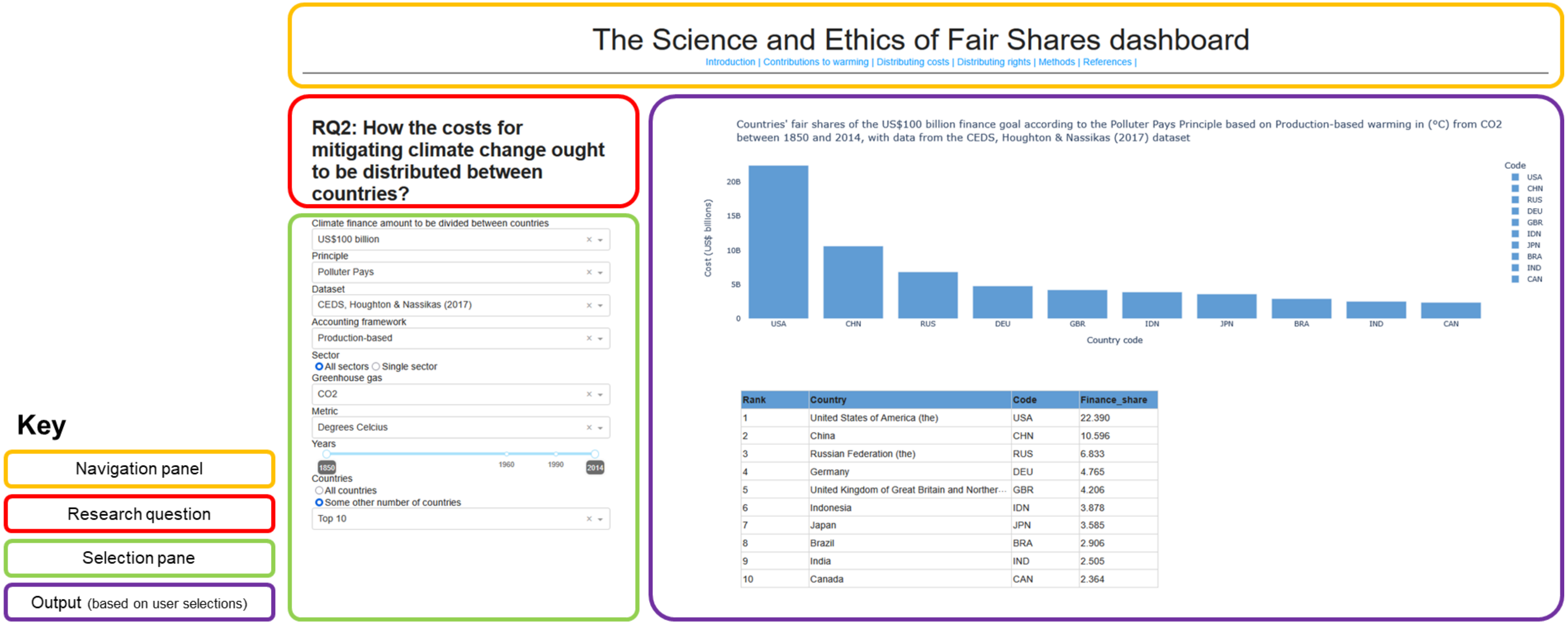


*Figure 9. Dashboard page layout for RQ2*

# §3.4 Datasets and pre-processing steps

A range of secondary dataset types are brought together within the SEFS dashboard to answer the three RQs. These include national GHG inventories, historical GHG emissions and land use datasets, multi-regional input-output (MRIO) tables, macroeconomic indicators and population datasets. The datasets include different numbers of countries. The country coverage (number of countries) of each dataset and its data source are detailed in Table 7 below.

Table 7 shows the eight data sources that are used in the SEFS dashboard and the four categories of actors in them: Annex I Parties (developed countries), non-Annex I Parties (developing countries), Neither and Other. Under the United Nations Framework Convention on Climate Change (UNFCCC), there are 43 Annex I Parties, and 155 non-Annex I Parties. One of the Annex I Parties is a supranational organisation, the European Union (EU). All other Parties are countries. A further ~52 countries are neither classified as neither Annex I, nor non-Annex I Parties under the Convention, yet appear in many of the datasets that are drawn on for this research. The final category – Other – includes regional groupings and an aggregated Rest of the World (RoW) grouping that appears in the Eora-26 dataset. There is high country coverage for Annex I Parties across the data sources, however non-Annex I Parties' coverage fluctuates between 108 (69%) and 152 (98%). A lack of consistent non-Annex I Party data across different datasets is a limitation of the information that is currently available.

| Dataset type | National GHG inventories | Historical GHG emissions and land use | Multi-regional input-output tables | Macroeconomic indicators | | | Population | |
|---|---|---|---|---|---|---|---|---|
| Data source<br><br>Principles<br><br>Metrics | UNFCCC<br><br>Polluter Pays<br>Equality-over-time<br>Grandfathering<br><br>kt of GHGs | CEDS, Houghton & Nassikas (2017)<br><br>Polluter Pays<br>Equality-over-time<br>Grandfathering<br><br>°C | Eora-26<br><br>Polluter Pays<br>Equality-over-time<br>Grandfathering<br><br>kt of GHGs | UNDP<br><br>Ability to Pay<br><br>GNI Per Capita, HDI | World Bank<br><br>Ability to Pay<br><br>GDP, GDP Per Capita, GNI | World Bank<br><br>Beneficiary Pays<br><br>Total Wealth, Total Wealth Per Capita | Our World In Data (HYDE & Gapminder v7)<br><br>Equality-over-time<br><br>Historical populations | Riahi et al. (2017)<br><br>Equality-over-time<br><br>Future population projections |
| **Annex I** | 43 | 42 | 42 | 41 | 43 | 38 | 42 | 41 |
| **non-Annex I** | 155 | 128 | 133 | 149 | 152 | 108 | 152 | 131 |
| **Neither** | 0 | 4* | 14 | 1 | 20 | 0 | 21 | 5 |
| **Other**<br>**(Extra data)** | 0 | | 1<br>(Rest of the World) | 0 | 4 | 0 | 51<br>(Groups of countries based on world region) | 0 |
| **Total** | **198** | **174** | **190** | **191** | **219** | **217** | **266** | **177** |

*Table 7. Country coverage (number of countries) of different datasets*

*included in the CEDS and Houghton & Nassikas (2017) dataset are the following countries:

- Guernsey
- Isle of Man
- Jersey
- Svalbard and Jan Mayen Islands

Figure 10 below outlines how data from the eight sources in Table 7 above are used in this research and the RQs that they relate to. Lengths of the peach boxes at the top of the diagram indicate the RQ relevance to different parts of the research and data below. The blue boxes indicate work carried out by researchers and organisations in gathering data and information to compile datasets. The pink boxes include the work done by researchers to write code which calculates countries' historical contributions to global warming.

The horizonal black line separating the blue and pink boxes from the yellow and green boxes has been used to differentiate work done outside this PhD project from work done during the PhD which makes use of the data (blue boxes) and builds upon code from Callahan and Mankin (2022) (pink boxes) during the research process. Beneath the black line, in the yellow and green boxes, the calculations and reformatting procedures which supported dashboard development are summarised.

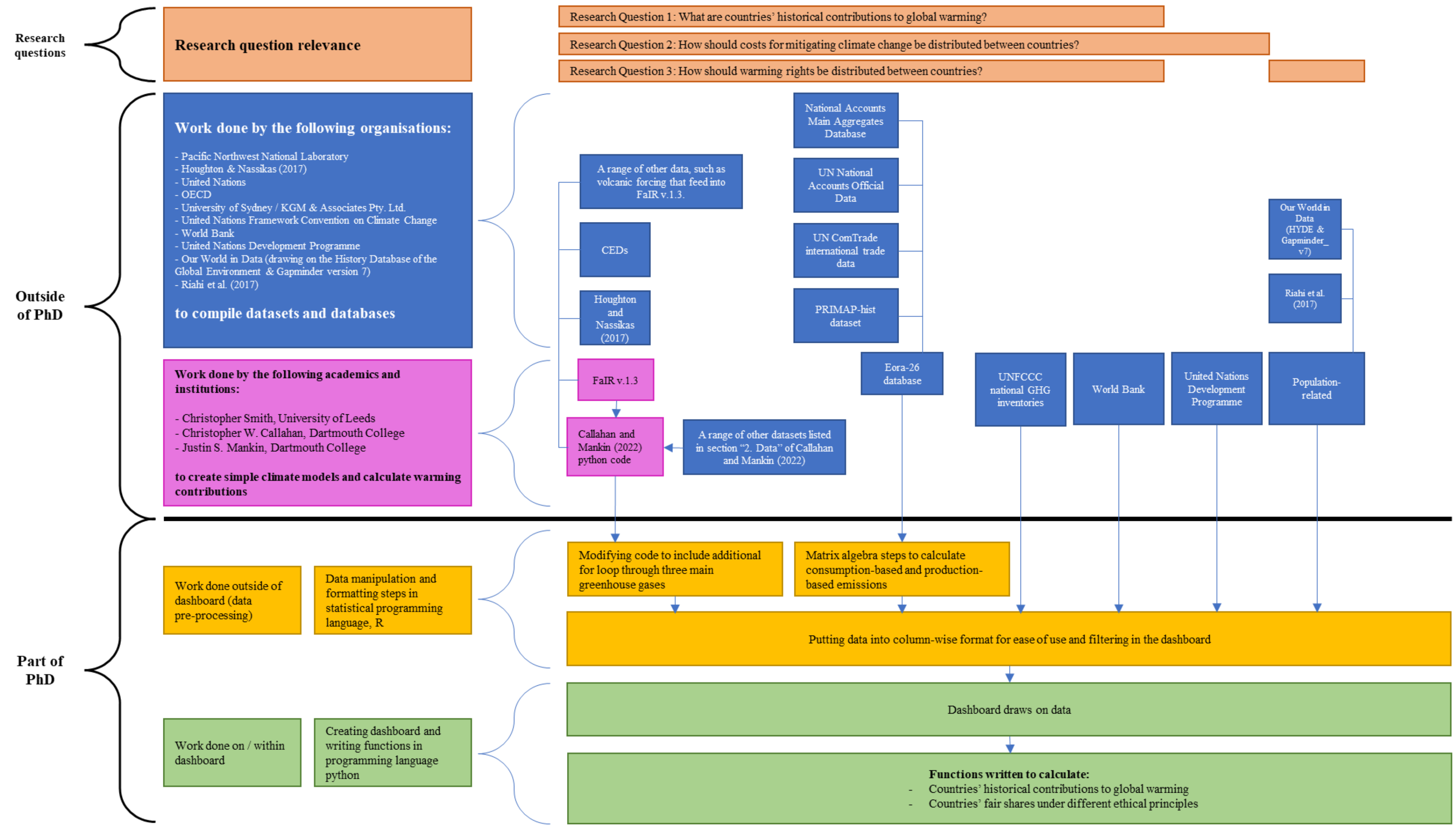


*Figure 10. Work done outside and as part of this PhD*

## §3.4.1 National GHG Inventories

While the trend of human-induced climate change has been occurring since pre-industrial times, it is only since the 1990s that countries began setting up the processes and resources to gather information about their GHG emissions. This information has been detailed in national GHG inventories, biennial update reports (BURs) and national communications (NCs), based on Intergovernmental Panel on Climate Change (IPCC) guidelines and countries' UNFCCC obligations (Kawanishi & Fujikura, 2020; Stevens et al., 2017).

Annex I Parties' UNFCCC Greenhous Gas Inventories (1990–2020) are used to support applications of the Polluter Pays, Grandfathering and Equality-over-time Principles. A limitation of the UNFCCC dataset is that, due to non-Annex I Party data being considerably inconsistent, only Annex I Party data has been included in the SEFS dashboard. Countries' national GHG Inventories include information about emissions which is grouped according to the following six sectors: agriculture, energy, industrial processes and product use (IPPU), land use, land-use change, and forestry (LULUCF), other and waste.

## §3.4.2 Historical GHG emissions and land use

A time-series of historical GHG emissions, including carbon dioxide ($CO_2$) emissions from burning fossil fuels ($CO_2$-fossil) and land use and land cover change (LULCC) carbon fluxes, are required for the FaIR SCM to calculate countries' historical contributions to warming to answer RQ1. The carbon fluxes from LULCC datasets are multiplied by 3.664 to convert them from tonnes of carbon to tonnes of $CO_2$ (Friedlingstein et al., 2022). These datasets also enable applications of the Polluter Pays, Grandfathering and Equality-over-time Principles to answer RQ2 and RQ3.

Several existing datasets, with GHG emissions estimates between 1750–2021, include the Global Carbon Project (GCP), the Reduced Complexity Model Intercomparison Project (RCMIP), the Community Emissions Data System (CEDS) and the Potsdam Realtime Integrated Model for probabilistic Assessment of emissions Paths (PRIMAP) historical timeseries (Friedlingstein et al., 2022; Gütschow et al., 2016; Hoesly et al., 2018; Nicholls et al., 2020). Often, these datasets make use of information from the same data sources, such as UNFCCC national GHG inventories, but combine this data with other sources in different ways.

The CEDS historical emissions dataset is used to calculate countries' contributions to warming for the SEFS dashboard. Developed by researchers at Pacific Northwest National Laboratory, the CEDS dataset includes estimates of country-level GHG emissions between 1750–2014. It provides information for 221 *regions*: countries, regions, territories or islands. This dataset was chosen for its long time-series, as well as its use in the Callahan and Mankin (2022) study, which this research builds upon (see §3.5 for more detail).

Existing LULCC datasets provide details about national-level carbon fluxes associated with countries' changing land use practices over time. Three prominent LULCC datasets include the *Bookkeeping of Land Use Emissions* (BLUE) model by Hansis et al. (2015), the *Global and Regional Fluxes of Carbon from Land Use and Land Cover Change* by Houghton and Nassikas (2017) and the reduced-form earth system model (ESM), OSCAR, by Gasser et al. (2020). These cover a range of periods between 1750–2018. The BLUE and the Houghton and Nassikas (2017) datasets are classified as bookkeeping models, which keep "track of the yearly changes of carbon in terrestrial ecosystems (including both biota and soils)" by including rates of LULCC and carbon densities as inputs (Houghton et al., 1983, p. 237). In contrast, OSCAR is a Dynamic Global Vegetation Model (DGVM), which is more detailed and encompasses biogeochemical feedbacks that take place.

The Houghton and Nassikas (2017) bookkeeping model is the particular LULCC dataset that has been used in the SEFS dashboard. It provides LULCC information for 186 countries and was chosen for its long time-series, as well as its use in the Callahan and Mankin (2022) study, which this research builds upon (see §3.5 for more detail).

The creation of many historical emissions and LULCC carbon flux datasets involve the gathering and piecing together of information from a range of sources that are available, in the absence of more specific, detailed and consistent records. This is why such historical time-series are often described as *estimates*. Where available, the CEDS dataset draws on national GHG inventory data, collected and put forward by UNFCCC-countries themselves. However, significant limitations are that such data is only available from 1990 onwards and it is particularly sparse for non-annex I Parties. Emissions factors and activity data, which includes information about fuel use and processing activity, are used to develop emissions estimates in place of inventory data. Then scaling and historical extensions take place to produce a consistent time-series back to 1750. The methodology for constructing this dataset is described as a "mosaic strategy" whereby different datasets have been pieced together to generate a complete time-series (Hoesly et al., 2018, p. 375).

When constructing LULCC datasets, an understanding is required about types of vegetation that were present at various points in time and vegetation growth rates over considerable lengths of time (some 165–170 years), where detailed and consistent records across countries are often not available. To construct this dataset, Houghton and Nassikas (2017) drew on a diverse range of data sources. These included country's own historical narratives and reviews, national statistics, the Food and Agriculture Organization (FAO) and its Forest Resources Assessment (FRAs), the Global Fire Emissions

Database (GFED), as well as some countries' national bureaus or census organisations and statistics agencies. Where available, data from country-specific LULCC studies were incorporated, and areas of specific land cover types (croplands and pastures) were "extrapolated on the basis of changes in population" prior to 1961 (p. 458).

Sources of uncertainty in historical LULCC carbon flux estimates and assumptions which have been made to support simplification of the bookkeeping model are described within Houghton and Nassikas (2017) and will not be covered in detail here. However, among the various estimates that have been done, different assumptions are made and "[i]t is not clear which of the alternative assumptions is more accurate. In this case, the different estimates represent uncertainty" (p. 468).

It is also worth noting that emissions from land-use change accounted for 30% of cumulative anthropogenic carbon emissions over the 1850–2020 period (Friedlingstein et al., 2022, p. 1940). However, LULCC emissions are increasingly accounting for smaller proportions of cumulative and annual emissions as they become dwarfed by $CO_2$-fossil emissions which have risen rapidly since 1960.

Two further trends in LULCC estimates are worth noting. First, mid-latitude countries are now becoming net LULCC emissions sinks as they remove carbon from the atmosphere due to recent forest growth, whereas countries in tropical regions are becoming the dominant LULCC emitters. Second, a large current source of uncertainty is in the estimate of deforestation rates and carbon densities within the tropics, with many estimates being revised across subsequent FRAs. The implication of this, provided deforestation trends continue growing in these areas in the future, is that a greater share of annual LULCC emissions will have higher levels of uncertainty associated with them.

Despite the obvious challenges, limitations and uncertainties associated with constructing a long term time-series of LULCC carbon fluxes, the Houghton and Nassikas (2017) dataset offers one of the most up-to-date estimates of country-level LULCC carbon flux information.

### §3.4.3 Multi-regional input-output (MRIO) tables

The Eora-26 database is an environmentally extended MRIO table which is used to calculate consumption-based emissions for 189 countries to answer RQ2 and RQ3 within the SEFS dashboard. Countries' historic GHG emissions between 1990–2015 are used to support applications of the Polluter Pays, Grandfathering and Equality-over-time Principles. Despite not extending over as long a time-period as other datasets, a benefit of the Eora-26 database is that its format enables computation of production- as well as consumption-based emissions, on a per gas basis, to offer multiple accounting lenses on nation-state responsibility for GHG emissions.

Compiled by researchers at the University of Sydney, the Eora-26 database combines country-level information from the range of databases indicated in Figure 10. This includes input-output tables (IOTs) from countries' National Statistics Offices (NSOs) and other MRIO databases, countries' national accounts and commodity and international trade statistics from United Nations databases, as well as a timeseries of countries' historical emissions from the Potsdam Realtime Integrated Model for probabilistic Assessment of emissions Paths (PRIMAP).

The process of constructing the Eora database is documented comprehensively in Lenzen et al. (2012) and Lenzen et al. (2013). In brief, the process involved the iterative construction of a time-series, which started with initial estimates of trade flow information for all countries in the year 2000, since this was found to have the greatest availability of national IOTs. Then, a series of back-casting and forecasting operations were performed to obtain estimates for years either side of this initial estimate.

Given its wide country and sectoral coverage and long time-series, relative to other GMRIO tables in Table 4, the Eora-26 dataset was chosen to calculate countries' consumption-based emissions for the SEFS dashboard. The dataset is also free for use with an academic license, which meant licensing costs did not present a barrier to access.

## §3.4.4 Macroeconomic indicators

A range of macroeconomic indicators – including Gross Domestic Product (GDP), Gross National Income (GNI), the Human Development Index (HDI) and Total Wealth – have been sourced from the World Bank and United Nations Development Programme (UNDP) websites and are employed as proxy metrics to apply the Ability to Pay and Beneficiary Pays Principles within the SEFS dashboard. These principles offer answers to RQ2: How should the costs for mitigating climate change be distributed between countries?

Limitations of these datasets include their variable country coverage (as indicated in Table 7) and different countries applying slightly different versions of the United Nations Systems of National Accounts (UNSNAs). For instance, many developed countries follow the 2008 standard, whereas developing countries follow the earlier 1993 standard. The conversion of different countries' currencies into United States Dollars (US$) is another area where discrepancies may arise. Often, prices are reported in purchasing power parities (PPP) figures which "equalize the purchasing power of currencies [by] measur[ing] the total amount of goods and services that a single unit of a country's currency can buy in another country" (World Bank, 2021, p. 81). However, prices are also reported in market exchange rates (MERs), in the case of the Total Wealth dataset, which do not reflect the relative sizes of economies in the same way (World Bank, 2021).

The sophistication of countries' statistical infrastructure also varies considerably across countries, which means macroeconomic indicators are likely to have variable reliability. Lequiller and Blades (2014) point out that the quality of national accounts "is highly dependent on the quality of the statistical system that exists in a given country … In international comparisons, it is important to note that the quality of national accounts is not the same in all countries" (p. 39). Therefore, for countries where certain information is missing or follows a slightly different set of standards, approximations and adjustments will need to be made on top of there being greater levels of uncertainty associated with this data.

## §3.4.5 Population

Both countries' historical population estimates and projected future population figures are used to apply the Equality-over-time principle within the SEFS dashboard to answer RQ3. Historical population estimates come from the Our World in Data dataset which captures a time-series running from 10,000 Before Common Era (BCE) until 2023. To create this time-series, Our World in Data combined three datasets in chronological order, including the History Database of the Global Environment (HYDE) dataset (10,000 BCE–1799), the Gapminder version 7 database (1800–1949) and the United Nations World Population Prospects (2024 revision) dataset (1950–2023).

Projected future population figures come from the Shared Socioeconomic Pathways (SSPs) from Riahi et al. (2017). The SSPs dataset gives population projections out to 2100, based on five different population growth scenarios described in Table 8 below.

| Population growth scenario | Name | World population (billions) by 2100 |
|---|---|---|
| SSP1 | Sustainability – Taking the Green Road | 7 |
| SSP2 | Middle of the Road | 9 |
| SSP3 | Regional Rivalry – A Rocky Road | 12.6 |
| SSP4 | Inequality – A Road Divided | 9.3 |
| SSP5 | Fossil-fuelled Development – Taking the Highway | 7.4 |

*Table 8. Shared Socioeconomic Pathways described in Riahi et al. (2017)*

Historical population estimates between 1850–2015 from the Our World in Data time-series are combined with projected future population figures between 2015–2050 from Riahi et al. (2017). The combination of these population datasets supports the allocation of warming and emissions rights between countries.

### §3.4.6 Pre-processing of data

Once useful data sources were identified and obtained, time was spent processing and converting the data into more suitable formats for the SEFS dashboard. Most processing of data was carried out in the statistical programming language, R, which contains libraries and in-built functions that are helpful for manipulating large datasets, like the tidyverse library. It became apparent that transforming datasets into a column-wise orientation or long format would be useful for filtering key variables to support country-level comparisons and analysis.

A column-wise format, where data is grouped in columns rather than across rows, enables variables to be referenced by specific column-headings. It is a more efficient way of organising information for use within dashboards, where a user can quicky query a database of information by selecting different column-headings. An example of the column-wise format is shown in Figure 11 below.

| Principle | Dataset | Accounting framework | Sector | Gas | Metric | Year | Value | Country | Code |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
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| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

*Figure 11. General column-wise format*

Appendix A includes the code that was written to transform data into a column-wise format, to support greater ease of use in the SEFS dashboard.

A challenge of drawing on multiple sources of information is that country names were found to vary across datasets. For instance, Palestine is known as the State of Palestine, or West Bank and Gaza in different datasets and Czechia is also known as the Czech Republic. Additionally, some country names have changed. For instance, Swaziland has become Eswatini. Spelling differences and abbreviation use in country names was a further factor which made it difficult to recognise the same country across datasets. In order to join and filter country-level information across datasets, a dictionary was created to relate different forms that country names were found to take to 3-letter International Organization for Standardization (ISO) codes. Table 9 below presents the Democratic Republic of Congo, and the six different ways this country's name appears in different datasets.

| Country name | 3-letter ISO country code |
|---|---|
| Congo (the Democratic Republic of the) | COD |
| Democratic Republic of the Congo | COD |
| Dem. Rep. Congo | COD |
| Congo the Democratic Republic of the | COD |
| Congo, Dem. Rep. | COD |
| Congo (Democratic Republic of the) | COD |

*Table 9. Varying names of the Democratic Republic of Congo found in datasets*

Appendix B includes the full dictionary of country names and 3-letter ISO codes that was created to match countries across different datasets.

### §3.4.7 Section summary

The SEFS dashboard draws on diverse datasets to answer the three RQs considered in this thesis. Many of these datasets have varying levels of country coverage and different assumptions and limitations. It is important to be aware of large uncertainties associated with the historical emissions and LULCC datasets, in particular. It is also important to recognise the different forms this uncertainty can take from uncertainty in emissions factor estimates, through to growing developing countries' emissions in the future, which are anticipated to make up a greater share of the world's emissions. Literature about many of these datasets highlighted the importance of improving the statistical infrastructure and reporting of developing countries which present a rapidly growing source of emissions in the future.

Significant time and effort were spent preparing data for use within the dashboard, including altering data formats to aid ease of use and filterability within the dashboard. The challenge of country names varying across different datasets was addressed by creating a dictionary of country codes, which corresponded with different combinations of text characters in country names.

Calculating countries' historical contributions to global warming is another example of pre-processing data to obtain relevant information. The following section (§3.5) explains how historical GHG emissions and LULCC estimates from the CEDS and Houghton and Nassikas (2017) datasets are used to calculate countries' historical warming contributions.

## §3.5 Calculating historical warming contributions

As mentioned in §2.4.2, climate scientists have developed a range of ESMs and SCMs or climate model emulators to replicate the global climate system and its response to perturbations, such as changing atmospheric concentrations of GHGs, volcanic and aerosol forcings, as well as cloud feedbacks (Held, 2005; National Research Council of the National Academies, 2012; Stocker, 2011). SCMs, like the FaIR model and the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC), as well as larger ESMs, allow warming at the global level to be analysed under different emissions scenarios. This is useful as the world collectively reviews how it is tracking against the Paris Agreement's Article 2 temperature targets.

However, many ESMs are large and computationally expensive to run. SCMs present an alternative means of testing how the climate system responds in a quick and relatively accurate fashion. In this research, the particular version of the FaIR model that was used to calculate countries' historical contributions to global warming is FaIRv1.3 (C. J. Smith et al., 2018). This version is used in the Callahan and Mankin (2022) study, which this research builds upon. FaIRv1.3 includes the following 39 species: $CO_2$ fossil, $CO_2$ land use, $CH_4$, $N_2O$, $SO_x$, CO, NMVOC, $NO_x$, BC, OC, $NH_3$, $CF_4$, $C_2F_6$, $C_6F_{14}$, HFC23, HFC32, HFC43-10, HFC125, HFC134a, HFC143a, HFC227ea, HFC245fa, $SF_6$, CFC11, CFC12, CFC113, CFC114, CFC115, CCl4, Methyl chloroform, HCFC22, HCFC141b, HCFC142b, Halon 1211, Halon 1202, Halon 1301, Halon 2402, $CH_3Br$ and $CH_3Cl$ (C. J. Smith et al., 2018)

While FaIRv1.3 is not the most recent version of the FaIR model, the structure of the model's code changed significantly in FaIRv2.0 to become object orientated. Simply building on the code developed by Callahan and Mankin (2022), which utilised the FaIRv1.3 model, offered a quicker and more straightforward approach than trying to write code from scratch that interfaced with later versions of the FaIR model.

The FaIRv1.3 model was used to run modified *leave-one-country-out* experiments so that contributions to historical global warming could be calculated for 174 countries over the 1850–2014 time-period for use in the SEFS dashboard. These experiments involve calculating warming contributions for each country and each GHG in turn, by isolating and removing these from the overall global warming for a given time-period when all countries and their GHG emissions are included. Each difference in warming is attributed to the particular country's GHG emissions which were left out. Code used in the Callahan and Mankin (2022) study was edited by including an additional for loop within the *leave-one-country-out* experiments to loop through individual countries, two GHG species – $CO_2$, methane ($CH_4$) – and an indirect short-lived climate forcer (SLCF) – nitrogen oxides (NOx). Appendix C shows the modified code, where edits are highlighted in yellow.

## §3.5.1 Section summary

Countries' historical contributions to global warming have been calculated for the SEFS dashboard by using the FaIR SCM, which includes radiative forcing and temperature response associated with 39 different species, to carry out modified *leave-one-country-out* experiments (C. J. Smith et al., 2018). These experiments isolate warming contributions from countries' $CO_2$, $CH_4$ and NOx emissions, one at a time, to determine global temperature changes in each species' absence and attribute these differences as per gas warming amounts to countries.

## §3.6 Calculating consumption-based emissions

As mentioned in §2.5.5, to calculate countries' consumption-based emissions, the method of EE-IOA can be applied to multi-regional input-output (MRIO) tables. In this research, EE-IOA has been applied to the Eora-26 database to calculate countries' consumption-based emissions over the 1990–2015 period for use in the SEFS dashboard. Appendix D includes the list of 26 sectors in the Eora-26 dataset. However, before describing the EE-IOA technique and MRIO tables in greater detail, a discussion of input-output analysis (IOA) and input-output tables (IOTs) will be necessary.

IOA is a technique, introduced in the 1930s by Soviet-American economist, Wassily Leontief, who later won the Nobel Prize in Economic Science in 1973 for his work in developing the input-output approach (Leontief, 1936; Wiedmann, 2009b). Initially, IOA was used to trace the flows of goods and services throughout an economy, from their points of production through to their final consumption. However, Leontief began extending IOA to environmental problems and other applications in the early 1970s (Leontief, 1970). The input-output technique has since found many applications from detailing energy and climate-related concerns through to water usage (Wiedmann, 2009b).

IOTs – a collection of trade-related information which represents the exchange of goods between different regions or countries – are what IOA is applied to. IOTs divide an economy up into its sectoral components. In the words of Leontief (1986), "An input-output table describes the flow of goods and services between all of the individual sectors of an economy over a stated period of time, say, a year" (p. 20).

The extension of IOA to environmental problems is referred to as EE-IOA. This falls within the field of IE, as explained in §3.2.3.2, and is regarded as a social science method: "The input-output framework is extended for environmental pressures by showing the primary resource requirements or emissions for each industry. The environmental inputs or wastes/emissions are hence treated much the same as labour and capital in the input-output framework" (Wood, 2017, p. 189).

Both environmentally extended IOTs and environmentally extended MRIO tables are expressed as a system of linear equations which describe the interdependencies between the different sectors of an economy, including the environmental resources and by-products associated with trade. Being expressed in this way provides a useful structure for performing matrix algebra operations to extract useful information from the tables, such as consumption-based emissions. The next section (§3.6.1) describes the structure of an environmentally extended MRIO table in more detail and the different matrices and information it includes.

### §3.6.1 Structure of an environmentally extended multi-regional input-output (MRIO) table

Figure 12 below shows the four matrices that an environmentally extended MRIO is composed of.

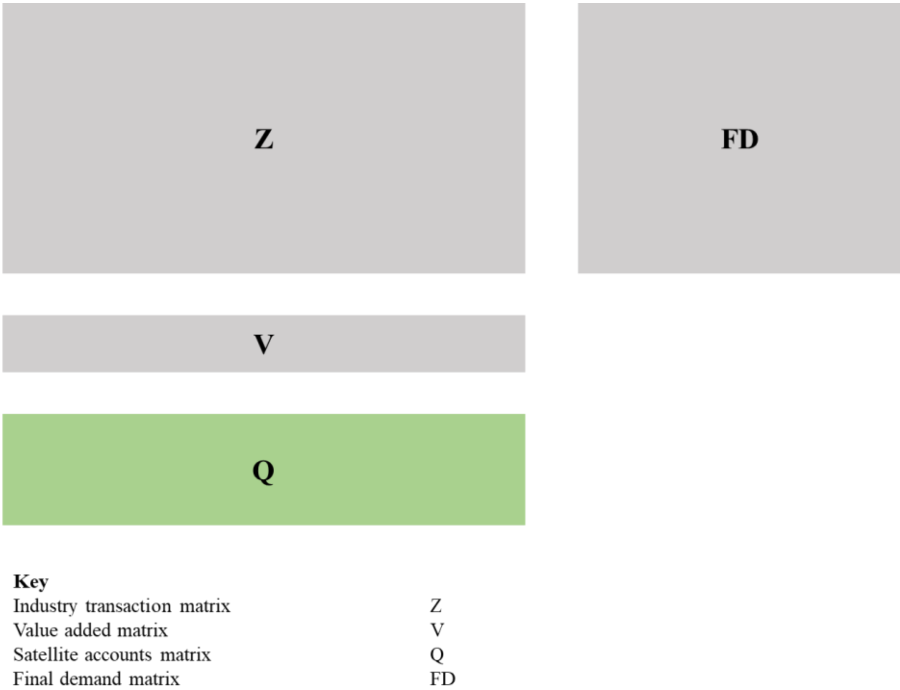



*Figure 12. Structure of an environmentally extended MRIO table*

The first matrix, Z, is the industry transaction matrix, also known as the transitions matrix, intermediate flow matrix, or intermediate demand matrix. It includes information about quantities of goods and services that are used as inputs to each sector, and which are used in production processes to generate outputs. The Z matrix is a square matrix with dimensions *n* x *n*.

In this matrix, each row and column corresponds to a different sector, where row entries represent sector inputs, and column entries represent sector outputs (Kitzes, 2013). The columns are sometimes referred to as production recipes because the rows within each column sector represent the quantities of raw materials which are required to produce outputs for that sector.

$$Z = \begin{bmatrix} Z_{11} & \cdots & Z_{1n} \\ \vdots & \ddots & \vdots \\ Z_{n1} & \cdots & Z_{nn} \end{bmatrix} \quad (1)$$

Beneath the Z matrix sits the value-added matrix, or primary inputs matrix, V, with dimensions *o* x *n*. The V matrix includes labour and capital costs and has the same number of columns as the Z matrix.

$$V = \begin{bmatrix} v_{11} & v_{1n} \\ v_{o1} & v_{on} \end{bmatrix} \quad (2)$$

The Q matrix sits beneath the V matrix and is referred to as the matrix of satellite accounts or nonmonetary inputs to production (Lenzen et al., 2012). Within the literature, the same matrix is denoted by a D and is referred to as the matrix of pollution output or direct impact interindustry activity (Miller & Blair, 2009).

Like the V matrix, the Q matrix has the same number of columns, *n*, as the Z matrix. However, it will likely have a different number of rows, depending on the quantity of satellite information associated with each of the production processes represented by the columns of Z.

The Q matrix (green matrix in Figure 12 above) contains quantities of nature-based inputs or environmental resources which are by-products of production processes, like water and GHG emissions. EE-IOA draws on the Q matrix to calculate quantities of GHGs which are associated with each of the different production processes of different sectoral inputs and outputs. This information is essential for calculating consumption-based emissions.

$$Q = \begin{bmatrix} q_{11} & q_{1n} \\ q_{p1} & q_{pn} \end{bmatrix} \quad (3)$$

The Final Demand matrix, FD, includes the demands that are driven by *industries* such as households, governments, inventories, capital formation (investment) and foreign exports. The six main industries in the Eora-26 dataset are:

- Households
- Non-profit Institutions Serving Households (NPISH)

- Government
- Gross fixed capital formation
- Changes in inventories
- Acquisitions less disposals of valuables

Therefore, the Eora-26 FD matrix has the dimensions of $n$ x $q$, where $q$ = 6.

$$FD = \begin{bmatrix} fd_1 & \cdots & fd_{1q} \\ \vdots & \ddots & \vdots \\ fd_{n1} & \cdots & fd_{nq} \end{bmatrix} \tag{4}$$

The next section outlines the matrix algebra steps that were taken to move from the Z matrix to the technical coefficient matrix, A, and ultimately calculate the upstream GHG emissions associated with producing goods and services from a particular sector.

## §3.6.2 Method for calculating consumption-based emissions

The steps taken to calculate countries' consumption-based emissions for each of the three main GHGs – $CO_2$, $CH_4$ and $N_2O$ – for use in the SEFS dashboard follow the industry-by-industry approach outlined in Kitzes (2013) and Leontief (1970), which are endorsed by Bunsen and Finkbeiner (2023). This section (§3.6.2) explains the matrix algebra operations for calculating countries' consumption-based emissions from the Eora-26 dataset. The R code for calculating countries' consumption-based emissions is included in Appendix E.

First, each element of the output vector, $y_{out_i}$, is created by adding together the row sums of the Z matrix and row sums of the FD matrix, according to the equation below, where $i$ = rows in Z and FD, $j$ = columns in Z and $k$ = columns in FD.

$$y_{out_i} = \sum_{j=1}^{n} Z_{ij} + \sum_{k=1}^{q} FD_{ik} \tag{5}$$

Second, three direct intensity vectors, one for each of the three main GHGs ($f_{CO_2}, f_{CH_4}, f_{N_2O}$), are created by dividing the relevant rows of the Q matrix (which contains information about each of the three main GHGs) by the $y_{out}$ vector.

$$f_{CO_2} = \frac{Q_{CO_2}}{y_{out}} \tag{6}$$

$$f_{CH_4} = \frac{Q_{CH_4}}{y_{out}} \tag{7}$$

$$f_{N_2O} = \frac{Q_{N_2O}}{y_{out}} \tag{8}$$

Third, the A matrix (also known as the technology matrix, direct coefficients matrix or direct requirements matrix) is created by dividing the Z matrix by the total output vector, $y_{out}$. Each element of the A matrix represents ratios of products that are required by sector $j$ from sector $i$ to produce one unit of sector $j's$ product. The A matrix has the same dimensions as Z, n x n.

$$A = \frac{Z}{y_{out}} \tag{9}$$

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}$$

Fourth, three total intensity vectors – one for each of the three main GHGs ($F_{CO_2}, F_{CH_4}, F_{N_2O}$) – are created by first calculating the Leontief inverse (also known as the total requirements matrix or output multipliers matrix), L. This is done by subtracting the A matrix from an n x n Identity matrix (a matrix with ones along its diagonal and zeros elsewhere) and then taking the inverse of this.

$$L = (I - A)^1 \tag{10}$$

The physical interpretation of the Leontief inverse is that its coefficients, also referred to as economic multipliers, reflect the flow on effects that increasing a unit of production can have for the wider economy. In the case of calculating countries' consumption-based emissions, the coefficients of the Leontief inverse become known as emissions multipliers and represent the indirect emissions associated with production processes. The Leontief inverse therefore captures how an increase in emissions in one production process can increase the emissions intensity of other processes throughout an economy.

Each total intensity vector is multiplied by the Leontief Inverse, as below.

$$F_{CO_2} = f_{CO_2} L \tag{11}$$

$$F_{CH_4} = f_{CH_4} L \tag{12}$$

$$F_{N_2O} = f_{N_2O} L \tag{13}$$

Finally, the upstream emissions can be calculated by multiplying each of the total intensity vectors that were created in the previous step by the sum of the rows of the FD matrix.

$$E_{CO_2} = F_{CO_2} \sum_{k=1}^{q} FD_{ik} \tag{14}$$

$$E_{CH_4} = F_{CH_4} \sum_{k=1}^{q} FD_{ik} \tag{15}$$

$$E_{N_2O} = F_{N_2O} \sum_{k=1}^{q} FD_{ik} \tag{16}$$

### §3.6.3 Section summary

This section (§3.6) has outlined the process by which country-level consumption-based emissions have been calculated for use in the SEFS dashboard. Code was written in the statistical programming language, R, to apply the EE-IOA method to the Eora-26 MRIO table in an industry-by-industry formulation. The matrix algebra steps that were followed to calculate countries' consumption-based emissions were detailed in §3.6.2.

## §3.7 Applying ethical distributional principles

This section (§3.7) describes the process by which countries' fair shares – according to five ethical distributional principles discussed in §2.6 – have been calculated and applied within the SEFS dashboard as possible answers to RQ2 and RQ3. First, §3.7.1 outlines the six-step process that was followed to develop an understanding of these ethical principles and how they could be applied. This involved surveying the philosophical and applied climate ethics literatures and engaging with academics who have published relevant studies or developed dashboard-style tools, similar in purpose to the SEFS dashboard.

Calculations to apply the three financial burden-sharing principles and two budget allocation principles are presented in §3.7.2 and §3.7.3. Features of the five principles, including related concepts and metrics that can be used to apply them, are outlined in §3.7.4. Finally, §3.7.5 summarises this section.

### §3.7.1 The six-step process of applying ethical distributional principles

The overall approach of applying the five ethical distributional principles within the SEFS dashboard is described in Figure 13 below, which depicts a predominant linear flow from understanding the philosophical climate ethics literature through to reflecting on each principle's features and information requirements for applications. However, in reality the flow was non-linear, with much jumping back and forth between the different steps – represented by the curved arrows – as more information was uncovered and greater levels of understanding were built. Steps 1 and 2 were covered in §2.6, where the literature on ethical distributional principles and relevant dashboard tools was reviewed.

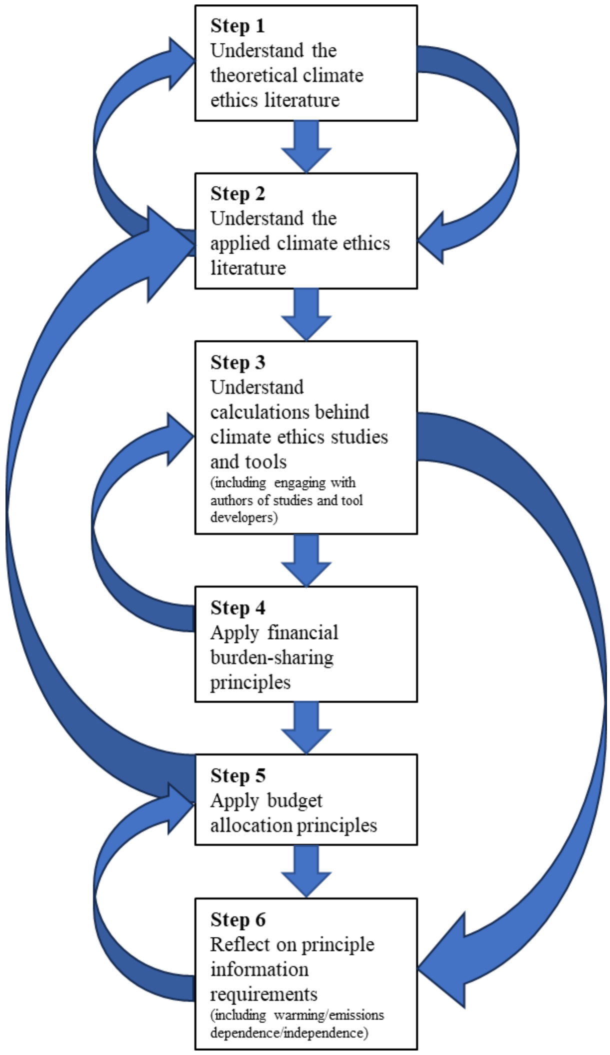



*Figure 13. Six-step process for applying principles in the dashboard*

Part of Step 3 involved interviewing several academics throughout May–September 2023 about applied climate ethics studies and climate equity-related dashboard tools they had written or were involved in the development of. These included Associate Professor Tejal Kanitkar at the National Institute of Advanced Studies in Bengaluru, India; Professor Lucas Bretschger at the University of ETH Zürich in Zürich, Switzerland; and Associate Professor Xunzhang Pan from the China University of Petroleum in Beijing, China.

Associate Professor Kanitkar is part of the team whom developed the Climate Equity Monitor dashboard – "the first initiative from the global South that will track equity in climate action by the signatories of the UNFCCC" (Climate Change Group (MSSRF), 2022, para. 2). Correspondence with Associate Professor Kanitkar's colleague, Aravindhan Nagarajan, supported an understanding of the datasets that sit behind the Climate Equity Monitor dashboard and how carbon debts and credits had been calculated.

The ETH Climate Calculator is one of only two practical ethical assessments presented in Table 6 which explicitly apply the Ability to Pay principle. To understand more about the ETH Climate Calculator and the specific calculations that sit behind it, Professor Lucas Bretschger was contacted. Professor Bretschger and his colleague, Matthias Leuthard, referred to the Bretschger and Mollet (2015) and Bretschger (2013) papers, which explain the calculator's calculations and underlying assumptions.

Finally, Associate Professor Xunzhang Pan was asked about a paper which he was the lead author of – *Implications of the consumption-based accounting for future national emissions budgets*. Associate Professor Pan has been a prominent proponent of the Equal Cumulative Per Capita Emissions (ECPCE) Principle and has written extensively on equitable carbon allocation schemes (Pan et al., 2015, 2017; Pan, Teng, Ha, et al., 2014; Pan, Teng, & Wang, 2014a, 2014b; Teng et al., 2011). Specific questions for Associate Professor Pan focussed on how carbon budgets were allocated across countries' changing populations over time. This information informed the approach for developing the Equality-over-time principle.

The researcher also intended to engage Professor Niklas Höhne from New Climate Institute, who was involved in development of the Climate Equity Reference Calculator, and Dr Shonali Pachauri from the International Institute for Applied Systems Analysis and lead author of an article which described the Fair Mitigation Finance Explorer (Holz et al., 2019; Pachauri et al., 2022). However, reading relevant articles provided sufficient detail about how these two tools work, including the calculations that sit behind them and the datasets they draw on.

Steps 4 and 5 will be covered next in §3.7.2. Step 6 of the process involved reflecting on principle information requirements. For instance, some principles are dependent on historical emissions data, while others are not. Features of warming- and emissions-dependence will be covered in greater detail in §3.7.4.

## §3.7.2 Applying the financial burden-sharing principles

The following three sections (§3.7.2.1–§3.7.2.3) outline the metrics and calculations used to apply the three financial burden-sharing principles to generate answers to RQ2.

### *§3.7.2.1 The Polluter Pays Principle*

A review of the climate ethics literature revealed several metrics for applying the Polluter Pays Principle, discussed in §2.6.1.1. These include countries' contributions to historical global warming and historical emissions.

The SEFS dashboard offers users three different datasets for applying the Polluter Pays Principle, described in Table 10 below. By selecting the CEDS & Houghton and Nassikas (2017) datasets, the principle can be operationalised according to countries' warming contributions (in °C). This reflects the historical responsibility formulation of the Polluter Pays Principle, as articulated by the Brazilian Proposal, mentioned previously in §2.3.2 and §2.7.1.

However, there are unresolved issues about how to treat short-lived versus long-lived GHGs. For instance, applying the Polluter Pays Principle based on cumulative emissions makes sense for long-lived or stock pollutants, like $CO_2$, which accumulate in the atmosphere. For these pollutants, it is the total stock that matters. In contrast, a cumulative emissions formulation for short-lived flow pollutants, like biogenic $CH_4$, makes less sense because for flow pollutants it is the *rate of change* in the concentration of these GHGs that matters.

The Eora-26 dataset provides the option to apply the Polluter Pays Principle with country-level GHG emissions under both the PBA and CBA frameworks, while the UNFCCC dataset includes Annex I Party data under only the PBA framework.

| Metric | Data source | Available years | Available Parties/countries |
|---|---|---:|---:|
| Warming amounts (°C) | CEDS & Houghton & Nassikas (2017) | 1850–2014 | 174 |
| GHG emissions (kt) | Eora-26 | 1990–2015 | 189 |
| GHG emissions (kt) | UNFCCC | 1990–2020 | Annex I Parties only |

*Table 10. Polluter Pays metrics in the SEFS dashboard*

The Polluter Pays Principle is operationalised within the SEFS dashboard according to the steps and equations below. Applying a warming-specific formulation of the principle from the CEDS and Houghton & Nassikas (2017) datasets are given as an example.

**Step 1:** Calculate the world's warming from cumulative GHG emissions for the chosen time-period by summing all countries' contributions in each year of that time-period.

$$W_{warming_T} = \sum_{y=1850}^{y=2014} \sum_{i=1}^{i=174} C_{warming_{iy}}, \qquad T = choice\ of\ the\ range\ of\ y \qquad [°C]\ (17)$$

Where

- $W_{warming_T}$ is the world's warming over the chosen time-period *T*
- $C_{warming_{iy}}$ is the warming contribution of country *i* in year *y*

**Step 2:** Calculate each country's share of the chosen climate finance goal, $CShare_{iT}$, by dividing each country's warming contribution by the world's total warming contribution for the same chosen time-period. Then multiply this figure by the chosen finance goal amount, from the $FGoal$ set of numbers.

$$CShare_{iT} = \frac{C_{warming_{iT}}}{W_{warming_T}} * FGoal, \qquad FGoal = \{100, 50, 25, 20, 15\} \qquad [US\$\ billions]\ (18)$$

Where

- $CShare_{iT}$ is the share of the chosen climate finance goal based on the warming contribution of country *i* over time-period *T*
- $C_{warming_{iT}}$ is the warming contribution of country *i* over chosen time-period *T*
- $FGoal$ is the chosen climate finance goal in US$ billions

### *§3.7.2.2 The Beneficiary Pays Principle*

A review of the Beneficiary Pays Principle in §2.6.1.2 found few instances of the principle being applied in practice. For this reason, Total Wealth – the proxy metric suggested in Page (2012) – is used to apply the principle within the SEFS dashboard. Because it was available, Total Wealth Per Capita is also used to apply the principle. These datasets have been taken from the World Bank database. Values are measured at market exchange rates (MERs) in constant US$, using a country-specific GDP deflator. This information is shown in Table 11 below.

| Metric | Data source | Available years | Available Parties/countries |
|---|---|---|---|
| Total Wealth | World Bank | 1995–2018 | 217 |
| Total Wealth Per Capita | World Bank | 1995–2018 | 146 |

*Table 11. Beneficiary Pays metrics in the SEFS dashboard*

Total Wealth includes produced capital, natural capital, human capital and net foreign assets. Applying the Beneficiary Pays Principle with the Total Wealth and Total Wealth Per Capita metrics involves a significant assumption: that a country's Total Wealth (and benefit) has been solely derived from past climate change causing actions. While there is likely to be some correlation between a country's current level of wealth and its historical GHG emissions, this will not necessarily be true for all countries. For instance, since the 1973 oil crisis, both France and Sweden have "significantly reduced their $CO_2$ emissions and fossil fuel dependency" and will have been able to grow different forms of capital in ways that have not contributed to climate change (Millot et al., 2020, p. 1). This means that both countries could be unfairly penalised under Total Wealth applications of the Beneficiary Pays Principle.

Another issue with using the Total Wealth metric as the basis for cost allocation is that countries' wealth may be tied up in non-liquid, physical infrastructure. Expecting countries to pay for climate-related costs, based on the value of their non-liquid assets, would face practical challenges in the real world. That said, it was challenging to identify more compelling metrics for the Beneficiary Pays Principle, where it appears to be one of the least applied principles in practical climate ethics assessments.

The Beneficiary Pays Principle is operationalised within the SEFS dashboard according to the steps and equations below.

**Step 1:** Calculate the world's total value of one of the two metrics in Table 11 above. The Total Wealth metric is used below as an example.

$$W_{wealth_y} = \sum_{i=1}^{i=217} C_{wealth_{iy}}, \qquad y \in [1995, 2018] \qquad [US\$\ billions]\ (19)$$

Where

- $W_{wealth_y}$ is the World's Total Wealth in year $y$

- $C_{wealth_{iy}}$ is the Total Wealth of country *i* in year *y*

**Step 2:** Calculate each country's share of the chosen climate finance goal, $CShare_{iy}$, by dividing the wealth of country *i* in year *y* by the world's Total Wealth in year *y*. Then multiply this figure by the chosen finance goal amount, from the $FGoal$ set of numbers.

$$CShare_{iy} = \frac{C_{wealth_{iy}}}{W_{wealth_y}} * FGoal, \qquad FGoal = \{100, 50, 25, 20, 15\} \qquad [US\$\ billions] \ (20)$$

Where

- $CShare_{iy}$ is the share of the chosen climate finance total for country *i* in year *y*
- $FGoal$ is the chosen climate finance goal in US$ billions

### *§3.7.2.3 The Ability to Pay Principle*

A review of the Ability to Pay Principle in §2.6.1.3 revealed that several proxy metrics are commonly used to apply the principle. Five of these proxy metrics – described in Table 12 and discussed below – are provided in the SEFS dashboard to apply the principle.

| Metric | Data source | Available years | Available Parties/countries |
|---|---|---|---|
| GDP | World Bank | 2021 | 219 |
| GNI | World Bank | 2021 | 219 |
| GDP Per Capita | World Bank | 2021 | 219 |
| GNI Per Capita | UNDP | 2021 | 191 |
| HDI | UNDP | 2021 | 191 |

*Table 12. Ability to Pay metrics in the SEFS dashboard*

GDP is a widely recognized macroeconomic indicator which is commonly used to signal a country's economic performance. Often misconstrued as a measure of wealth or how well a country is doing, GDP includes all the output that has been generated by people working within an economic territory, which is defined as "the geographic area corresponding to the nation state" (Lequiller & Blades, 2014b, p. 153). Sitting behind the choice to use GDP as a measure or indication of a country's ability to bear climate-related costs is the assumption that the higher the output of a country, the more a country will be able to afford to address the costs of climate change.

The next metric for applying the Ability to Pay Principle – GNI – is similar to GDP but "does not include primary incomes generated in the territory by non-resident agents" (Lequiller & Blades, 2014b, p. 330). This means that the incomes of people who work in one country but live in another will not count towards the overall income of the country or economic territory in which they work. In other words, GNI excludes the economic activity or output that has been generated outside the borders of the economic territory.

The next two metric options – GDP Per Capita and GNI Per Capita – are variations of the first two options in that they divide GDP and GNI amounts by countries' population figures. In this way, they incorporate a consideration of country size. For instance, it would generally be expected that a large country would produce more output than a smaller country. Converting the output and income into per capita terms provides a greater indication of the efficiency of each country, where, it could be argued, that countries with more efficient production or higher levels of income per person will have the ability to contribute more towards the costs of addressing climate change.

The final metric for applying the Ability to Pay Principle – the HDI – is a number between zero and one and takes three variables into account: standard of living, education level, and standard of health (Lequiller & Blades, 2014b). People in countries with a higher HDI tend to enjoy higher levels of these measures, on average. An underlaying assumption of using the HDI to operationalise the Ability to Pay Principle is that countries ought to pay for the costs of climate change in proportion to their level of human development. The higher a country's development level, the more financial capacity the people in that country have for addressing the costs of climate change.

The Ability to Pay Principle is operationalised within the SEFS dashboard according to the steps and equations below. No year subscript is shown in the equations because all data is for the year 2021.

**Step 1:** Calculate the world's total value of one of the five metrics in Table 12 above. The GDP metric is used below as an example.

$$W_{GDP} = \sum_{i=1}^{i=219} C_{GDP_i} \qquad [US\$\ billions]\ (21)$$

Where

- $W_{GDP}$ is the sum of the value of each country's GDP
- $C_{GDP_i}$ is the value of the HDI for country $i$

**Step 2:** Calculate a country's share, $CShare_i$, of the total global finance goal.

$$CShare_i = \frac{C_{GDP_i}}{W_{GDP}} * FGoal, \qquad FGoal = \{100, 50, 25, 20, 15\} \qquad [US\$\ billions] \quad (22)$$

Where

- $CShare_i$ is a country's share of a chosen total finance goal
- $FGoal$ is a chosen climate finance goal in US$ billions

## §3.7.3 Applying the budget allocation principles

The following two sections (§3.7.3.1–§3.7.3.2) outline the metrics and calculations used to apply two budget allocation principles – Grandfathering and Equality-over-time – to generate answers to RQ3.

### *§3.7.3.1 The Grandfathering Principle*

Like the Polluter Pays Principle, the Grandfathering Principle is concerned with what has happened in the past and is applied within the SEFS dashboard using the same three combinations of historical warming and GHG emissions datasets as the Polluter Pays Principle. However, instead of using countries' historical contributions to climate change to calculate their shares of a global climate finance goal, this information is instead used to calculate shares of a remaining carbon budget (RCB) or global temperature change target. Under a Grandfathering Principle, countries' historical contributions provide a basis for future warming or rights to emit GHGs.

| Metric | Data source | Available years | Available Parties/countries |
|---|---|---|---|
| Warming amounts (°C) | CEDS & Houghton & Nassikas (2017) | 1850–2014 | 174 |
| GHG emissions (kt) | Eora-26 | 1990–2015 | 189 |
| GHG emissions (kt) | UNFCCC | 1990–2020 | Annex I Parties only |

*Table 13. Grandfathering metrics in the SEFS dashboard*

The Grandfathering principle is operationalised within the SEFS dashboard according to the steps and equations below. Applying an emissions-specific formulation of the principle, based on $CO_2$ emissions only, is given as an example.

**Step 1:** Calculate the world's cumulative $CO_2$ emissions for the chosen time-period, by summing all countries $CO_2$ emissions in each year of that time-period.

$$E_T = \sum_{y=1990}^{y=2015} \sum_{i=1}^{i=189} C_{iy}, \qquad T = choice\ of\ the\ range\ of\ y \qquad [ktCO_2]\ (23)$$

Where

- $E_T$ are the world's cumulative $CO_2$ emissions over the chosen time-period $T$
- $C_{iy}$ are the $CO_2$ emissions of country $i$ in year $y$

**Step 2:** Calculate each country's proportion of historical $CO_2$ emissions by dividing each country's $CO_2$ emissions by the world's total $CO_2$ emissions for the chosen time-period $T$.

$$CShare_{iT} = \frac{C_{iT}}{E_T}, \qquad T = choice\ of\ the\ range\ of\ y \qquad [Dimensionless]\ (24)$$

Where

- $CShare_{iT}$ are the $CO_2$ emissions that country $i$ emitted as a proportion of the world's overall emissions amount over time-period $T$
- $C_{iT}$ are the cumulative $CO_2$ emissions of country $i$ over chosen time-period $T$
- $E_T$ are the World's cumulative $CO_2$ emissions over the chosen time-period $T$

**Step 3:** Calculate each country's share of the RCB by multiplying the carbon budget by each country's proportion of the world's historical $CO_2$ emissions over the time-period *T*.

$$CShare_{iF} = CShare_{iT} * BGoal \qquad [kt\mathrm{CO_2}] \ (25)$$

Where

- $CShare_{iF}$ is a country's share of $CO_2$ emissions for the future time-period $F$
- $CShare_{iT}$ are the emissions that country i emitted, as a proportion of the world's overall $CO_2$ emissions amount over time-period $T$
- $BGoal$ is the RCB

### *§3.7.3.2 The Equality-over-time Principle*

Engagement with Associate Professor Pan, who applied the Equal Cumulative Per Capta Emissions (ECPCE) principle in a recent study as discussed in §3.7.1, motivated the development and application of the Equality-over-time Principle within the SEFS dashboard. The approach and calculations for applying the principle to obtain warming rights will be described first, followed by the approach for applying the principle to obtain emissions rights.

When applying this principle in a warming-dependent way, a distinction is made between *use* of past warming and *rights* to future warming. This is because the distributions of past warming were not formally allocated to countries as rights. Countries simply used up this space, in a way that some have referred to as "atmospheric appropriation" or "carbon colonialism" (Fanning & Hickel, 2023, p. 1077; Page, 2013b, p. 237). In the future, warming could be allocated to countries as rights. Rather than simply assuming usage, this rights-based framing is more intentional and deliberate and is used to differentiate between past usage and future rights.

Calculations for applying the Equality-over-time Principle in a warming-dependent way take the following four pieces of information into account:

- Countries' historical warming use between 1850–2014
- Countries' historical populations between 1850–2014
- Countries' projected future populations, based on the five different SSPs from Table 8, between 2015–2050
- A temperature target as a function of past warming

This information is included in Table 14 below.

| Metric | Data source | Available years | Available Parties/countries |
|---|---|---|---|
| Warming amounts (°C) | CEDS & Houghton & Nassikas (2017) | 1850–2014 | 174 |
| GHG emissions (kt) | Eora-26 | 1990–2015 | 189 |
| GHG emissions (kt) | UNFCCC | 1990–2020 | Annex I Parties only |
| Historical populations | Our World In Data (HYDE & Gapminder) | 1850–2021 | 251 regions (including countries) |
| Future population projections | Riahi et al. (2017) | 1990–2100 | 177 |

*Table 14. Equality-over-time metrics in the SEFS dashboard*

The Equality-over-time Principle is operationalised according to the idea of person-years, where a person-year is defined as a person being alive in any given year. The number of person-years for a particular period of interest is the sum of countries' annual populations over that period.

The Equality-over-time Principle is operationalised within the SEFS dashboard according to the steps and equations below. Applying a warming-specific formulation of the principle, based on warming from countries' cumulative $CO_2$ emissions only, is given as an example.

**Step 1:** Calculate the total number of person-years over the time-period of interest. This includes historical person-years and future person-years, based on a particular population growth scenario.

$$Personyears_{world} = Personyears_{historical} + Personyears_{future}$$

$$p_{wTS} = \sum_{y=1850}^{y=2014} \sum_{i=1}^{i=174} P_{iy} + \sum_{y=2015}^{y=2050} \sum_{i=1}^{i=174} P_{iyS}, \quad S = \{SSP1, SSP2, SSP3, SSP4, SSP5\} \ [personyears] \quad (26)$$

Where

- $p_{wTS}$ are the person-years of the world over time-period $T$, according to Future Population Scenario $S$
- $P_{iy}$ is the population of country $i$ in year $y$

- $P_{iyS}$ is the population of country *i* in year *y*, according to Future Population Scenario *S*
- $S$ is a set of different Future Population Scenarios

**Step 2:** Calculate the World's historical warming from cumulative $CO_2$ emissions for the time-period of interest.

$$W_T = \sum_{y=1850}^{y=2014} \sum_{i=1}^{i=174} C_{iy}, \qquad T = choice\ of\ the\ range\ of\ y \qquad [°C]\ (27)$$

Where

- $W_T$ is the world's warming from cumulative $CO_2$ emissions for the historical time-period *T*
- $C_{iy}$ is the warming from cumulative $CO_2$ emissions generated by country *i* in year *y*

**Step 3:** Calculate the average warming contribution per person-year over the historical and future time-periods, where $W_T$ is scaled by a factor of 1.5 to account for future warming. Because the method needed to be flexible enough to accommodate any chosen time-period, $T$, a simple approach for determining the allowed future warming was to scale existing warming up to that point by a factor. Different factors would give different results. This is what is elsewhere referred to as the temperature target when discussing the Equality-over-time Principle.

$$I_{avg} = \frac{1.5 * W_T}{p_{wTS}} \qquad \left[\frac{°C}{personyear}\right]\ (28)$$

Where

- $I_{avg}$ is the average warming amount per person-year that the world can afford while remaining beneath the temperature target, across the historical and future time-period

**Step 4:** Calculate a country's person-years for the historical and future time-period.

$$p_{iT} = \left( \sum_{y=1850}^{y=2014} P_{iy} + \sum_{y=2015}^{y=2050} P_{iyS} \right) \qquad [personyears] (29)$$

Where

- $p_{iT}$ are the person-years of country *i* for the total time-period *T*
- $P_{iy}$ is the population of country *i* in year *y*
- $P_{iyS}$ is the population of country *i* in year *y*, according to Future Population Scenario *S*

**Step 5:** Calculate country-level shares of the temperature target for the 2015–2050 period.

$$CShare_{iF} = I_{avg} * p_{iT} - \sum_{y=1850}^{y=2014} C_{iy} \qquad [°C] \; (30)$$

Where

- $CShare_{iF}$ is the share of the temperature target that is available to country *i* over the future time-period *F*
- $I_{avg}$ is the average warming amount per person-year that the world can afford while remaining beneath the temperature target, across the historical and future time-period
- $p_{iT}$ are the person-years of country *i* for the total time-period *T* (1850–2050)
- $C_{iy}$ is the historical warming contribution of country *i* in year *y*

When applying the Equality-over-time principle in an emissions-dependent way, the following four pieces of information are taken into account:

- Countries' historical emissions between 1990–2020
- Countries' historical populations between 1990–2020
- Countries' projected future populations, based on the five different SSPs from Table 8, between 2021–2050
- An emissions limit as a function of past emissions

The Equality-over-time Principle is operationalised within the SEFS dashboard according to the steps and equations below. Applying an emissions-specific formulation of the principle, based on countries' cumulative $CO_2$ emissions only, is given as an example.

**Step 1:** Calculate the total number of person-years over the time-period of interest. This includes historical person-years and future person-years, based on a particular population growth scenario.

$$Personyears_{world} = Personyears_{historical} + Personyears_{future}$$

$$p_{wTS} = \sum_{y=1990}^{y=2015} \sum_{i=1}^{i=189} P_{iy} + \sum_{y=2016}^{y=2050} \sum_{i=1}^{i=189} P_{iyS}, \quad S = \{SSP1, SSP2, SSP3, SSP4, SSP5\} \; [personyears] \; (26a)$$

Where

- $p_{wTS}$ are the person-years of the world over time-period *T*, according to Future Population Scenario *S*
- $P_{iy}$ is the population of country *i* in year *y*
- $P_{iyS}$ is the population of country *i* in year *y*, according to Future Population Scenario *S*

$S$ is a set of different Future Population Scenarios

**Step 2:** Calculate the World's historical cumulative $CO_2$ emissions for the time-period of interest.

$$E_T = \sum_{y=1990}^{y=2015} \sum_{i=1}^{i=189} C_{iy}, \qquad T = choice\ of\ the\ range\ of\ y \qquad [ktCO_2] \; (27a)$$

Where

- $E_T$ are the world's cumulative $CO_2$ emissions for the historical time-period *T*
- $C_{iy}$ are the cumulative $CO_2$ emissions of country *i* in year *y*

**Step 3:** Calculate the average emissions per person-year over the historical and future time-periods, where $E_T$ is scaled by a factor of 1.5 to account for future emissions. Because the method needed to be flexible enough to accommodate any chosen time-period, $T$, a simple approach for determining the allowed future emissions was to scale existing emissions up to that point by a factor. Different factors would give different results. This is what is elsewhere referred to as the RCB when discussing the Equality-over-time Principle.

$$J_{avg} = \frac{1.5 * E_T}{p_{wTS}} \qquad \left[\frac{ktCO_2}{personyear}\right] (28a)$$

**Step 4:** Calculate a country's person-years for the historical and future time-period.

$$p_{iT} = \left( \sum_{y=1990}^{y=2015} P_{iy} + \sum_{y=2016}^{y=2050} P_{iyS} \right) \qquad [personyears](29a)$$

Where

- $p_{iT}$ are the person-years of country *i* for the total time-period *T*
- $P_{iy}$ is the population of country *i* in year *y*
- $P_{iyS}$ is the population of country *i* in year *y*, according to Future Population Scenario *S*

**Step 5:** Calculate country-level shares of the RCB for the 2016–2050 period.

$$CShare_{iF} = J_{avg} * p_{iT} - \sum_{y=1990}^{y=2015} C_{iy} \qquad [ktCO_2]\ (30a)$$

Where

- $CShare_{iF}$ is the share of the RCB that is available to country *i* over future time-period *F*
- $J_{avg}$ are the average $CO_2$ emissions per person-year that the world can afford while remaining within the RCB, across the historical and future time-period
- $p_{iT}$ are the person-years of country *i* for the total time-period *T* (1990–2050)
- $C_{iy}$ are the historical $CO_2$ emissions of country *i* in year *y*

## §3.7.4 Features of ethical principles and information for applying them

The five ethical principles applied within the SEFS dashboard have a range of features that are worth drawing closer attention to, and which influence how they are applied. Table 15 provides a summary of these features and how these compare across different principles.

First, all principles have been found to go by different names or related concepts in the literature. Being aware of this was important when it came to reviewing the climate ethics literature and identifying relevant studies to compare the SEFS dashboard's results with.

Second, depending on their conceptions of justice, principles are described as having a forward- or backward-looking focus and this is reflected in the information that is used to apply them. For instance, the Polluter Pays Principle is backward-looking because it is focussed on what has occurred in the past, where climate finance obligations can be based upon historical GHG emissions or the warming associated with these emissions. In contrast, the Ability to Pay Principle is forward-looking because it is concerned with actors' current circumstances.

The Beneficiary Pays, Grandfathering and Equality-over-time Principles all have both a forward- and a backward-looking focus. In the theoretical climate ethics literature, the Beneficiary Pays Principle is described as having both forward- and backward-looking elements because of how it focuses on future and existing benefits and isolates only those benefits that are strongly associated with historical climate change furthering acts (Page, 2012). However, the SEFS dashboard's application of the Beneficiary Pays Principle is reduced to a solely forward-looking orientation, by using the proxy metric of countries' wealth-related information in a single recent year.

The Grandfathering and Equality-over-time Principles are also both forward- and backward-looking. A past reference year – which sets a baseline for future emissions levels – is the Grandfathering Principle's backward-looking element, and the forward projection of countries' future emission reductions is the Grandfathering Principle's forward-looking element. The Equality-over-time Principle is both forward- and backward-looking in the way that it distributes a global temperature target or RCB across past and future generations. This information is captured in Table 15.

Third, as discussed previously, the Ability to Pay and Beneficiary Pays Principles are commonly applied with proxy metrics. The most challenging principle to operationalise in this research was the Beneficiary Pays Principle. Aside from one suggested operationalisation within Page (2012), to the researcher's knowledge there are no existing dashboard-style tools or practical climate ethics assessments which have applied the Beneficiary Pays Principle. A lack of other examples could, at least in part, be due to the challenge of quantifying the level of benefit that different countries have derived from historical contributions to climate change.

This challenge of applying certain principles, as well as their absence from practical ethical assessments, has raised the question of whether principle applications may potentially be a source of moral bias, where there may be a tendency for applied ethics practitioners to reach for those principles which can be most easily applied. If this were the case, it would mean that the scope of moral perspectives on country-level fair shares for addressing climate change will be inadvertently limited by the applicability of principles. However, the ease with which a principle can be applied merely reflects what scientific information and data has been available and measurable to date. These factors are not morally significant reasons to use or not use a principle, yet there remains a risk that they may unnecessarily restrict ranges of ethical perspectives that are considered in climate ethics assessments.

A further important feature of ethical distributional principles is whether they are operationalised in a warming- or emissions-dependent or independent way. A principle is warming- or emissions-dependent when it uses information about a country's past contributions to climate change – either their historical warming or historical emissions.

The Polluter Pays, Grandfathering and Equality-over-time Principles are all warming- and emissions-dependent principles and have been applied in the SEFS dashboard in warming- and emissions-dependent ways. When applying these principles, choices need to be made about the particular dataset, accounting framework, whether one or multiple climate forcers are included, the type of metric, sectors and time-period over which warming or emissions are considered.

Operationalising the Beneficiary Pays Principle in a way which is warming- or emissions-dependent is one way the principle could incorporate a backward-looking element to take on the hybrid form discussed in the literature (see §2.6.1.2). The Beneficiary Pays Principle, as it has been applied in the SEFS dashboard, is not a warming- or emissions-dependent application. However, the Beneficiary Pays Principle could become warming- or emissions-dependent if it were to be operationalised in a way that linked the principle with different GHG accounting frameworks, particularly the consumption-based one, as discussed in §2.6.1.4. Additionally, the extraction-based accounting framework presents a further option for applying the Beneficiary Pays Principle in a warming- or emissions-dependent way within the dashboard, which is discussed further in §5.4.2.

Warming- and emissions-dependent principles require more information and a greater number of choices to apply than non-warming-dependent and non-emissions-dependent principles, like the Ability to Pay Principle. For this reason, their applications span a greater space of possible solutions. Figure 14 compares the different information requirements for the warming- and emissions-dependent principles in the SEFS dashboard.

| Feature / Principle | Polluter Pays | Beneficiary Pays | Ability to Pay | Grandfathering | Equality-over-time |
|---|---|---|---|---|---|
| **Definition / notion of fairness** | Efforts or costs should be shared in proportion to each actor's contribution to causing the problem. In the case of anthropogenic climate change, the cause of the problem is GHG emissions. | Effort or costs should be shared in proportion to the benefit that each actor has derived from harm-causing actions. In the case of anthropogenic climate change, downstream harms are caused by emitting GHGs. | Those actors with the greatest financial resources should bear the greatest costs or pay the most. | Remaining GHG emissions (or warming) rights shall be granted to actors in the same proportions to historical emissions (or warming). | Remaining $CO_2$ emissions (or warming from $CO_2$ emissions) shall be granted to actors based on equalising cumulative $CO_2$ emissions (or warming from $CO_2$ emissions) over past and future projected populations.<br><br>This is a more sophisticated version of the Equal Per Capita (EPC) and Equal Cumulative Per Cumulative Capita (ECPCE) Principles |
| **Related concepts** | Historical responsibility | Responsibility | Capability<br>Capacity | Staged approaches<br>Inertia principle<br>Constant emissions ratio | Emissions egalitarianism |
| **Forward- or backward-looking application within the SEFS dashboard?** | Backward-looking | Forward-looking, although the climate ethics literature describes this principle as a hybrid one, with both forward- and backward-looking elements | Forward-looking | Forward- and backward-looking | Forward- and backward-looking |
| **Metric or proxy metric** | Historical GHG emissions<br>Historical warming (from GHG emissions) | Total Wealth<br>Total Wealth Per Capita | Gross Domestic Product<br>Gross Domestic Product Per Capita<br>Gross National Income<br>Gross National Income Per Capita<br>Human Development Index | Historical GHG emissions<br>Historical warming (from GHG emissions) | Historical GHG emissions<br>Historical warming (from GHG emissions)<br>Historical population<br>Future population projections |
| **Other possible proxy metrics suggested from dashboard demos** | | Cumulative Total Wealth<br>Carbon intensity: $CO_2$ emissions per dollar of GDP (1820–2018). Source: Our World in Data | National Disposable Income | | |
| **Warming- or emissions-dependent application within the SEFS dashboard?** | Yes | No, but it could be operationalised in this way | No | Yes | Yes |

*Table 15. Features of the five ethical distributional principles in the SEFS dashboard*

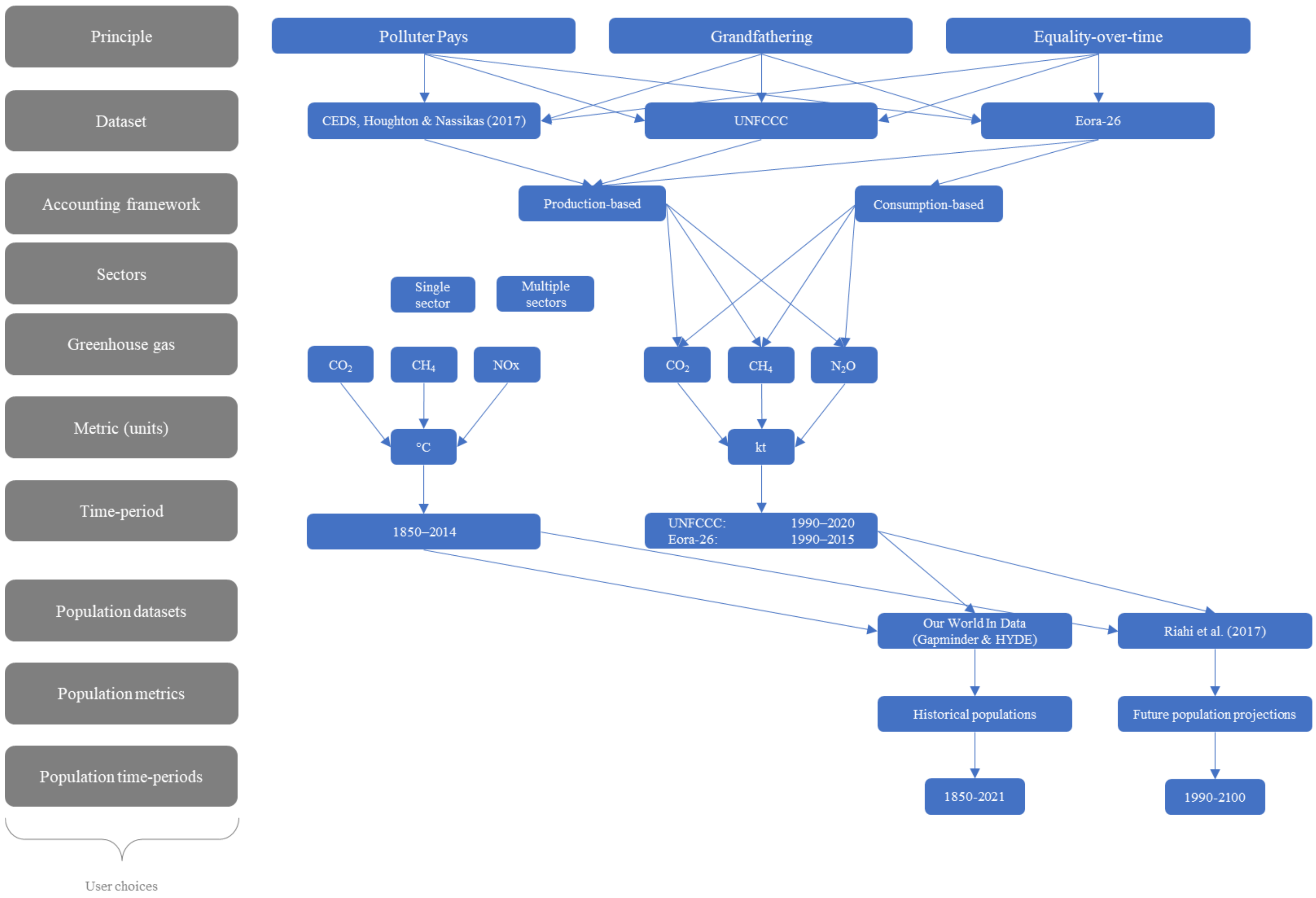



*Figure 14. Information requirements and choices for applying warming- and emissions-dependent principles*

Of the three warming- and emissions-dependent principles shown in Figure 14 above, the Equality-over-time Principle is the most information-intensive principle to apply. This is because it requires countries' climate change-related contributions, as well as countries' historical and projected future population figures. A disadvantage of needing to rely on so many datasets to apply the principle is that certain countries, which do not collect data for all three datasets, become excluded from the analysis. This is illustrated by the Venn diagram in Figure 15 below, which shows the overlap of common countries in different datasets.

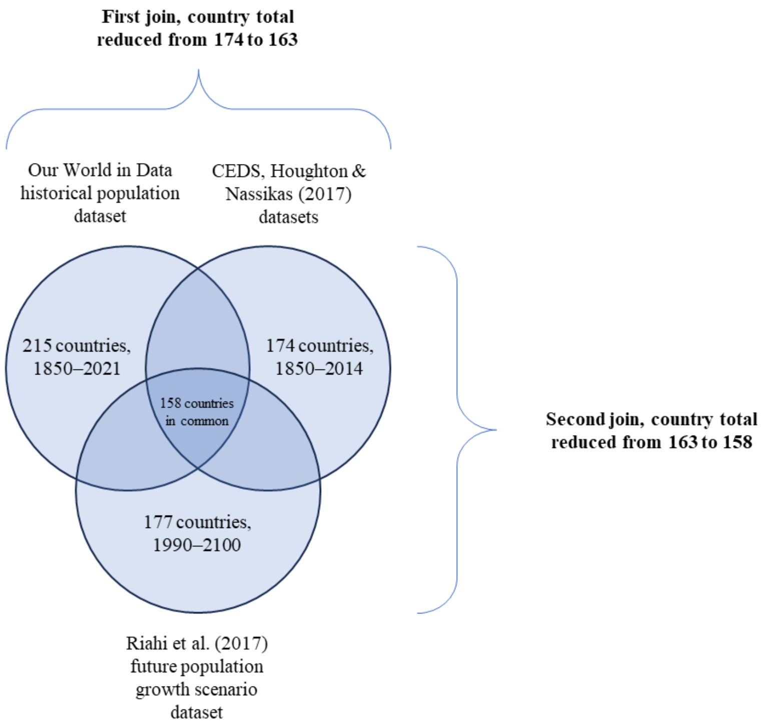



*Figure 15. Common countries in datasets for applying the Equality-over-time Principle*

Operationalising the Equality-over-time principle led to some countries being excluded from the analysis because not all datasets contained information for every country. However, losing sixteen countries, which were not common to all three main datasets, is relatively insubstantial given the 158 common countries that remained.

## §3.7.5 Section summary

This section (§3.7) has outlined the methodology by which the applied ethics component of the research was carried out. §3.7.1 described the six-step approach for applying ethical principles and highlighted the importance of developing a robust understanding of the climate ethics literature. This was especially the case when it came to understanding and applying the three financial burden-sharing principles, which have been comprehensively discussed and debated in the abstract by climate ethicists and philosophers, yet not applied to the same extent as the two budget allocation principles.

Calculations for applying the principles were informed by engagement with climate experts who had written on applied ethics topics or developed similar dashboard-style tools to the SEFS dashboard. The mathematical equations for calculating countries' fair shares for addressing climate change under each of the five ethical principles were outlined in §3.7.2 and §3.7.3. The next section (§3.8) describes the dashboard development and demonstrations that took place to obtain further feedback from climate experts and refine the tool.

## §3.8 Dashboard development and demonstrations

The SEFS dashboard was developed by following an Agile Programming approach. New features were defined as minimum viable products (MVPs) and work was done to develop these features quickly and build on them through making iterative improvements. The work involved switching back and forth between multiple literatures, especially the climate ethics literature, to understand theoretical definitions and philosophical objections against the ethical principles, as well as practical assessments and dashboard-style tools. These tools provided examples of data and information that could be used to apply the principles.

### §3.8.1 Dashboard structure and code layout

The SEFS dashboard includes six pages which users can navigate between, listed below.

Page 1 Introduction
Page 2 Contributions to warming
Page 3 Distributing costs
Page 4 Distributing rights
Page 5 Methods
Page 6 References

The code for each of these pages is contained in separate python files, of the same name. There is one main python file, app.py. This file references the six other files (introduction.py, contributions_to_warming.py, distributing_costs.py, distributing_rights.py, methods.py and references.py).

| | |
|---|---|
| APP-1 | <- Main folder within the repository |
| --app.py | <- Main python file, which calls the other files |
| ----pages | <- Sub-folder |
| ------introduction.py | <- Python code to structure the introduction page |
| ------contributions_to_warming.py | <- Python code to structure the contributions to warming page |
| ------distributing_costs.py | <- Python code to structure the distributing costs page |
| ------distributing_rights.py | <- Python code to structure the distributing rights page |
| ------methods.py | <- Python code to structure the methods page |
| ------references.py | <- Python code to structure the references page |

Figure 16 below shows the relationships between the different files and how they work together, as well as the names of the various functions that are called to carry out specific calculations.

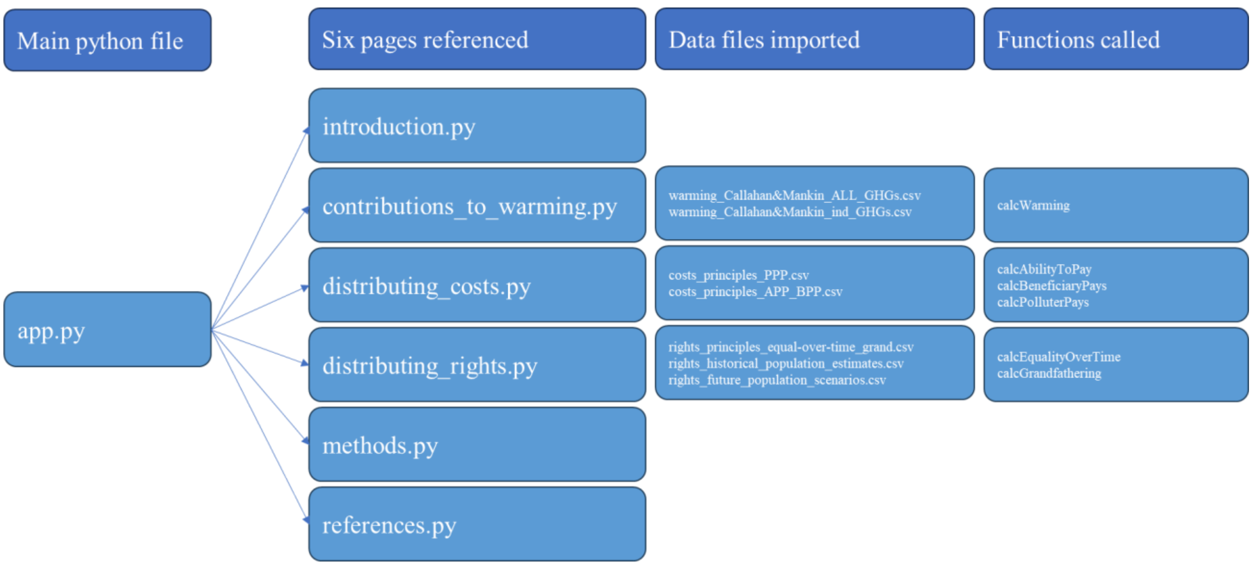



*Figure 16. SEFS dashboard code layout*

Seven .csv files contain all of the data that is required to perform calculations within the dashboard. These are shown in the middle column of Figure 16 above and are also listed in Table 16 below.

| Page of dashboard | RQ | Name of .csv file |
|---|---|---|
| 2 | 1 | warming_Callahan&Mankin_ALL_GHGs.csv |
| 2 | 1 | warming_Callahan&Manking_ind_GHGs.csv |
| 3 | 2 | costs_principles_PPP.csv |
| 3 | 2 | costs_principles_APP_BPP.csv |
| 4 | 3 | rights_principles_equal-over-time_grand.csv |
| 4 | 3 | rights_historical_population_estimates.csv |
| 4 | 3 | rights_future_population_scenarios.csv |

*Table 16. .csv files that the dashboard takes as inputs*

There are also several functions which include the calculations to apply various ethical principles. These are shown in the right-most column of Figure 16 above and are also listed in Table 17 below.

| Function name | Purpose |
|---|---|
| calcWarming | Calculates countries' historical contributions to global warming |
| calcAbilityToPay | Calculates countries' finance shares according to the Ability to Pay principle |
| calcBeneficiaryBays | Calculates countries' finance shares according to the Beneficiary Pays Principle |
| calcPolluterPays | Calculates countries' finance shares according to the Polluter Pays Principle |
| calcEqualityOverTime | Calculates countries' GHG emissions or warming shares according to the Equality-over-time Principle |
| calcGrandfathering | Calculates countries' GHG emissions or warming shares according to Grandfathering Principle |

*Table 17. Functions within the dashboard*

## §3.8.2 Dashboard demonstrations

Between July–September 2023, informal demonstrations of the SEFS dashboard were given to six climate experts. Feedback received during these demonstrations influenced further refinements to the SEFS dashboard that took place throughout August 2023–April 2024. This feedback is summarised in Table 18 below, which lists interviewees' suggested improvements that could be made to the SEFS dashboard and the rationale behind these suggestions in the first and second columns. The third column contains the researcher's response to such suggestions.

| Interviewee's suggestion | Interviewee's rationale | Researcher's response |
|---|---|---|
| Extend the historical time-period. | Only displaying datasets with a 1990 start date is a significant limitation. | A previous version of the SEFS dashboard only contained datasets with post-1990 information. By building on code from the Callahan and Mankin (2022) study – which includes a longer historical time-series of GHG emissions back to 1850 – the historical time-period for calculating countries' warming contributions was extended. A dataset of countries' historical population estimates back to 1850 was also included to apply the Equality-over-time principle. |

| Interviewee's suggestion | Interviewee's rationale | Researcher's response |
|---|---|---|
| Refer to principles as *distributive* not *ethical*. | Grandfathering is not an ethical principle. | Grandfathering arguably is an ethical principle because of the moral arguments that have arisen in defence of it, as discussed in §2.6.2.1. As explained previously, including the Grandfathering Principle within the SEFS dashboard should not be viewed as support for the principle. The principle has been included because it is commonly put into practice and has shaped international climate politics through the Kyoto Protocol and climate policy instruments like emissions trading schemes (ETSs). This has made the principle of unavoidable relevance to this project. |
| Build links between different dashboard pages. | In its current state, there are no clear links between each page of the dashboard and the three RQs. | The three main pages of the dashboard remain as standalone pages. However, the discussion of warming- and emissions-dependent principles in §3.7.4 serves to highlight the links between RQ1 – which is concerned with countries' historical contributions to global warming – and how warming- and emissions-dependent principles can be applied to answer RQ2 and RQ3. |

| Interviewee's suggestion | Interviewee's rationale | Researcher's response |
|---|---|---|
| The Appropriator Pays Principle would be an interesting principle to include in the dashboard. | The Appropriator Pays Principle would assign responsibility to those actors who have taken up some of the atmosphere's absorptive capacity, without authority or permission, for their own use in a form of environmental colonialism. This principle is relevant to distributive climate justice questions because of how it focusses on appropriation of an atmospheric sink and how the sink's capacity might be distributed. Countries which have used more of this sink, or its absorptive capacity, have denied other countries the opportunity to access this. | An Appropriator Pays Principle has not yet been included within the SEFS dashboard.<br>Despite references to atmospheric appropriation within the climate ethics literature and climate ethicist Dale Jamieson stating that: "Climate ethicists often say that climate change at its core is a problem of rich people appropriating more than their share of a global public good", the Appropriator Pays Principle has not yet been explicitly discussed and applied as an ethical principle (Fanning & Hickel, 2023; Jamieson, 2014, p. 6; Page, 2013b). Further work would be required to define and clearly distinguish this principle from other well-recognised ones, and investigate possible ways to apply it. |

| Interviewee's suggestion | Interviewee's rationale | Researcher's response |
|---|---|---|
| Consider including a page with marginal abatement cost curves (MACCs). | It can be useful for countries to understand how much it will cost them to mitigate climate change. | This would be useful to do but does not align with the overall aims of this particular doctoral research project.<br>MACCs are graphs which show the abatement potential of different climate mitigation measures, and the relative costs associated with each measure. They are used to identify least-cost emission reductions within a particular territory. However, this project is focussed on apportioning responsibility to nation-state actors. |

*Table 18. Suggested dashboard improvements from climate experts*

# §3.9 Chapter summary

Chapter 3 has outlined the research approach and introduced a tangible output of the research: the SEFS dashboard. The research design, including how multiple methodologies and methods are situated within an overarching pragmatist-positivist paradigm, was presented in §3.2.

This was followed by overviews of the SEFS dashboard's layout (§3.3), data sources which are combined within the dashboard and the steps taken to pre-process and convert this data into useable formats (§3.4). The procedures for calculating countries' contributions to global warming (§3.5) and consumption-based emissions (§3.6) were then explained.

Next, the datasets and formulae behind applications of each of the five ethical distributional principles were detailed and information requirements for applying each principle were reflected on in §3.7. The chapter concluded by summarising climate experts' feedback on the SEFS dashboard in §3.8, which helped strengthen the dashboard's design.

In summary, Chapter 3 has articulated how a range of knowledge and methods from the fields of climate science, IE and applied ethics have been brought together during this research project to produce a novel dashboard-style tool. The manner in which the dashboard was developed is best described as an iterative one, with much switching back and forth or *to and froing* between developing components of the dashboard and then returning to various literatures to be informed and guided by these. The next chapter presents and discusses results that were obtained from the dashboard to answer the three RQs.

# Chapter 4 Results and discussion

## §4.1 Chapter overview

This chapter presents charts and tables from the Science and Ethics of Fair Shares (SEFS) dashboard and discusses these as answers to each of the three research questions (RQs). Most of the results in this section come directly from the SEFS dashboard. However, several charts have been created from dashboard outputs and do not appear in the dashboard itself.

Answers to RQ1, which focusses on country-level contributions to historical global warming, are presented and discussed in §4.2. Next, §4.3 presents answers to RQ2, which focusses on fair distributions of financial costs for mitigating climate change. The *costs* referred to in RQ2 are financial in nature. Therefore, a discussion of answers to this question requires situating the results within the climate finance literature and drawing on real-world climate finance estimates, including the US$100 billion climate finance pledge mentioned previously and the New Collective Quantified Goal (NCQG) on climate finance.

Next, §4.4 presents and discusses answers to RQ3, which focusses on fair distributions of warming rights within fixed global temperature change targets. The *rights* referred to in RQ3 are akin to property rights or rights to exploit the global atmospheric commons. RQ3 is answered by way of two budget allocation principles – Grandfathering and Equality-over-time. As mentioned in Chapter 1, these budget allocation principles represent very different ideas of justice and allow for a form of technology-assisted wide reflective equilibrium (WRE). For instance, the Equality-over-time Principle ascribes to an egalitarian notion of justice, whereas the Grandfathering Principle follows a first-in first-served or customary rights-based approach.

Finally, §4.5 discusses the links between each of the RQs in terms of the data each uses and how answers to RQ1 can inform answers to RQ2 and RQ3, depending on which distributional principle is selected by a user. This section also concludes the chapter.

As climate change progresses, policymakers and international climate negotiators will continue grappling with how to address the challenge fairly in years to come. Scientific knowledge of greenhouse gases (GHGs) and how they warm the world differently has been crucial in enabling a better understanding of human-induced climate change and what it is driven by. However, scientific knowledge, data and evidence alone are insufficient to support efforts to address the issue. Questions relating to countries' fair shares are ultimately ethical in nature. The SEFS dashboard invites users to explore how a country's fair share varies when different information and ethical principles are applied, thereby encouraging value judgements sitting behind these principles to be seen and acknowledged for a richer discussion.

## §4.2 Countries' contributions to global warming

Understanding how countries have *warmed* the planet over different time-periods is the focus of RQ1. Historical precedents, like the 1997 Brazilian Proposal, argued that countries' responsibilities for addressing climate change should be in proportion to how much warming they had generated (Brazil, 1997; den Elzen, 1999; La Rovere et al., 2002; Skeie et al., 2017). This explicit focus on countries' contributions to global *warming* within international climate negotiations motivated a range of studies in the early 2000s to develop methodologies for calculating countries' historical warming contributions (Blanchard, 2002; den Elzen et al., 2005, 2005; Höhne & Blok, 2005).

More recently, an explicit focus on global *warming* can also be seen in the framing of the Paris Agreement's Article 2 temperature targets, which 196 parties to the agreement have agreed to not surpass. There is also a well-established literature on carbon budgets, which link allowable quantities of carbon emissions that can be emitted to these targets (Allen et al., 2009; Anderson & Bows, 2008; Meinshausen et al., 2009).

Yet calculating countries' historical contributions to warming is not a straightforward process, as §3.5 outlines. This may, in part, explain why few studies quantify warming contributions at the national level. The SEFS dashboard allows users to view countries' contributions to warming by utilising outputs from a simple climate model (SCM) which was used to run modified *leave-one-country-out* experiments, elaborated on in §3.5. These experiments involved extending the code developed by Callahan and Mankin (2022) so that warming associated with carbon dioxide ($CO_2$), methane ($CH_4$) and nitrogen oxides (NOx) emissions could be calculated.

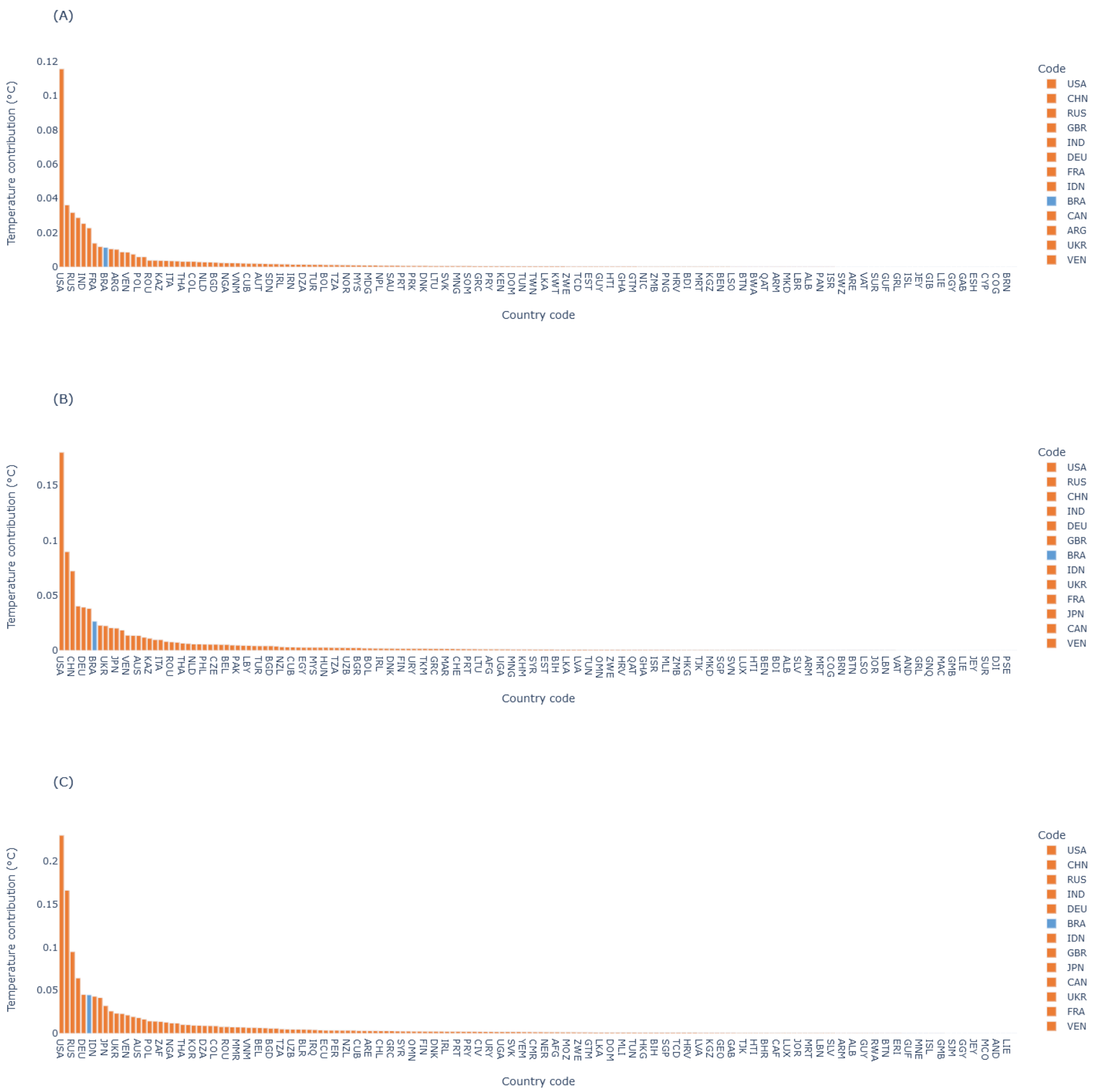
### §4.2.1 Results and discussion

The SEFS dashboard offers users a choice of six time-periods over which to view countries' historical contributions to global warming, listed below.

1. 1850–1960
2. 1850–1990
3. 1850–2014

4. 1960–1990
5. 1960–2014
6. 1990–2014

Figure 17 displays countries' historical contributions to warming (in °C) over the above six time-periods from the emissions of $CO_2$, $CH_4$ and NOx. It should be noted that the country codes along the x-axis do not align with each bar in the chart. The purpose of displaying these charts is to show the different shapes and spreads of the distributions. The index on the right-hand-side of each chart specifies the top thirteen countries. The warming contribution of Brazil (BRA) is shown as a blue bar in each chart to indicate the country's position and relative contribution, and how these have changed with time for comparative purposes.



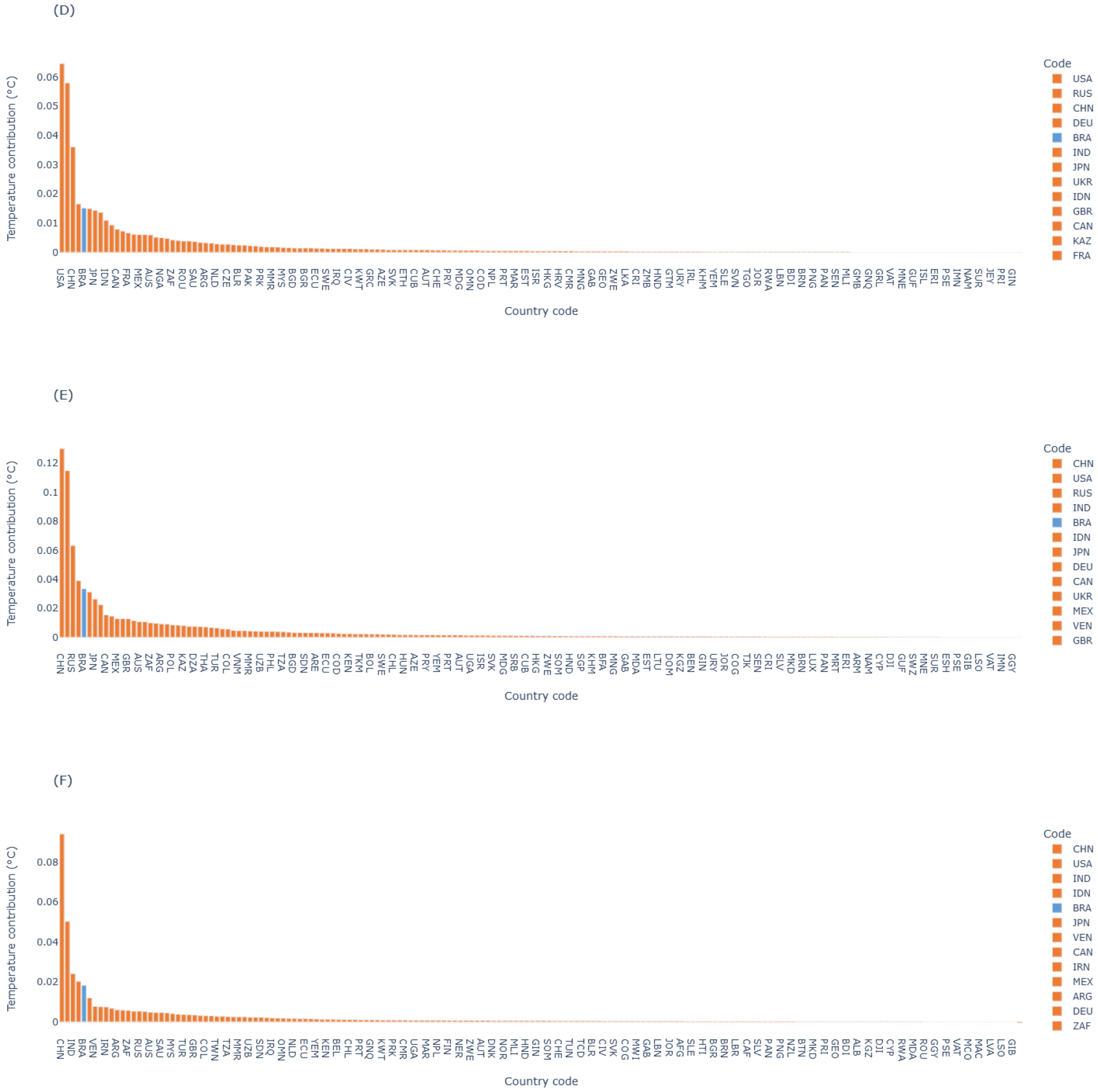



*Figure 17. Countries' contributions to warming (°C) from $CO_2$, $CH_4$ and NOx emissions*

*(A) 1850–1960, (B) 1850–1990, (C) 1850–2014, (D) 1960–1990, (E) 1960–2014, (F) 1990–2014*

In charts A, B and C of Figure 17, where the start date is 1850, the United States features prominently as the largest contributor to historical global warming. In chart D, where the start date is 1960 and the end date is 1990, the contributions of Russia and China become more comparable with the United States. In E and F, where the end date is 2014, China overtakes the United States as the largest contributor to global warming. China's increasing cumulative warming contribution in these later time-periods reflects the later start of China's industrialisation journey.

Brazil's contribution to warming (blue bar), relative to other countries, also increases in later time-periods. Growing fossil fuel use in rapidly industrialising regions and greater deforestation to make room for agricultural expansion, particularly in Latin American countries, has driven GHG emissions increases in many African, Asian and Latin American countries between 1990–2018 (Lamb et al., 2021). This can explain why Brazil's relative contribution and ranking increases in later time-periods.

Overall, these results show that early emitters, like the United States, have the greatest contributions to warming when late 19$^{th}$ and early 20$^{th}$ century warming is included. However, a different story emerges after 1990, as large developing countries like China and Brazil undergo their processes of industrialisation.

Table 19, Table 20 and Table 21 below show the top ten countries which have contributed to historical global warming from the same three climate forcers over the 1850–1960, 1850–1990 and 1850–2014 time-periods. These tables are taken from the dashboard and have been displayed here to more easily show the ranking of major warming contributors and their temperature contributions. Values in the *Temp_difference* column are the warming amounts (in °C) that each country has contributed over the given time-period.

| Rank | Country | Code | Temp_difference |
|---|---|---|---|
| 1 | United States of America (the) | USA | 0.116 |
| 2 | China | CHN | 0.036 |
| 3 | Russian Federation (the) | RUS | 0.032 |
| 4 | United Kingdom of Great Britain and Northe... | GBR | 0.029 |
| 5 | India | IND | 0.025 |
| 6 | Germany | DEU | 0.023 |
| 7 | France | FRA | 0.014 |
| 8 | Indonesia | IDN | 0.012 |
| 9 | Brazil | BRA | 0.011 |
| 10 | Canada | CAN | 0.011 |

*Table 19. Top ten countries' contributions to warming (°C) from all GHGs, 1850–1960*

| Rank | Country | Code | Temp_difference |
|---|---|---|---|
| 1 | United States of America (the) | USA | 0.180 |
| 2 | Russian Federation (the) | RUS | 0.090 |
| 3 | China | CHN | 0.072 |
| 4 | India | IND | 0.040 |
| 5 | Germany | DEU | 0.039 |
| 6 | United Kingdom of Great Britain and Northe… | GBR | 0.038 |
| 7 | Brazil | BRA | 0.026 |
| 8 | Indonesia | IDN | 0.023 |
| 9 | Ukraine | UKR | 0.022 |
| 10 | France | FRA | 0.020 |

*Table 20. Top ten countries' contributions to warming (°C) from all GHGs, 1850–1990*

| Rank | Country | Code | Temp_difference |
|---|---|---|---|
| 1 | United States of America (the) | USA | 0.230 |
| 2 | China | CHN | 0.166 |
| 3 | Russian Federation (the) | RUS | 0.095 |
| 4 | India | IND | 0.064 |
| 5 | Germany | DEU | 0.045 |
| 6 | Brazil | BRA | 0.045 |
| 7 | Indonesia | IDN | 0.043 |
| 8 | United Kingdom of Great Britain and Northe… | GBR | 0.041 |
| 9 | Japan | JPN | 0.032 |
| 10 | Canada | CAN | 0.026 |

*Table 21. Top ten countries' contributions to warming (°C) from all GHGs, 1850–2014*

Table 22 below gives countries' top ten rankings from Table 19, Table 20 and Table 21, as well those over the later three time-periods: 1960–1990, 1960–1990 and 1990–2014.

| Country / time-period | 1850–1960 | 1850–1990 | 1850–2014 | 1960–1990 | 1960–2014 | 1990–2014 |
|---|---|---|---|---|---|---|
| US | 1 | 1 | 1 | 1 | 2 | 2 |
| China | 2 | 3 | 2 | 3 | 1 | 1 |
| Russia | 3 | 2 | 3 | 2 | 3 | - |
| UK | 4 | 6 | 8 | 10 | - | - |
| India | 5 | 4 | 4 | 6 | 4 | 3 |
| Germany | 6 | 5 | 5 | 4 | 8 | - |
| France | 7 | 10 | - | - | - | - |
| Indonesia | 8 | 8 | 7 | 9 | 6 | 4 |
| Brazil | 9 | 7 | 6 | 5 | 5 | 5 |
| Canada | 10 | - | 10 | - | 9 | - |
| Ukraine | - | 9 | - | 8 | 10 | 8 |
| Japan | - | - | 9 | 7 | 7 | 6 |
| Venezuela | - | - | - | - | - | 7 |
| Iran | - | - | - | - | - | 9 |
| Mexico | - | - | - | - | - | 10 |

*Table 22. Country positions within the top ten contributors to warming over the six time-periods*

Across all time-periods, five countries consistently feature in the top ten: the United States, China, India, Indonesia and Brazil. These countries' rows are highlighted in yellow in Table 22 above. While the United States and China are always the highest or second highest contributors to warming, the positions of India, Indonesia and Brazil rise with time and all three of these countries appear in the top five contributors to warming when the most recent time-period – 1990–2014 – is chosen. Other noticeable trends are the way in which the United Kingdom, Russia, Germany and France drop out of the top ten countries when more recent time-periods are chosen – where the start year is 1960 or later and the end year is 2014. Canada, Ukraine and Japan also appear in the top ten countries, but not across all time-periods. These countries' rankings within the top ten tend to be slightly lower over the time-periods with 1850 start dates. Finally, when the latest time-period is selected, a group of new countries enter the top ten that were not in periods when the start date was earlier than 1990: Venezuela, Iran and Mexico.

These results align with real-world observations. For instance, European countries and the United States have achieved annual GHG emissions reductions on average between 2011–2018, with significant reductions in their energy-related emissions (Lamb et al., 2022). This can be explained by these countries' successes in shifting away from fossil fuels through diversifying their energy portfolios to incorporate renewable and nuclear sources. This was particularly the case for France and Sweden, which chose to become less oil dependent following the 1973 oil crisis, and have on average reduced their annual emissions since 1970 (Millot et al., 2020).

The rising warming contributions of Venezuela, Iran and Mexico can be explained by these three countries having abundant oil reserves, which they have exported to other countries, and which have also begun playing an increasing role in underpinning their domestic economies (Agbanike et al., 2019; Agnani & Iza, 2011; Esfahani & Pesaran, 2009). Interestingly, these countries have suffered multiple economic crises but have also experienced periods of rapid economic growth in the late 1990s and early 2000s (Solaymani, 2020; Weisbrot & Sandoval, 2007). The rapidly rising populations of Mexico and Iran over the 1990–2014 period can also explain higher levels of warming from rising energy needs (Escamilla-García et al., 2024; Esfahani & Pesaran, 2009; Rendón-Huerta et al., 2013; Solaymani, 2020).

In contrast to developed countries decarbonising their economies, many large developing countries have not begun decarbonising their energy sectors to the same extent or have begun consuming greater proportions of their produced fossil fuels than they did previously, as is the case for Venezuela (Agbanike et al., 2019). These countries are now overtaking large historical emitters in what is anticipated to be a continuing trend (Jiang et al., 2019).

While it can be useful to consider countries' contributions to warming from multiple climate forcers at once, there is also benefit in isolating and analysing the warming effect from just one or two. The charts in Figure 18 and Figure 19 (below) display countries' historical contributions to global warming across three different time-periods, from combinations of one or two climate forcers. A–C of Figure 18 includes warming from $CO_2$ only, while A–C of Figure 19 includes warming from both $CH_4$ and NOx.

The SEFS dashboard includes functionality to filter charts so that only the top fifty contributing countries are displayed. An advantage of this is that country codes and bars align. To demonstrate this functionality, the charts in Figure 18 and Figure 19 include only the top fifty countries. The warming contribution of Brazil (BRA) is again shown as a blue bar in each chart to indicate the country's position and relative contribution, and how these have changed with time for comparative purposes.

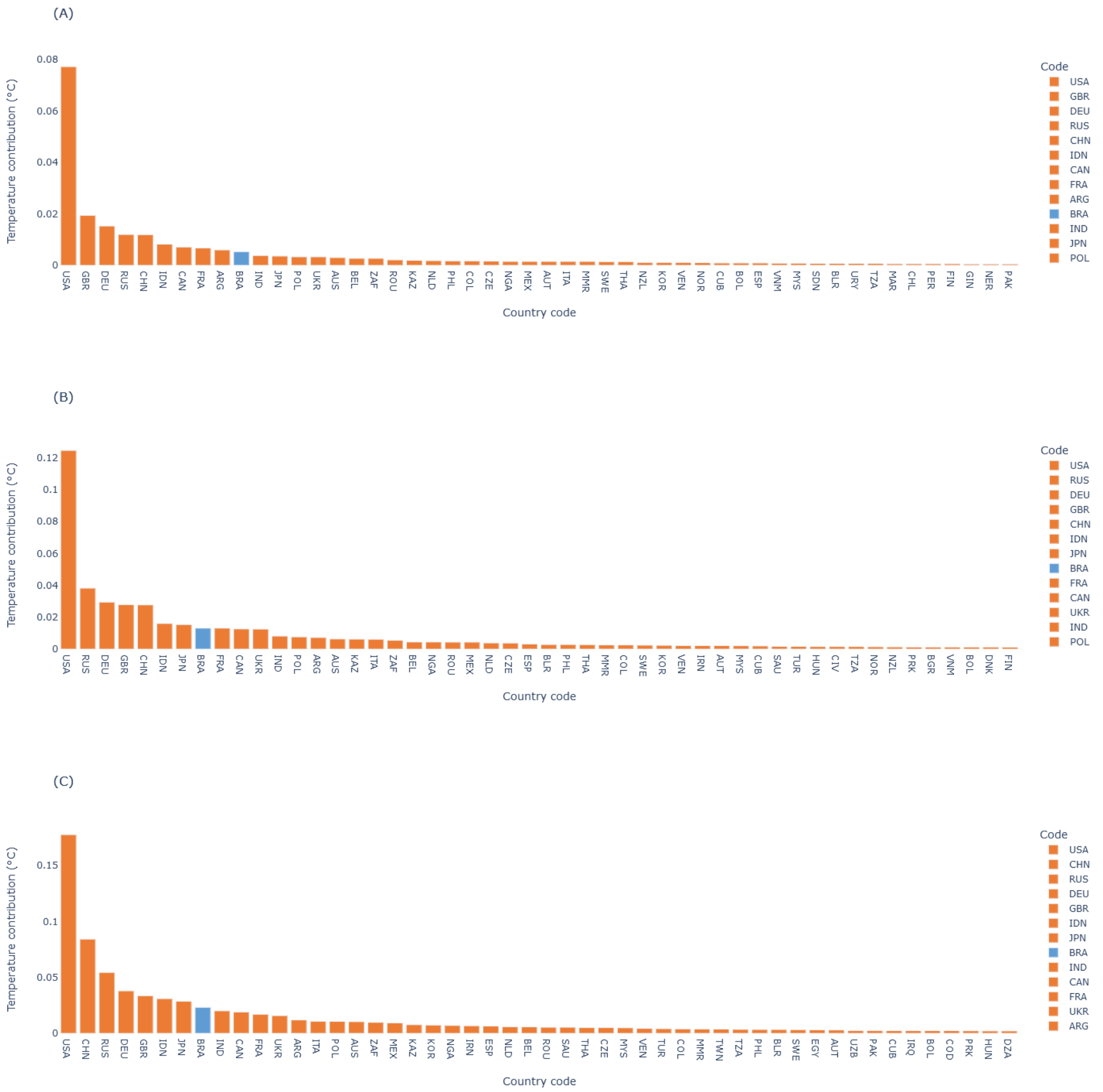



*Figure 18. Countries' contributions to warming (°C) from $CO_2$ emissions only*

*(A) 1850–1960, (B) 1850–1990, (C) 1850–2014*

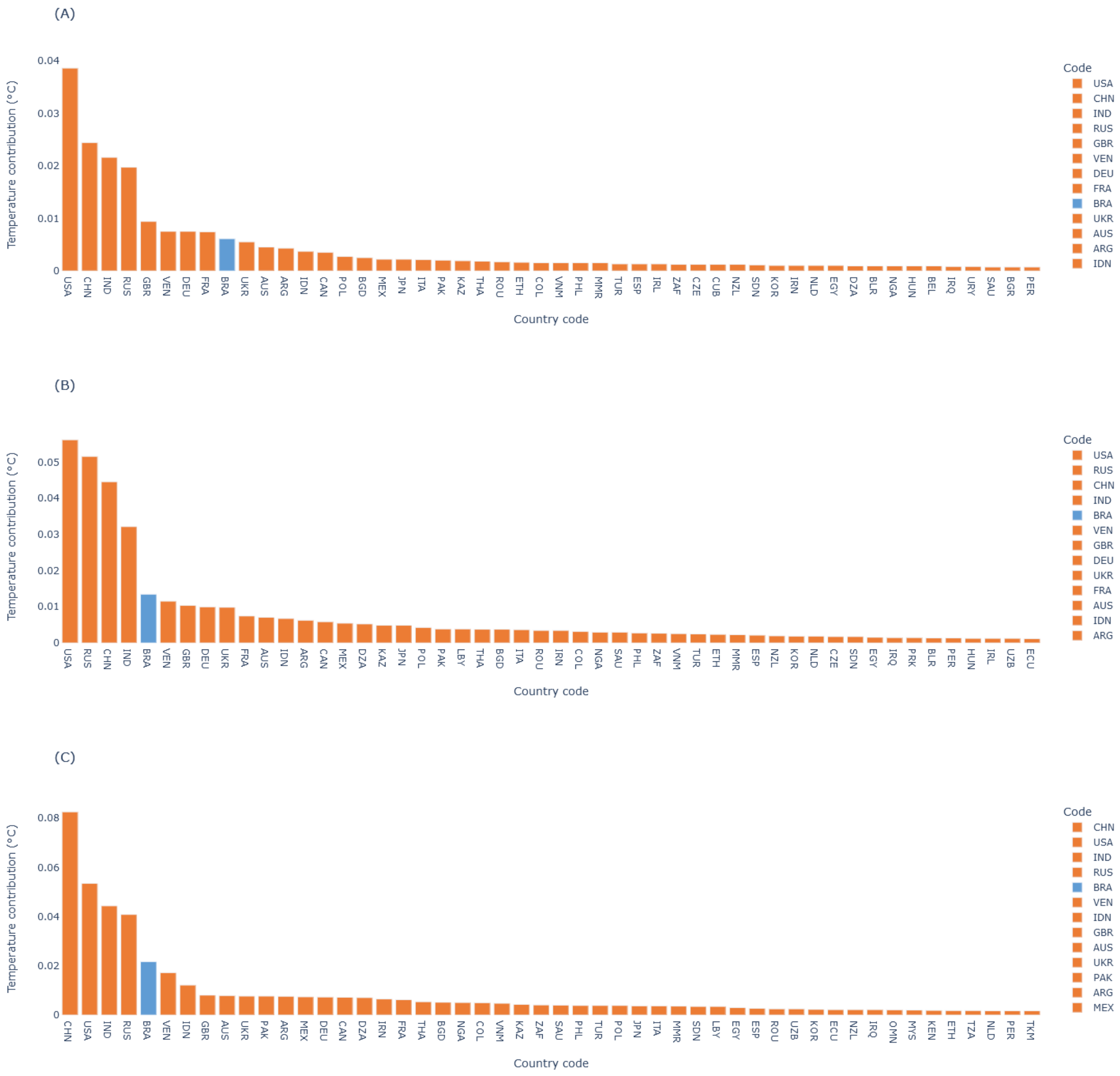



*Figure 19. Countries' contributions to warming (°C) from $CH_4$ and NOx emissions (A) 1850–1960, (B) 1850–1990, (C) 1850–2014*

The charts in Figure 18 and Figure 19 will now be compared with those in Figure 17, which gave the results of countries' combined contributions to warming from $CO_2$, $CH_4$ and NOx, as well as Table 22, which displayed countries' positions within the top ten contributors to warming over the six time-periods. The distributions in Figure 18 are similar in shape to those in A–C of Figure 17. For instance, in chart A of both Figures the warming contributions are highly skewed towards the United States, which has a significantly higher contribution than the next country.

However, when comparing the order of countries which make up the next largest contributors to warming in Figure 18 and Figure 19 with those in Table 22, noticeable differences emerge. Looking at the first column of Table 22, which includes warming from all three climate forcers over the 1850–

1960 time period, China and Russia had the second and third highest warming contributions, followed by the United Kingdom and India in fourth and fifth. However, when *only* $CO_2$ emissions are considered over the same time period in chart A of Figure 18, the United Kingdom, Germany and Russia come in at second, third and fourth, whereas China falls to fifth and India to the eleventh highest contributor. This reflects the industrialised nature of the developed countries' former economies, and how $CH_4$ and NOx have tended to play a greater role in the former economies of large developing countries like China and India, which were associated with agricultural activities to a greater degree.

The comparative scale of China's and India's agricultural sectors can be appreciated by the proportions of their total populations that have been engaged in agricultural activities. For instance, in 1975 the Chinese population was between 850–900 million, where the number of Chinese engaged in agricultural activities was 680–765 million, or 80–85% of the total population (Wortman, 1975). For India, agriculture accounted for nearly half of the country's national income and was the main source of employment at the time of Independence in 1947, when ~72% of the total working population was engaged in agriculture (Tripathi & Prasad, 2009). By 2009, still more than 60% of the Indian workforce was engaged in agriculture (Tripathi & Prasad, 2009). In comparison, the United States' agricultural labour force in 1975 consisted of only 4.2 million workers, or 2% of the total population of 210 million (Wortman, 1975).

When only emissions from $CH_4$ and NOx are included in the calculation of countries' warming contributions over the same time-period – 1850–1960 – the United States shows significantly less dominance than it did when emissions from all three climate forcers ($CO_2$, $CH_4$ and NOx) or only $CO_2$ emissions were included. Finally, when the longest time-period – 1850–2014 – is selected, China has the highest warming contribution from $CH_4$ and NOx emissions, followed by the United States and then India. This again reflects the nature of these countries' economies and the types of activities they engage in. The significantly higher proportions of warming coming from China's and India's $CH_4$ emissions can be explained by their large agricultural sectors, where rice is the most commonly grown crop, and rice paddies are a significant source of $CH_4$ emissions (Sprague, 1975; Tripathi & Prasad, 2009; Wortman, 1975).

These results show that countries' contributions to warming are highly sensitive to not just the time-period selected, but also the choice to include the warming effect of multiple or isolated climate forcers. A disadvantage of translating the warming effect of multiple climate forcers into an overall figure (in °C) is that proportions of short-lived and long-lived warming are hidden. As explained in §2.4, the atmospheric residence time is what determines the temporary or more permanent warming effects of GHGs. Differentiating between temporary and permanent warming can have important policy implications and will be discussed further in relation to applications of the Grandfathering Principle in §4.4.2, where countries may inherit cooling obligations.

While RQ1 is concerned with determining countries' historical contributions to global warming, the results in this section can also be used to explore answers to the question of what proportion of warming countries ought to be held responsible for. This relates to the concepts of excusable ignorance and inexcusable negligence, discussed in §2.6.1.1. The dashboard does not give specific answers to this question, however it can help show what possible answers would be and how different perspectives on temporal responsibility might play out, given the facts. For instance, if one were to take a post-1990 view of responsibility, then large obligations associated with addressing pre-1990 warming would be absolved for early industrialising nations. However, if one were to believe that countries should not be completely absolved of responsibility for their pre-1990 warming, then early industrialising countries would bear greater obligations.

As mentioned in Chapter 1, instead of providing a single *right* answer to RQ1, the SEFS dashboard's virtue is in it enabling its users to explore their value differences by viewing a range of possible answers. Such answers reflect varying perspectives about temporal moral responsibility and can support debates about proportions of short-lived versus long-lived warming within global temperature change targets. Given that base years and time-periods for culpability are contested, the SEFS dashboard affords its users an opportunity to experiment with different time-periods and warming from different combinations of GHGs, to test their own intuitions of fairness. In this way, climate negotiators and policymakers can investigate the results of assigning moral responsibility for past warming in different ways, to better inform ethical debate.

## §4.2.2 Comparison with similar studies

The sample of results obtained from the SEFS dashboard will now be discussed in relation to similar practical climate ethics assessments and studies. One of these studies – Skeie et al. (2017) – also calculated countries' contributions to warming by using an SCM. Skeie et al. (2017) used the Center for International Climate and Environmental Research–Oslo (CICERO)-SCM and included territorial or production-based emissions from 1850–2012. The study calculated aggregated warming amounts of Annex I Parties, the United States, and the European Union and its 28 members (EU28). At the time, the United Kingdom was still part of the European Union (EU). Annex I Parties were found to have accounted for 68% of total historical global warming from their cumulative $CO_2$ emissions between 1850–2012, yet only 54% of total warming when $CH_4$ and nitrous oxide ($N_2O$) were also included.

In its current state, the SEFS dashboard does not include a feature to group warming contributions of countries at the regional level or by common coalitions, such as Annex I Parties and the EU28. This was deemed out of scope for the current research project. However, developing this type of feature, which would enable direct comparisons to be made between the results of the Skeie et al. (2017) study and the SEFS dashboard, could be incorporated into future iterations of the tool.

Another study which calculates countries' warming contributions is the Jones et al. (2023) study. This study makes use of the same LULCC dataset, but a different historical $CO_2$-fossil emissions dataset from the Global Carbon Project (GCP). Jones et al. (2023) enables analysis of countries' contributions to global mean surface temperature (GMST) change between 1851–2021. The results are presented as choropleth graphs, with colour scales indicating contributions to climate change – both in terms of a temperature increase and as a proportion of total anthropogenic warming to date. Across all three time-periods – 1851–1960, 1851–2000 and 1851–2021 – considered by the Jones et al. (2023) study, the United States contributes towards the greatest temperature change. However, the rise in China's contribution since 2000 is evident. The United States' historical dominance as a large contributor to global warming and China's notable rise as a significant contributor in recent decades align with findings from the SEFS dashboard. The reduction in European nations' warming contributions as a proportion of total anthropogenic warming is another trend in the choropleth graphs which matches the SEFS dashboard's results.

Both Skeie et al. (2017) and Jones et al. (2023) also draw attention to the varying proportions of warming that are associated with $CO_2$ fossil emissions and $CO_2$ emissions from land use change. They highlight the effect that choosing whether to include or exclude these emissions can have on countries like Brazil and Indonesia, which have substantial contributions to warming from their land use sectors. The SEFS dashboard, in its current state, does not differentiate between $CO_2$-based warming from countries' fossil fuel and land use sectors. This is because in the Finite Amplitude Impulse Response (FaIR) model v1.3, both $CO_2$-fossil emissions and carbon fluxes associated with land use change must be combined to calculate $CO_2$ emissions when the climate model is run. This means that the two cannot be distinguished.

### §4.2.3 Section summary

This section (§4.2) has presented and discussed samples of results from the SEFS dashboard, as a range of possible answers to RQ1: *What are countries' historical contributions to global warming?* The results highlight that countries' contributions to warming depend on the time-period over which warming is considered and whether warming from several climate forcers, or just one or two, are included.

When earlier time-periods – 1850–1960 and 1850–1990 – are selected, it is observed that many of the early emitters, like the United States, the United Kingdom, Russia, Germany and France account for significantly higher proportions of historical warming contributions than in later periods. However, when warming prior to 1990 is not included, Middle Eastern, Central American and South American countries enter the top ten and the comparative rankings of India, Indonesia and Brazil noticeably rise.

The choice of start date raises questions about from what point in time countries ought to be held morally responsible for their historical warming contributions. There are a range of perspectives on this topic which include considerations of excusable ignorance and inexcusable negligence, as previously discussed in §2.6.1.1. These considerations are also relevant to the results of Polluter Pays Principle applications, discussed in §4.3.3. Additionally, the entry of large developing countries into the top ten contributors to warming over more recent time-periods highlights what is anticipated to be a continued trend. That is, as developing countries' energy-related emissions have stagnated, it will be large developing nations' emissions which will determine the world's future warming trajectory.

Up until the 1990s, the dominance of developed countries' contributions to climate change provided a strong rationale for only Annex I Parties having emission reduction commitments under the Kyoto Protocol. However, the SEFS dashboard can help shine a light on discussions about how responsibility falls differently under different time-periods. If a dashboard user is of the view that ignorance can only be excused up until 1990, then this puts the weight of responsibility onto developing countries. This, in turn, raises ethical questions and potentially undercuts the spirit of the Common But Differentiated Responsibilities and Respective Capabilities (CBDR-RC) principle.

While it is interesting to consider countries' historical contributions to global warming, this thesis is ultimately concerned with using such information to better understand countries' ethical obligations. The results presented and discussed in the subsequent two sections – §4.3 and §4.4 – use information about countries' warming contributions in applications of several principles. These results shed light on approaches for fairly sharing climate mitigation efforts in terms of financial costs and warming and emissions rights.

## §4.3 Distributing the costs for addressing climate change

Addressing climate change is going to cost money. The question of how financial costs for addressing climate change ought to be shared between countries is an ongoing ethical and political debate. These debates also occur within a context of urgency, because, as the landmark 2006 Stern Review concluded, the benefits of taking early action on climate change would far outweigh the economic costs of inaction (N. Stern, 2006).

While the direst future scenarios – that the world might reach between 5–7°C of warming by the end of the 21st century – are becoming less likely, human-altered climate change continues to worsen with time (Hausfather & Peters, 2020). As a result, climate finance estimates have increased to US$1 trillion by 2030 (Songwe et al., 2022).

At the 15th Conference of the Parties (COP15) in Copenhagen in 2009, an explicit climate finance agenda was put on the table. Developed countries pledged to mobilise US$100 billion annually towards climate finance for developing countries by 2020 (Roberts et al., 2021). Recent Organization for Economic Co-operation and Development (OECD) assessments have found that the goal was not reached until two years after the target date (OECD, 2022). At the most recent COP in Azerbaijan last November, countries agreed to the NCQG on climate finance. There are two parts to this goal. These are reaching:

- US$300 billion annually by 2035 of climate finance to developing countries from developed countries; and
- US$1.3 trillion annually by 2035 of climate finance to developing countries, from public and private sources.

The climate finance amounts in these goals includes financial resources for both climate adaptation and mitigation efforts. For this reason, RQ2 has real-world relevance in that it could help with informing debates about country-level fair shares of collective climate finance mobilising efforts. There are four climate finance goal options within the SEFS dashboard, shown below, all expressed in US$ billions. The US$100 billion climate finance option aligns with the COP15 climate finance pledge.

- 100
- 50
- 25
- 20

Once a climate finance goal has been chosen within the dashboard, users have the option to operationalise the three financial burden-sharing principles presented in Table 1 with different datasets, to see how climate mitigation finance could be distributed under these principles. The following three sections (§4.3.1, §4.3.2 and §4.3.3) present and discuss the results of applying each principle, starting with the Ability to Pay. Climate finance amounts are proportions of the US$100 billion pledge.

## §4.3.1 The Ability to Pay Principle

The Ability to Pay Principle is the first principle that users can choose to operationalise within the SEFS dashboard to answer the question of how climate finance goals can be shared. This principle is also commonly referred to as the *capacity* or *capability* principle in similar studies and dashboard-style tools (Dooley et al., 2021; Rajamani et al., 2021). The five different metrics, below – often referred to as *proxy* metrics in the climate ethics literature – can be used to operationalise this principle within the SEFS dashboard. They are called proxy metrics because they are imperfect approximations of the principle. These metrics were defined and discussed §3.7.2.3.

- Gross Domestic Product (GDP)
- Gross National Income (GNI)
- Gross Domestic Product Per Capita
- Gross National Income Per Capita
- Human Development Index (HDI)

### *§4.3.1.1 Results and discussion*

Charts A–E in Figure 20 below are the result of applying the Ability to Pay Principle with each of the five metrics. These charts show the distribution of mitigation finance obligations for 219 countries in the case of charts A, B and C and 191 countries for D and E. It should be noted that country codes along each chart's x-axis do not align with each bar. However, the index on the right-hand-side of each chart specifies the top thirteen countries. The purpose of displaying these charts is to highlight the shape and spread of the distributions as indications of how climate finance can be shared by countries, according to different Ability to Pay metrics.

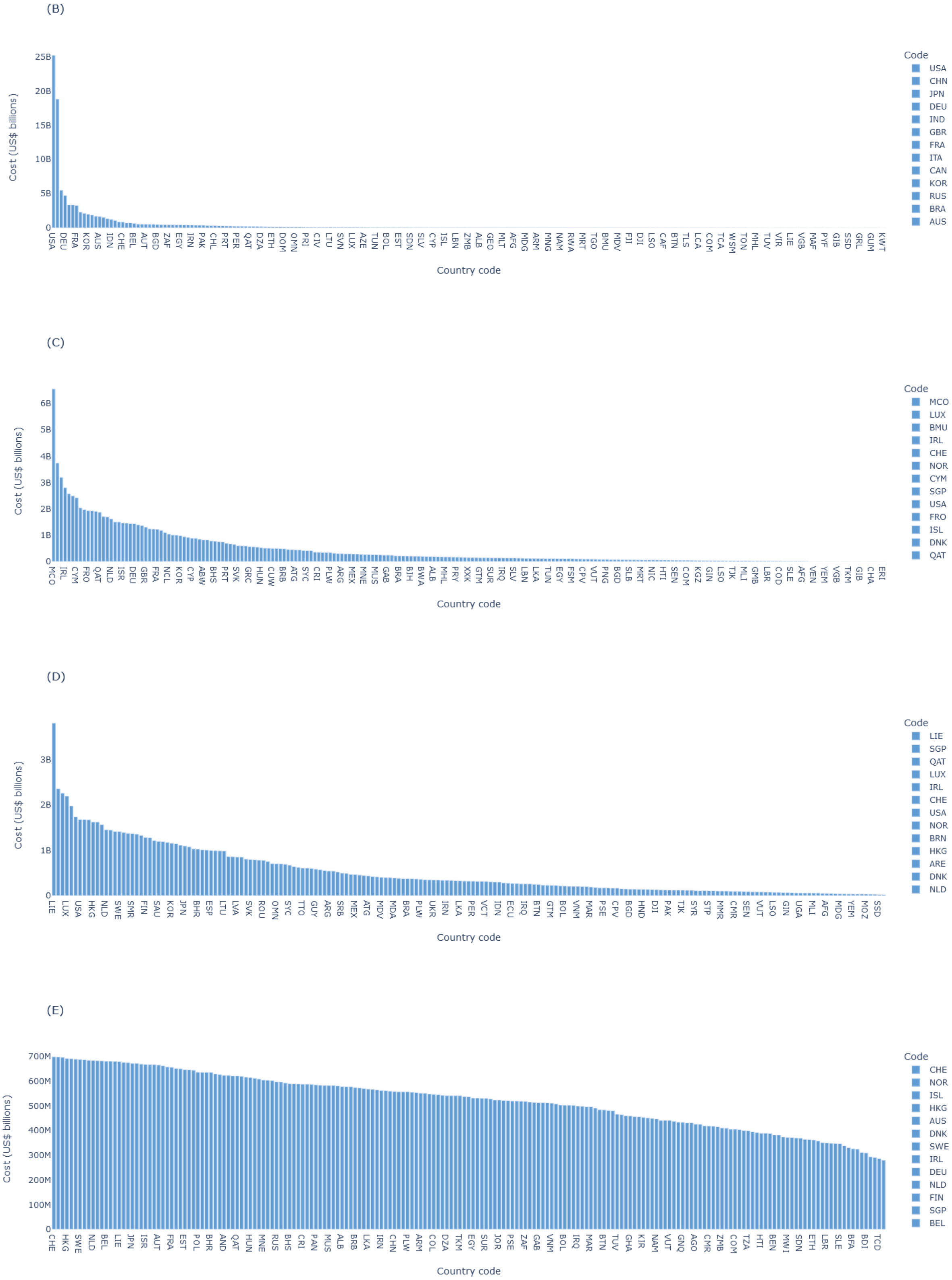
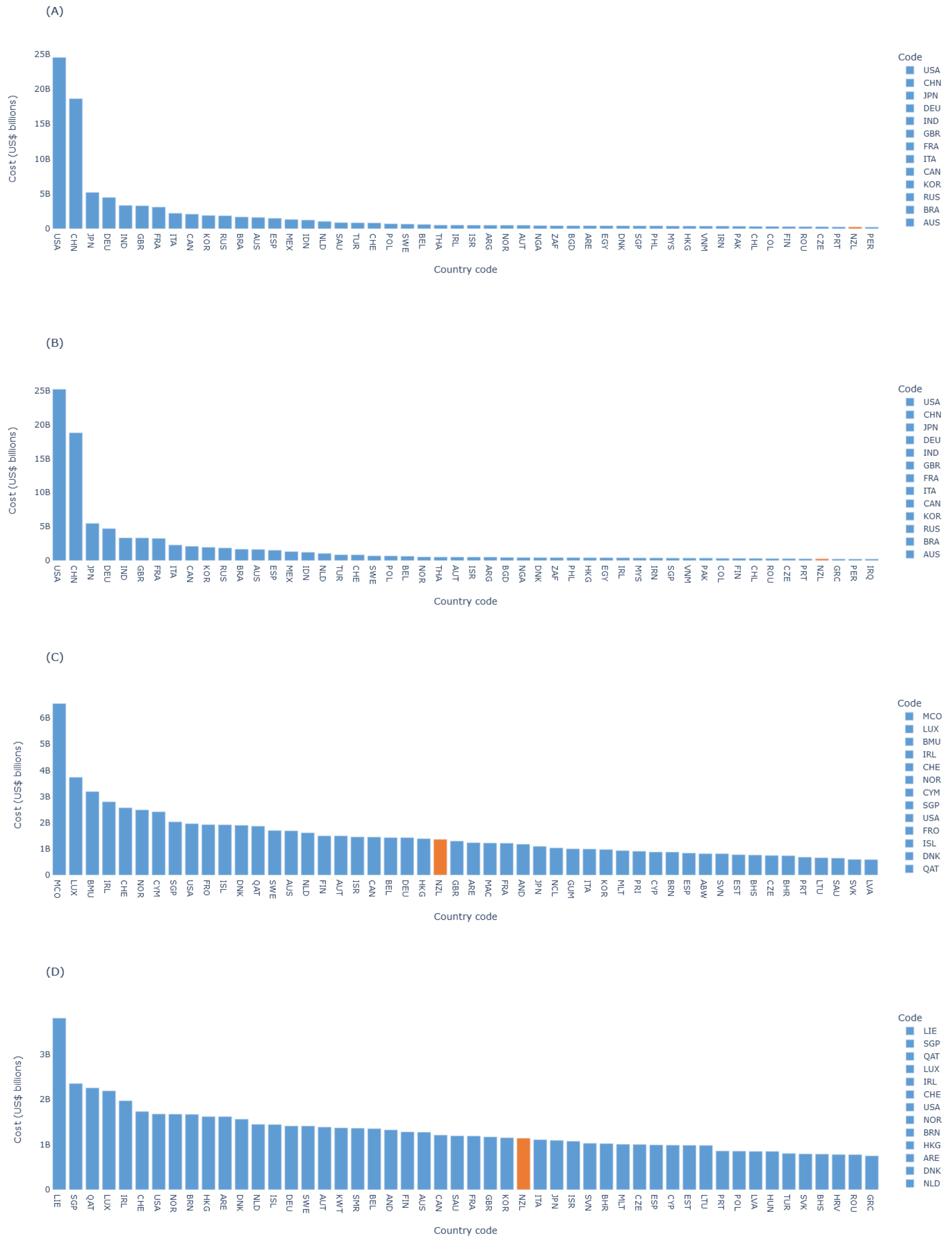



*Figure 20. Shares of the US$100 billion pledge according to the Ability to Pay Principle based on (A) GDP, (B) GNI, (C) GDP Per Capita, (D) GNI Per Capita, (E) HDI*

Charts A–E of Figure 21 below provide a more zoomed in view of the charts in Figure 20, by only displaying the top fifty paying countries. New Zealand appears in the top fifty paying group of countries across all metrics. The bar for New Zealand (NZL) is orange instead of blue to highlight the country's position for comparative purposes.



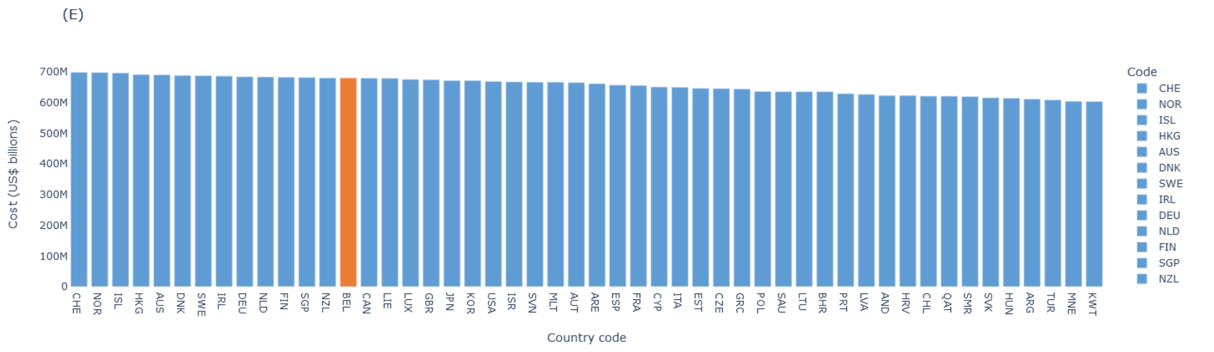



*Figure 21. Shares of the US$100 billion pledge according to the Ability to Pay Principle based on (A) GDP, (B) GNI, (C) GDP Per Capita, (D) GNI Per Capita, (E) HDI*

The charts presented in Figure 20 and Figure 21 above will now be discussed. Ultimately, the charts paint very different pictures of potential cost sharing allocations. When the Ability to Pay principle is operationalised with the metrics of GDP and GNI in charts A and B of Figure 20 and Figure 21, the same four countries – the United States, China, Japan and Germany – would be expected to bear just over half (53% and 54%) of the total financial burden respectively.

It cannot be determined from the static charts in this thesis, however, by hovering your cursor over different countries in charts A and B of the dashboard, it can be seen that Tuvalu is the country which would be expected to have the lowest climate finance shares: US$56,000 under the GDP metric and US$76,000 under the GNI metric. By contrast, when the per capita versions of these macroeconomic indicators are applied to produce charts C and D, the distribution of cost sharing is not as heavily skewed towards such a small number of countries. Burundi would be the country with the lowest climate finance share of US$18.9 million under the GNI Per Capita metric and US$6.1 million under the GDP Per Capita metric.

The most equal distribution of cost sharing is produced by using the HDI to apply the Ability to Pay Principle in chart E. South Sudan would be expected to pay the lowest share of the total, which is US$280 million (or 0.28%). This is a significantly higher amount than what the countries with the lowest finance shares would be expected to pay under the other four metrics. The more even sharing of costs across countries under the HDI metric can be explained by the HDI being a three decimal point number between zero and one, where the three decimal points are not broad enough to capture the granularity of countries' wide-ranging levels of development. As a result, the HDI gives a considerably more even spread of climate finance shares than other metrics. This means that even countries with Least Developed Country (LDC) status, like South Sudan, are expected to pay significant sums, closer in value to highly developed countries like Switzerland and Norway.

The charts in Figure 21, which show only the top fifty paying countries, demonstrate that applying the Ability to Pay Principle with different metrics can result in very different mixes of countries appearing in the highest paying groups of countries. When the Ability to Pay Principle is operationalised with the metrics of GDP and GNI, many Group of Twenty (G20) nations are expected to pay the highest amounts. In charts A and B, the order of the top ten paying countries under the GDP and GNI metrics is the same, with only slight differences in each country's expected payment under each metric. For instance, the United States' share of the cost allocation is slightly higher under the GNI metric than the GDP metric, with the opposite being true for China. These slight differences can be explained by how the metrics are calculated. For instance, the GNI metric includes the incomes of businesses and individuals that lie outside of the economic territory (Clarke, 2005). This explains how the many American businesses, entrepreneurs and individuals which reside outside of the United States enable the country to secure a positive financial inflow from overseas economic activities and assets, resulting in the United States' GNI figure being slightly higher than its GDP figure. The opposite is the case for China, where its citizens and businesses that operate overseas generate less income compared to the income that is generated by the foreign citizens and businesses operating within China.

When GDP Per Capita and GNI Per Capita are applied instead, the highest paying countries are small, wealthy European countries like Monaco, Liechtenstein and Luxembourg and a few overseas territories and tax havens, such as Bermuda, the Cayman Islands and the Faroe Islands. Singapore, the United States and Norway also appear in the top ten when the per capita metrics are applied. While Monaco, Liechtenstein and Luxembourg might be incredibly wealthy on a per capita basis, they do have very low populations (~37,000, ~39,000 and ~640,000 respectively) and therefore it might seem inappropriate that they be expected to pay such substantial amounts towards a climate finance goal. Nevertheless, it raises an interesting point when it comes to discussions about fairly sharing climate finance.

How much New Zealand would be expected to pay can be seen by hovering over the orange bar in each of the charts of Figure 21 in the dashboard. In charts A and B, where the GDP and GNI metrics have been selected, New Zealand would be expected to pay $263 and $262 million respectively, whereas in charts C and D, under the per capita versions of these metrics, New Zealand would be expected to pay between $1.36 and $1.14 billion. In chart E, where the HDI has been selected, New Zealand would be expected to pay $681 million. Across these metrics, the range of New Zealand's climate finance share is $1.1 billion. To put these figures in context, climate finance shares ranging between US$263 million – $1.4 billion represents between 0.1–0.5% of New Zealand's annual GDP, which was US$253.5 billion in 2023. This does not seem too substantial a figure, however if climate negotiators were to argue in New Zealand's interests from a purely self-interested perspective, they might choose to advocate for the use of metrics which make New Zealand's climate finance share smaller.

The chart in Figure 22 below is not included within the dashboard but has been created from outputs of applying the Ability to Pay Principle with the five different metrics for twelve countries. The chart shows that the climate finance amounts for Canada, Denmark, Germany, Japan, Singapore, Sweden, the United Kingdom and the United States vary considerably under different metrics. This suggests that these countries ought to care significantly about the metrics that might be used to reflect their capacity or ability to pay for climate change-related costs. In contrast, the results for South Sudan, Tonga, Trinidad and Tobago and the United Arab Emirates do not differ substantially. Conversely, for these countries the choice of metric is unlikely to matter as much within a negotiating context.

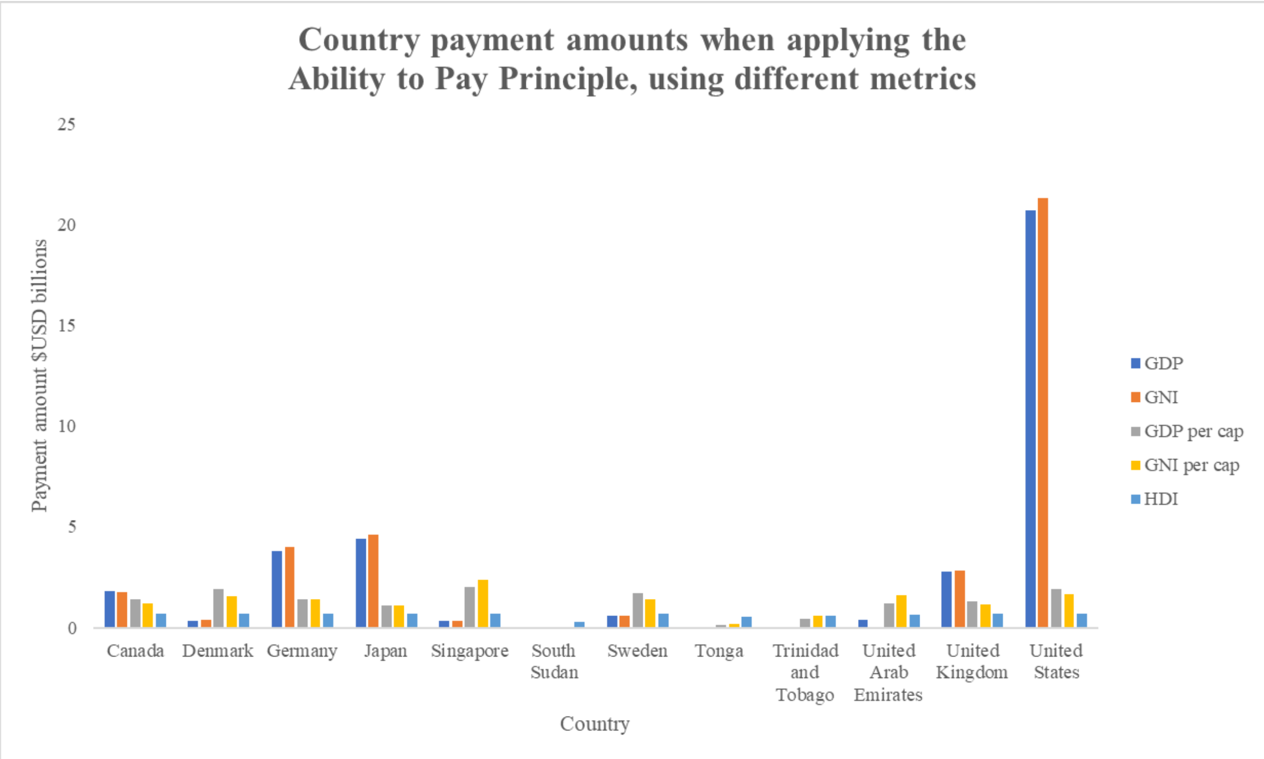



*Figure 22. Climate finance shares under Ability to Pay Principle metrics*

The remainder of this section (§4.3.1.1) will focus on discussing the potential relevance and inadequacies of using the five metrics to apply each of the principles, starting with the HDI.

Under an HDI application of the Ability to Pay Principle, every country would be expected to pay between US$280–699 million. A more even spread of climate finance holds appeal when considering the collective challenge of addressing climate change, where practically every country contributes to the issue and must therefore hold some responsibility for addressing it. However, the considerably more even spread of countries' climate finance obligations under the HDI metric, when compared with the highly skewed GDP and GNI metric distributions, raises a question about the adequacy of relying solely on the HDI as a measure of countries' capacities for addressing climate change.

A shortcoming of relying on macroeconomic indicators like GDP and GNI for determining countries' climate finance shares is that these do not capture the rate at which national resources are being depleted. While a country's economic output might have been high over some recent time-period, it does not necessarily mean this will be the case in the future. The potential short-sightedness of these metrics may not provide a reasonable reflection of a country's capacity to continue producing output and the wealth associated with this in the future. Because climate change is a long-term issue, it could be worthwhile including a metric which takes countries' future economic output potential, for instance, into account. This idea is discussed briefly in §4.3.2.

A further consideration is the degree to which countries are susceptible to the effects of climate change, based on their location in the world. For instance, one could make the case that countries which are closer to the equator are likely to enter climate extremes which are outside the range they have become adapted to at a faster rate than those countries which lie in the mid-latitude regions. Therefore, it could be argued that, in the future the Ability to Pay Principle ought to have some aspect of the degree of climatic change that countries are experiencing or likely to experience built into it. One such indicator that might be suitable is the Environmental Vulnerability Index (EVI). Developed by the South Pacific Applied Geoscience Commission (SOPAC) and the United Nations Environment Programme (UNEP), the EVI quantifies an area's environmental vulnerability (Pratt et al., 2022). The index combines information such as the proportion of GDP that primary industries like agriculture make up, the share of population in low lying coastal zones and the remoteness or landlockedness of countries.

Finally, some countries' shares of a climate finance goal under the GDP and GNI metrics are close to or effectively zero. The reasons for this can be quite diverse. For instance, the Cayman Islands with a population of ~68,000 would be expected to pay very little when the metric of GDP is prioritised. While the Cayman Islands and its residents might be considered relatively wealthy, much of the wealth associated with this overseas territory is produced offshore within other economic territories. Since GDP is a measure of the economic activity that takes place *within* an economic territory, much of the Cayman Islands' offshore economic output does not count towards its total GDP figure, which is a comparatively small ~US$5.9 billion. On the other hand, for countries which have been engaged in a civil War for many years, like Syria, it is likely that economic records have not been kept. For this reason, Syria's GDP figure is effectively zero and so would be its climate finance share, when based upon this metric. This raises the possibility of exempting certain countries from their climate finance obligations when they are engaged in more pressing domestic matters like War. Such exemptions would be similar to the exemption claim to the Subsistence Emission Principle, mentioned in §2.6.2.3.

This discussion has drawn to light potential inadequacies of relying on proxy metrics for calculating countries' shares of collective climate finance goals. How these metrics are calculated, including the information they draw upon and potential data gaps for certain countries, ought to be carefully considered when using them to inform debate about countries' potential shares of collective climate finance goals.

An updated SEFS dashboard includes the clustered bar charts in Figure 23 below, which display the top ten countries' climate finance shares based upon different metrics for applying the Ability to Pay principle.

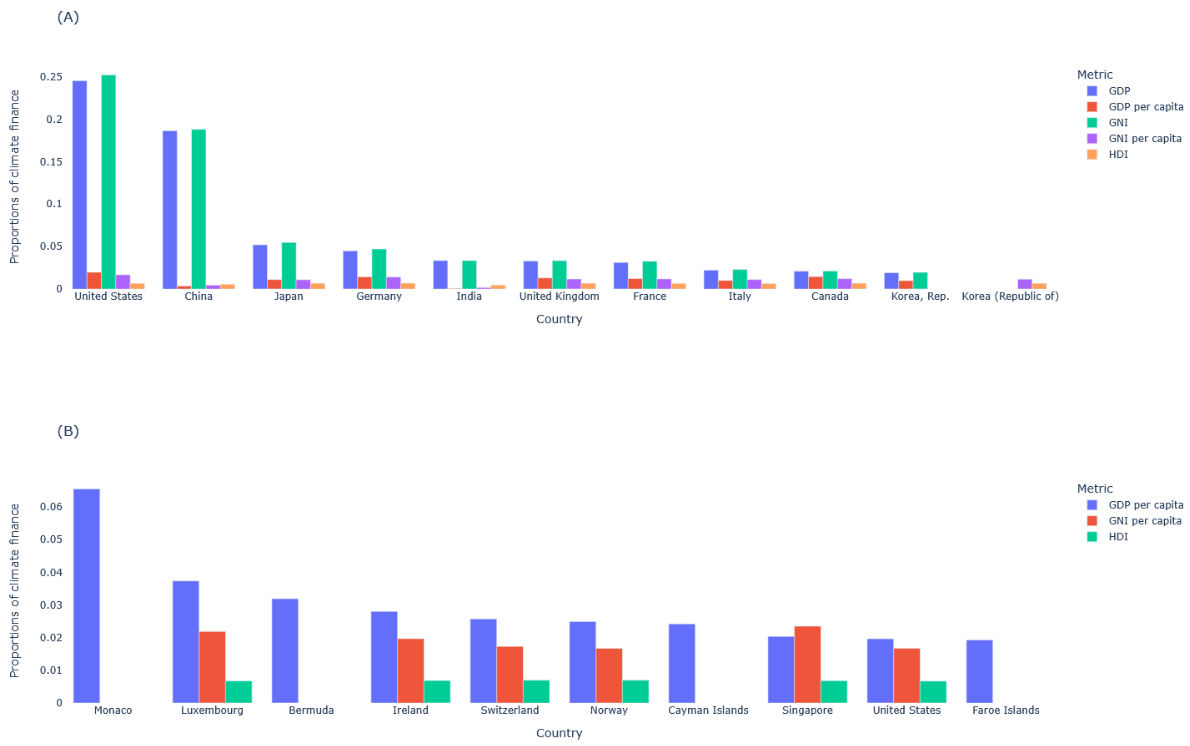



*Figure 23. Clustered bar charts for showing principle applications with different metrics (A) All five Ability to Pay metrics (B) Three Ability to Pay metrics*

### *§4.3.1.2 Comparison with similar studies*

The results of applying the Ability to Pay Principle within the SEFS dashboard will now be compared with similar climate ethics assessments and dashboard-style tools which explicitly allocate costs for addressing climate change under the Ability to Pay principle, or the related *capacity* and *capability* principles.

The Climate Equity Reference Calculator is an online tool which includes applications of the Ability to Pay Principle via its Responsibility-capacity-indicator (Holz et al., 2018, 2019). However, the calculator's application of the capacity principle includes a development threshold to exclude those individuals within countries "whose income and emissions fall below the development threshold" (Holz et al., 2018, pp. 122–123). This represents a different form of the Ability to Pay Principle that was mentioned in §2.6.1.3, which incorporates a sufficientarian or needs-based component because it can be made more or less progressive.

This sufficientarian or needs-based component ensures climate finance contributions do not compromise peoples' basic needs from being met. However, the SEFS dashboard currently does not include this component making the assessment less comparable. The application of the calculator's Responsibility-capacity-indicator also deviates from the focus of the Ability to Pay principle within the SEFS dashboard in that it is used to allocate carbon budgets out to 2030. This makes the results from the calculator slightly more relevant to RQ3, which is about distributing warming rights and emissions rights. It also represents a conflation of ethical domains that was identified in §2.7.

Another relevant tool for comparing the SEFS dashboard's results with is the Fair Mitigation Finance Explorer (Pachauri et al., 2022). This does have a specific focus on sharing the costs of climate mitigation, rather than carbon or emissions budgets. However, the tool focuses on world regions rather than individual countries. The explorer includes *Responsibility* and *Capability* indicators. It also includes an additional, third indicator of *Need*. One of the metrics for applying the explorer's Capability indicator is GDP Per Capita – one of the five metrics which are also used to apply the Ability to Pay Principle within the SEFS dashboard.

The *Responsibility*, *Capability* and *Need* indicators within the explorer can all have various weights applied to them. When the *Capability* indicator weight is set to 100%, the *Responsibility* and *Need* indicators are both set to 0%, and the metric of GDP Per Capita is used, the North American (NAM) region is expected to be the highest payer of mitigation finance, followed by Europe (EUR) and then Eastern Asia (EAS). This result broadly aligns with applying the Ability to Pay Principle using the metric of GDP Per Capita within the SEFS dashboard. However, the Fair Mitigation Finance Explorer's world region aggregation makes it impossible to compare individual country contributions.

The explorer uses the same Total GDP Per Capita from the World Bank's World Development Indicators dataset. However, the data is for the year 2019 in purchasing power parities (PPP) (constant 2017 international US$), whereas the data for the SEFS dashboard is for the year 2021.

Finally, a study by Winkler et al. (2002) is one example of an explicit application of the Ability to Pay Principle. However, it is in reference to carbon allocation schemes – a similar concept to carbon budgets. It uses the proxy metric of GDP Per Capita and considers a much smaller sample of countries – the six large developing nations of China, India, Brazil, South Africa, Argentina and Nigeria. The older data and significantly smaller sample size of just six countries in the Winkler et al. (2002) study, as well as the Ability to Pay Principle being applied to carbon allocation schemes, make a meaningful comparison with the Ability to Pay results from the SEFS dashboard difficult.

The SEFS dashboard's country-level layer of granularity and wider reach over existing dashboards makes a unique and novel contribution to the climate ethics literature. By restricting applications of the Ability to Pay Principle to financial burden-sharing questions, the dashboard also averts the conflation of ethical domains that the Climate Equity Reference Calculator and Winkler et al. (2002) have suffered from.

### §4.3.2 The Beneficiary Pays Principle

The unjust enrichment version of the Beneficiary Pays Principle – put forward and defended in Page (2012) – is operationalised within the SEFS dashboard. A *beneficiary* on Page's definition, when applied to questions of sharing the costs of *mitigating* climate change, is an actor that benefits from actions which have caused the harm of climate change. Beneficiaries are expected to pay in proportion to the amount of benefit they have derived and the particular metric that Page proposes to reflect this benefit is Total Wealth.

Page (2012) suggests using total wealth from a World Bank dataset to apply the Beneficiary Pays Principle. A "climate beneficiary levy" is then calculated in proportion to a country's total wealth. It must be noted that this is an emissions- or warming-agnostic application of the Beneficiary Pays Principle (p. 325). A further discussion of how the Beneficiary Pays Principle could link with accounting frameworks and emissions- or warming-orientated datasets was considered in §2.6.1.4 and §3.7.4.

The World Bank's *The Changing Wealth of Nations* report defines wealth in the following way: "Wealth – the stock of produced, natural, and human capital – is measured as the sum of assets that yield a stream of benefits over time. Changes in the wealth of nations matter because they reflect the change in countries' assets that underpin future income. Countries regularly track GDP as an indicator of their economic progress, but not wealth, and national wealth has a more direct and long-term impact on people's lives" (World Bank, 2021, p. 460). This quote highlights the usefulness of tracking a range of resources that countries have within their borders over time. This can serve as a more helpful indicator of countries' future income potential (and capacity for dealing with climate change), as opposed to how much economic output countries generate.

The Total Wealth datasets that are used within the SEFS dashboard include the following types of capital and assets:

- Human capital
- Natural capital
- Produced capital
- Net foreign assets

Humans themselves present a source of capital because of the way they can engage in various wealth-generating activities. Within the World Bank's Total Wealth dataset, human capital is measured by the expected earnings of individuals over their lifetime. However, viewing humans solely as a source of labour potential neglects other important factors like their education and skill levels. In 2018, human capital was the largest contributor to the World's total wealth, accounting for roughly 64% of global wealth (World Bank, 2021).

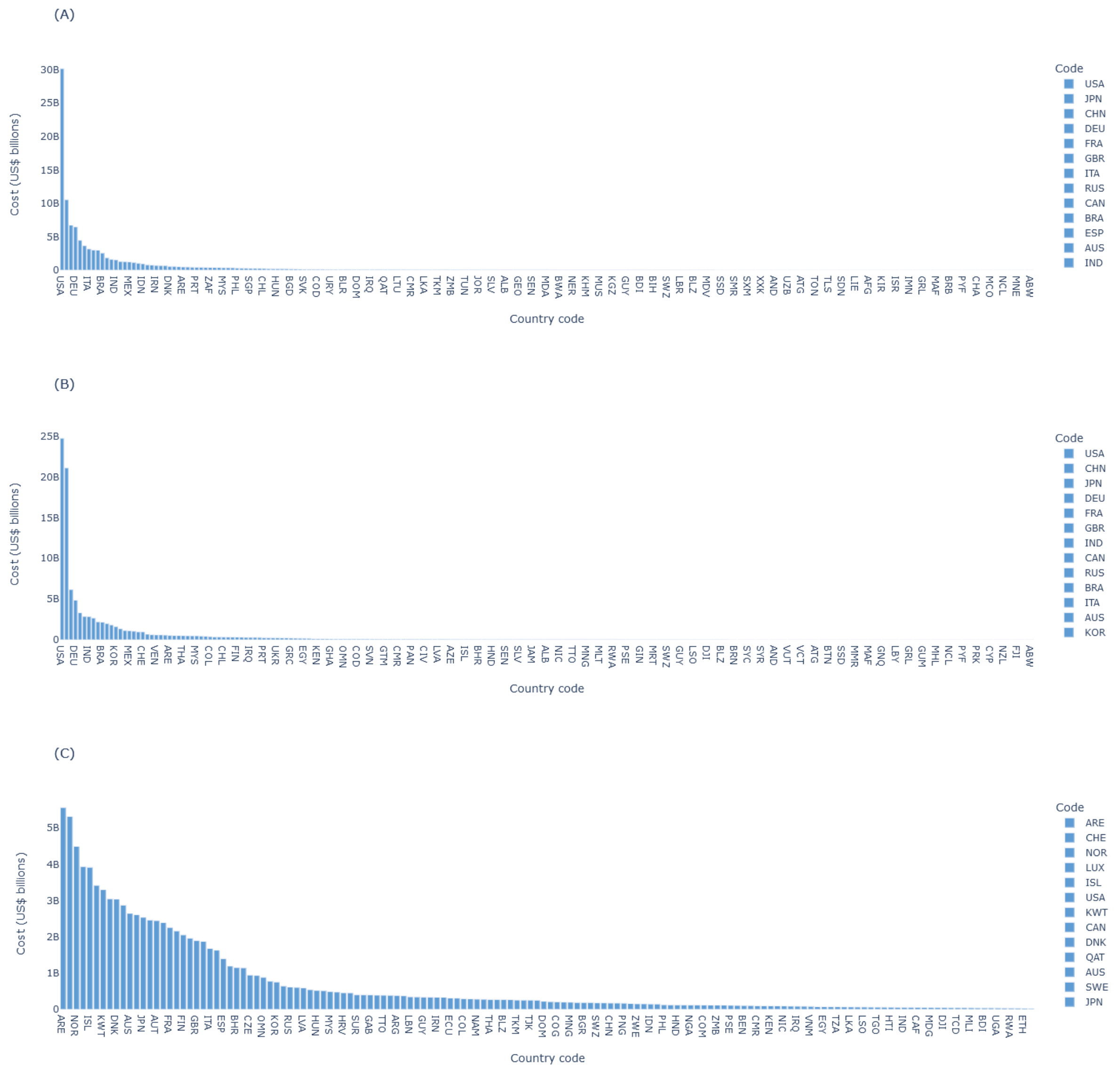
Natural capital recognises a value of natural resources insofar as they can be turned into profitable goods and services and traded to generate economic output and wealth. For instance, included within the World Bank's natural capital category are different types of agricultural land, fisheries, forests, mangroves, non-renewable assets like fossil fuels, protected areas, and renewable assets.

Produced capital includes the value of built-environment assets like machinery, buildings and other structures, equipment, and residential and non-residential urban land. Finally, net foreign assets are calculated by subtracting a country's financial liabilities in other countries from its financial assets in other countries, such as portfolio equity, debt securities and foreign direct investment.

It is wealth-generating activities that, directly or indirectly, release GHG emissions. Behind using Total Wealth as an indicator for the Beneficiary Pays Principle sits a significant assumption: Total Wealth represents the degree to which countries have benefitted from climate change. Yet, basing a country's total wealth on calculations which include these different forms of capital and assets may not reliably represent the degree to which countries have profited and benefited from climate change-causing activities in the past. This is because not all countries have drawn on various capitals in ways that simultaneously generate wealth and contribute to climate change. For instance, the French and Swedish energy sector diversifications (discussed in §4.2.1) are examples for how economies can be powered in ways that do not also worsen climate change. However, Total Wealth is the only suggested measure for applying the Beneficiary Pays Principle that has been identified to date within the climate ethics literature.

### *§4.3.2.1 Results and discussion*

The charts in Figure 24 and Figure 25 are the result of applying the Beneficiary Pays Principle with the proxy metrics of Total Wealth for 217 countries and Total Wealth Per Capita for 146 countries in the years 1995 and 2018. Charts A–D in Figure 24 below show the shape of the distribution of climate mitigation finance. It should be noted that country codes along each chart's x-axis do not align with each bar. The index on the right-hand-side of each chart specifies the top thirteen countries.



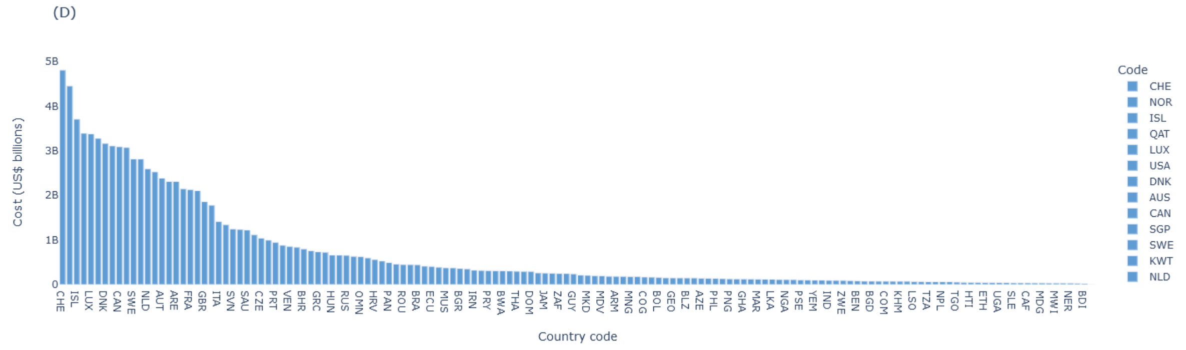
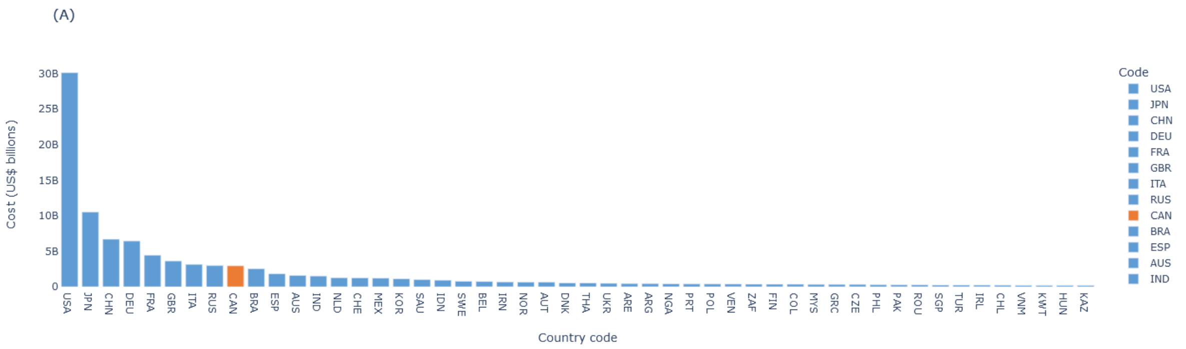
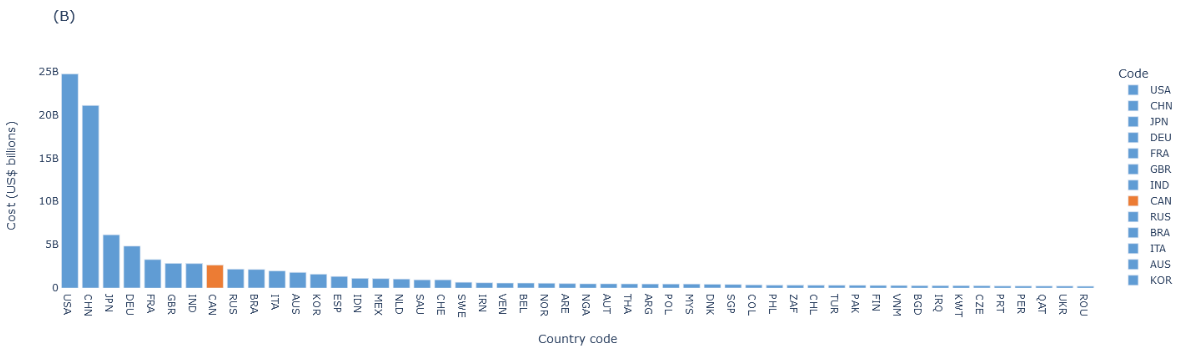



*Figure 24. Shares of the US$100 billion pledge according to the Beneficiary Pays Principle based on (A) Total Wealth in 1995, (B) Total Wealth in 2018, (C) Total Wealth Per Capita in 1995, (D) Total Wealth Per Capita in 2018*

Charts A–D in Figure 25 below show only the first fifty countries from each chart in Figure 24. The bar for Canada (CAN) is orange instead of blue to highlight the country's position for comparative purposes. Canada holds a relatively consistent rank as the eighth or ninth highest paying country across these charts.



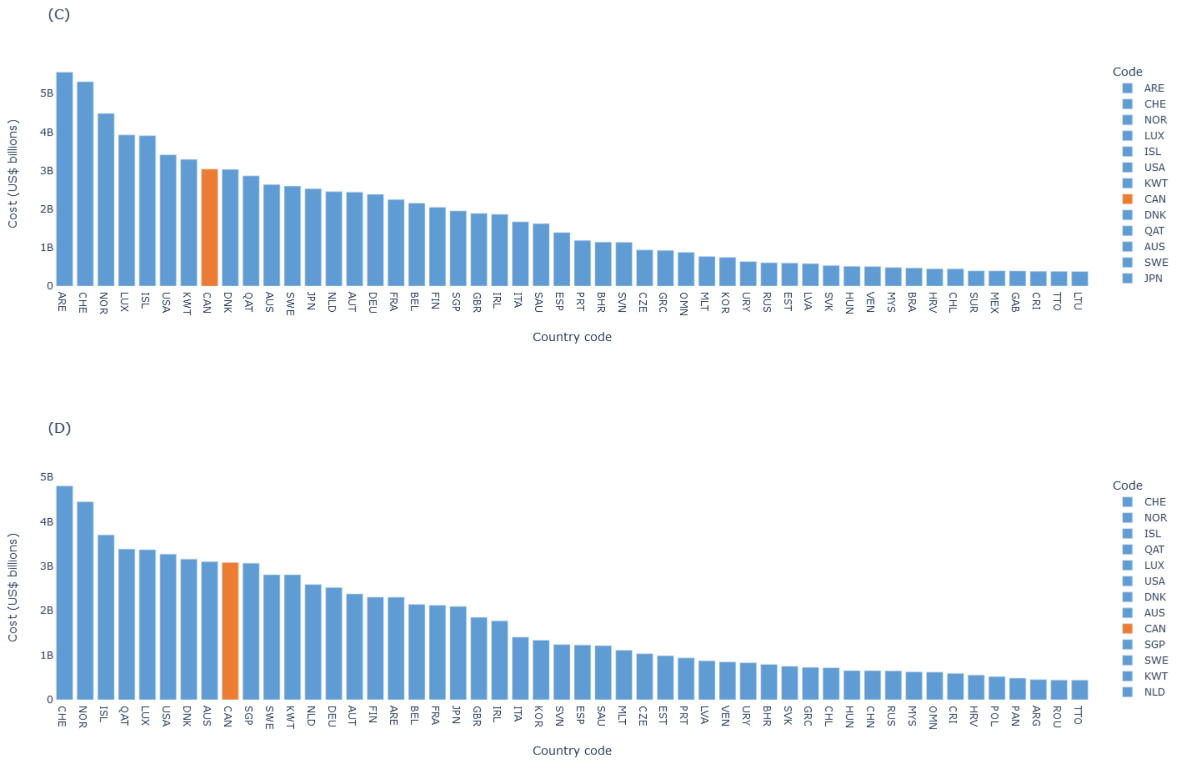



*Figure 25. Shares of the US$100 billion pledge according to a Beneficiary Pays Principle based on (A) Total Wealth in 1995, (B) Total Wealth in 2018, (C) Total Wealth Per Capita in 1995, (D) Total Wealth Per Capita in 2018*

The charts in Figure 24 and Figure 25 show that different distributions of climate finance result when different metrics and years are chosen to apply the Beneficiary Pays Principle. Under the Total Wealth metric, the shape of distributions in A–B of Figure 24 is similar in 1995 and 2018. In both cases, the distribution is highly skewed towards the United States, China, Japan and Germany. A and B are reminiscent of the charts in Figure 20, where the GDP and GNI metrics were used to apply the Ability to Pay Principle. All other countries are expected to pay significantly less. The shape of the distributions in charts C and D of Figure 24 are similar to each other and the climate finance goal is less highly skewed towards just several large countries, like in A and B. The top paying countries under the Total Wealth Per Capita metric include Switzerland, Norway, Iceland and Qatar in 2018.

To better understand these results, we must delve into how each form of capital contributes towards each country's Total Wealth figures. For instance, nonrenewable natural capital accounts for 5% and 34% of Norway's and Qatar's Total Wealth, and none of Switzerland's and Iceland's Total Wealth. This can be explained by Norway's and Qatar's substantial oil reserves. In contrast, human capital contributes 64% and 62% towards Iceland's and Switzerland's Total Wealth, which is in line with the proportion that human capital contributes towards global wealth. Yet the human capital figures as proportions of Total Wealth for Qatar and Norway are significantly lower at 45% and 22%. Proportions that all four countries' produced capital contributes towards Total Wealth falls within a comparable range of 29–35%, while net foreign assets make up considerably higher proportions of Norway's and Qatar's Total Wealth at 13% and 14%, than for Switzerland and Iceland at 8% and 1% respectively.

This further analysis of the degrees to which different forms of capital contribute towards these four countries' wealth shows that a country's wealth depends on proportions of each of the four capitals. The oil reserves of Norway and Qatar will be contributing substantially to these nations' total wealth, and both countries will have benefitted by selling their oil assets to other countries. However, for countries like Switzerland and Iceland, whose high per capita wealth is more attributable to high human capital, the total wealth metric is likely to be a less useful indicator of the level of benefit that these countries have derived from climate causing actions.

Table 23, Table 24, Table 25 and Table 26 show climate finance values of the top ten paying countries across the two metrics – Total Wealth and Total Wealth Per Capita – for the years 1995 and 2018.

| Rank | Country | Code | Value |
|---|---|---|---|
| 1 | United States | USA | 30.141 |
| 2 | Japan | JPN | 10.516 |
| 3 | China | CHN | 6.691 |
| 4 | Germany | DEU | 6.442 |
| 5 | France | FRA | 4.438 |
| 6 | United Kingdom | GBR | 3.627 |
| 7 | Italy | ITA | 3.147 |
| 8 | Russian Federation | RUS | 2.981 |
| 9 | Canada | CAN | 2.948 |
| 10 | Brazil | BRA | 2.534 |

*Table 23. Total Wealth of top ten countries 1995*

| Rank | Country | Code | Value |
|---|---|---|---|
| 1 | United States | USA | 24.719 |
| 2 | China | CHN | 21.076 |
| 3 | Japan | JPN | 6.141 |
| 4 | Germany | DEU | 4.831 |
| 5 | France | FRA | 3.287 |
| 6 | United Kingdom | GBR | 2.845 |
| 7 | India | IND | 2.828 |
| 8 | Canada | CAN | 2.645 |
| 9 | Russian Federation | RUS | 2.177 |
| 10 | Brazil | BRA | 2.134 |

*Table 24. Total Wealth of top ten countries in 2018*

| Rank | Country | Code | Value |
|---|---|---|---|
| 1 | United Arab Emirates | ARE | 5.558 |
| 2 | Switzerland | CHE | 5.310 |
| 3 | Norway | NOR | 4.486 |
| 4 | Luxembourg | LUX | 3.930 |
| 5 | Iceland | ISL | 3.909 |
| 6 | United States | USA | 3.413 |
| 7 | Kuwait | KWT | 3.292 |
| 8 | Canada | CAN | 3.041 |
| 9 | Denmark | DNK | 3.032 |
| 10 | Qatar | QAT | 2.865 |

*Table 25. Total Wealth Per Capita of top ten countries in 1995*

| Rank | Country | Code | Value |
|---|---|---|---|
| 1 | Switzerland | CHE | 4.801 |
| 2 | Norway | NOR | 4.445 |
| 3 | Iceland | ISL | 3.701 |
| 4 | Qatar | QAT | 3.385 |
| 5 | Luxembourg | LUX | 3.369 |
| 6 | United States | USA | 3.271 |
| 7 | Denmark | DNK | 3.158 |
| 8 | Australia | AUS | 3.103 |
| 9 | Canada | CAN | 3.084 |
| 10 | Singapore | SGP | 3.067 |

*Table 26. Total Wealth Per Capita of top ten countries in 2018*

When looking at the top ten paying countries in Table 23 and Table 24, a striking difference is the threefold increase in China's finance share from US$6.7 billion in 1995 to US$21 billion in 2018. China also switches rank with Japan to become the second highest paying country in 2018, where in 1995 it was the third highest paying country. Japan's climate finance share drops from US$10.5 billion in 1995 to US$6.1 billion in 2018. This threefold increase in the size of China's share can largely be explained by the five factor increase in China's per capita human capital over this time period, where human capital contributed 73% towards China's total wealth in 2018 (World Bank, 2021). This increase in per capita human capital and overall wealth also resulted in China's development status change from a low-income country in 1995 to an upper-middle-income country in 2018.

On the other hand, when the Beneficiary Pays Principle is operationalised using the metric of Total Wealth Per Capita, Table 25 and Table 26 show a very different group of top ten paying countries and there is a significantly more even spread or sharing of the climate finance goal across countries in C–D of Figure 24. The same four Scandinavian countries – Switzerland, Norway, Iceland, Denmark – and two North American countries – the United States and Canada – appear in the top ten paying countries in 1995 and 2018, as well as Luxembourg and Qatar. However, two Middle Eastern countries – Kuwait and the United Arab Emirates – that were present in the 1995 top ten paying countries drop out of the top ten and are replaced by Australia and Singapore in 2018. Another notable observation is that many of the top ten countries' expected payment amounts remain relatively stable. For instance, Switzerland's share only decreased from US$5.3 billion in 2018 to US$4.8

billion in 1995 and Norway's share is also relatively stable with only a US$100 million reduction in 2018.

An interesting finding from applying the Beneficiary Pays Principle with the Total Wealth and Total Wealth Per Capita metrics is that Canada was consistently ranked the 8th or 9th highest paying country across all four applications, with its share of climate finance falling within the US$2.6–3.1 billion range. This consistent rank and climate finance amount provoked the question of whether certain countries should care more than others about the particular metric that is used to determine their climate finance burdens. For countries like Canada, it would seem that their perceived accountability and responsibility is less sensitive to the choices of metric and year when applying the Beneficiary Pays Principle. In contrast, a country like China – with very different climate finance obligations under different applications of the principle – might care considerably more.

Finally, when considering the results of applying the Beneficiary Pays Principle in the SEFS dashboard, concerns about potential unfairness arise. For instance, as countries transition towards powering their economies with renewable energy sources instead of fossil fuel-based ones, it will be possible for countries to maintain or increase their total wealth without further contributing to climate change. This means that using the metric of total wealth may become increasingly inaccurate as a measure of the degree to which countries' have benefitted from actions which contribute to climate change as their economies change. Further, if operationalising the Beneficiary Pays Principle in warming- or emissions-centric ways were to be made possible in the future, a reliance on emissions data over recent periods to apply the principle could also risk unfairly penalising many developing countries which could have less ability and resources than developed countries to switch to low-carbon alternatives.

As a broader point, the World Bank's *The Changing Wealth of Nations* report argues against narrowly focussing on GDP and instead advocates for aggregating countries' capitals as indications of resources that countries have at their disposal to support wealth-generating activities in the future (World Bank, 2021). This idea shows the importance of striking a balance between different principles and metrics, which follows from the commitments of this research project to principlism and pluralism. In other words, drawing on a wider range of information will enable the representation of different countries' capacities for bearing climate finance obligations as time progresses and countries' circumstances and vulnerabilities to the issue change.

### *§4.3.2.2 Comparison with similar studies*

Comparing the results of applying the Beneficiary Pays Principle within the SEFS dashboard with similar studies has been difficult. While climate ethicists have dedicated substantial effort towards theorising about the Beneficiary Pays Principle in the abstract, no practical ethical assessments were found that explicitly apply this principle. To the researcher's knowledge, only one article within the climate ethics literature suggests data for operationalising this principle (Page, 2012). This presents a disconnect between the philosophical climate ethics literature and the practical ethical assessments which have been developed to support the international climate policy community in their financial burden-sharing discussions.

It is striking to notice how a principle's theoretical strengths and weaknesses can be asserted and debated so robustly in the abstract, yet when one goes to apply the principle in practice an entirely new set of challenges are encountered. Seeking to apply the Beneficiary Pays Principle revealed a new range of barriers, with theoretical objections relegated to second-order issues.

To validate the results of applying the Beneficiary Pays Principle within the SEFS dashboard, the Page (2012) application of a climate beneficiary levy, based on countries' 2005 total national wealth values, can be directly compared with the Total Wealth dataset in the SEFS dashboard for the year 2005.

| Rank | Country | Code | Value |
|---|---|---|---|
| 1 | United States | USA | 30.168 |
| 2 | China | CHN | 11.259 |
| 3 | Japan | JPN | 8.243 |
| 4 | Germany | DEU | 5.201 |
| 5 | France | FRA | 4.001 |
| 6 | United Kingdom | GBR | 3.686 |
| 7 | Canada | CAN | 2.802 |
| 8 | Italy | ITA | 2.676 |
| 9 | Russian Federation | RUS | 2.575 |
| 10 | Brazil | BRA | 2.424 |

*Table 27. Top ten countries – Total wealth in 2005 to compare with results from Page (2012)*

The results of applying the Beneficiary Pays Principle within the SEFS dashboard, using 2005 Total Wealth data, closely mirror those of Page (2012). Nine of the top ten paying countries are the same across Table 2 of Page (2012) and Table 27 above. The proportions of climate finance that each country is expected to pay are similar, with the greatest deviations being for the United States and China. The United States would be expected to pay US$30.2 billion under the SEFS dashboard application, but only US$30.7 billion under the Page (2012) application. China has substantially lower total national wealth and would consequently be expected to pay a significantly less US$3.5 billion under the *climate beneficiary levy* calculated in Page (2012), than the US$8.2 billion in the SEFS dashboard. It is likely that these differences can be explained by revisions to countries' total wealth estimates as data gathering practices have improved. For instance, the 2021 Changing Wealth of Nations Report mentions how advances in the rigor of asset valuations have improved estimates of countries' natural capital, which now also includes blue natural capital to account for marine fisheries and mangroves (World Bank, 2021).

A further difference is that Spain appears in the top ten paying countries under the Page (2012) climate beneficiary levy, but in the SEFS dashboard's results, Spain is ranked 14$^{th}$, behind Italy, Australia and South Korea. The opposite is true for the Russian Federation. These differences between the Page (2012) beneficiary levy and the SEFS dashboard's results can again likely be explained by updates to countries' total wealth estimates as data collection practices have improved.

## §4.3.3 The Polluter Pays Principle

Of the three financial burden-sharing principles, the Polluter Pays Principle is the most information-intensive to apply. Once users have selected a dataset, further choices become available for applying the Polluter Pays Principle. These include the specific time-period, sectors, accounting frameworks, GHGs and metrics to use. The SEFS dashboard provides users with three different dataset options for applying the Polluter Pays Principle, listed below.

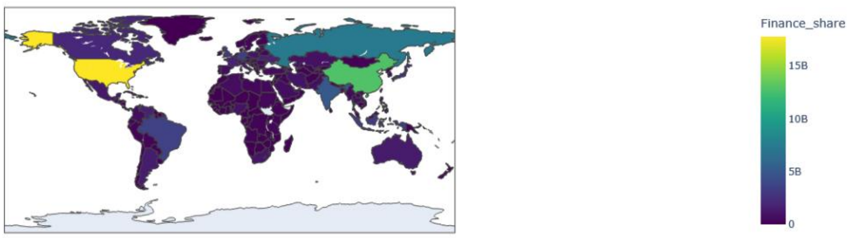
1. Community Emissions Data System (CEDS) and Houghton & Nassikas (2017)
2. Eora-26
3. United Nations Framework Convention on Climate Change (UNFCCC) GHG Inventories

Results of applying the Polluter Pays Principle with these different datasets will be displayed and discussed in turn. The first dataset enables users to apply the Polluter Pays Principle based on countries' historical warming contributions from $CO_2$, $CH_4$ and NOx emissions. The second and third datasets enable users to apply the Polluter Pays Principle based on $CO_2$, $CH_4$ and $N_2O$ emissions amounts instead of warming contributions. In terms of accounting frameworks, only the Eora-26 dataset offers users the choice to view countries' climate finance shares based on GHG emissions being assigned under both production-based accounting (PBA) and consumption-based accounting (CBA) perspectives. The UNFCCC GHG Inventories dataset contains information about only Annex I Parties' GHG emissions, because this data is more comprehensive than Non-Annex I Party data. Allocating a climate finance goal based on this dataset presents one way of testing how the US$100 billion climate finance goal ought to have been shared by developed countries in 2020.

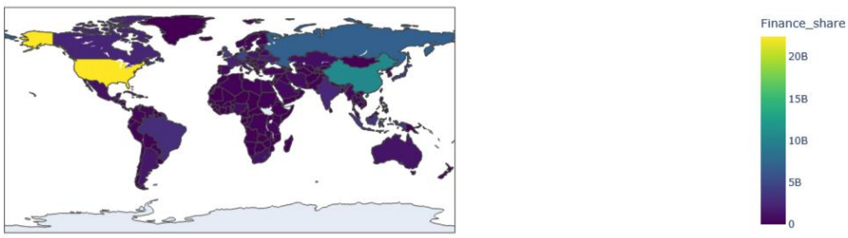
### *§4.3.3.1 Results and discussion*

The set of choropleth charts in Figure 26 are the result of applying the Polluter Pays Principle based on historical warming (in °C) over different time periods. Chart A includes warming from all three climate forcers: $CO_2$, $CH_4$ and NOx. Charts B–D include warming from only individual climate forcers.

(A)




(B)



(C)


(D)


*Figure 26. Shares of the US$100 billion pledge according to the Polluter Pays Principle based on warming (°C), calculated from the CEDS and Houghton & Nassikas (2017) datasets between the years 1850–2014, where (A) All three climate forcers, (B) $CO_2$, (C) $CH_4$, (D) NOx*

Results of applying the Polluter Pays Principle within the SEFS dashboard will now be discussed, starting with applying the principle based on the metric of historical warming. It is important to reiterate that the CEDS and Houghton & Nassiskas (2017) datasets use the PBA framework. This means that warming contributions are allocated to the country where GHG emissions were physically released.

When the Polluter Pays Principle is applied using the metric of historical warming (in °C) from the three climate forcers – $CO_2$, $CH_4$ and NOx – between 1850–2014, the United States is the country with the highest climate finance share of US$17.8 billion, followed by China ($12.8 billion) and Russia ($7.3 billion). When the Polluter Pays Principle is restricted to considering warming from $CO_2$ emissions only over the same time-period, the United States' share increases to US$22.4 billion, China's reduces to US$10.6 billion, and Russia's also reduces to US$6.8 billion.

When the Polluter Pays Principle considers warming from $CH_4$ emissions only over the same time-period, China becomes the country that ought to pay the most and would be expected to pay US$15.2 billion, the United States would be next at US$9.8 billion, and India would be close behind the United

States at US$9 billion. It is interesting to note this entry of India into the top three paying countries. A large proportion of the world’s $CH_4$ emissions are associated with agricultural food production. As mentioned previously, China and India both have had substantially larger agricultural industries than the United States. This shows the how a country’s contribution to warming is highly related to its economic activities.

Finally, when the Polluter Pays Principle is restricted to considering warming from NOx emissions only over the same time-period, China is again the country with the highest payment obligation at a very significant US$25.1 billion, the United States follows at US$17 billion and India and Russia are next as was the case when only warming from $CH_4$ emissions were taken into account. While not a GHG, NOx is associated with the burning of fossil fuels. These results highlight that countries’ climate finance obligations vary depending on which climate forcers are being considered and the time-period over which their associated warming is considered.

The set of charts in Figure 27 show countries’ climate finance shares under the Polluter Pays Principle, when it is operationalised with $CO_2$ emissions (in kilotons) from all sectors under the PBA and CBA frameworks from the Eora-26 dataset.

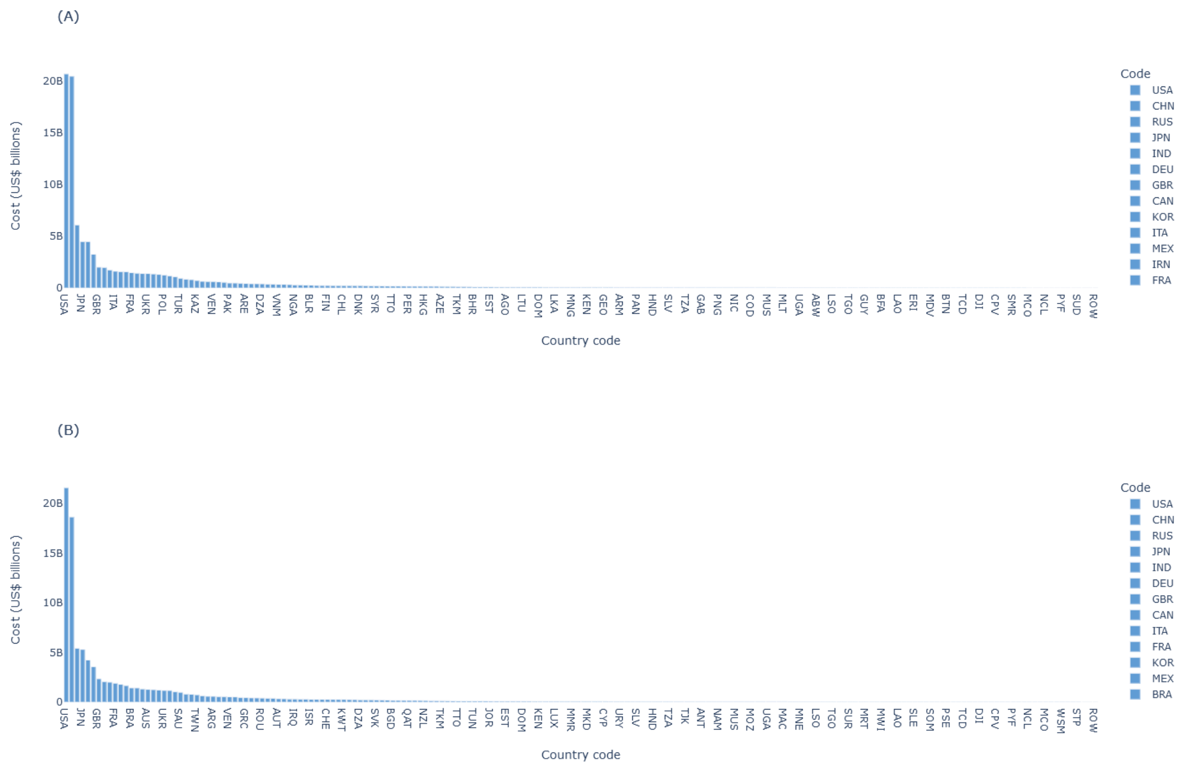



*Figure 27. Shares of the US$100 billion pledge according to the Polluter Pays Principle based on $CO_2$ emissions (kt), from the Eora-26 dataset between the years 1990–2015, where (A) Production-based emissions, (B) Consumption-based emissions*

The hypothesis made at the beginning of this research project in §1.5 was that China's climate finance shares would differ substantially under the PBA and CBA frameworks, since China is an exporting nation and outsources many of its emissions to other countries through global trade. However, China's climate finance shares within both charts of Figure 27 were found to be relatively similar under both the PBA and CBA frameworks, at US$20.4 billion US$18.6 billion respectively. These differences are less substantial than anticipated, given that China produces many goods and services for other countries. However, these results can be explained by China being a large producer of goods and services which it sends offshore and also consumes a high proportion of domestically.

Figure 28 below shows China's PBA and CBA emissions over a more recent time-period of 2010–2015. This has been done to see whether there are substantial differences between China's PBA and CBA emissions in more recent years.

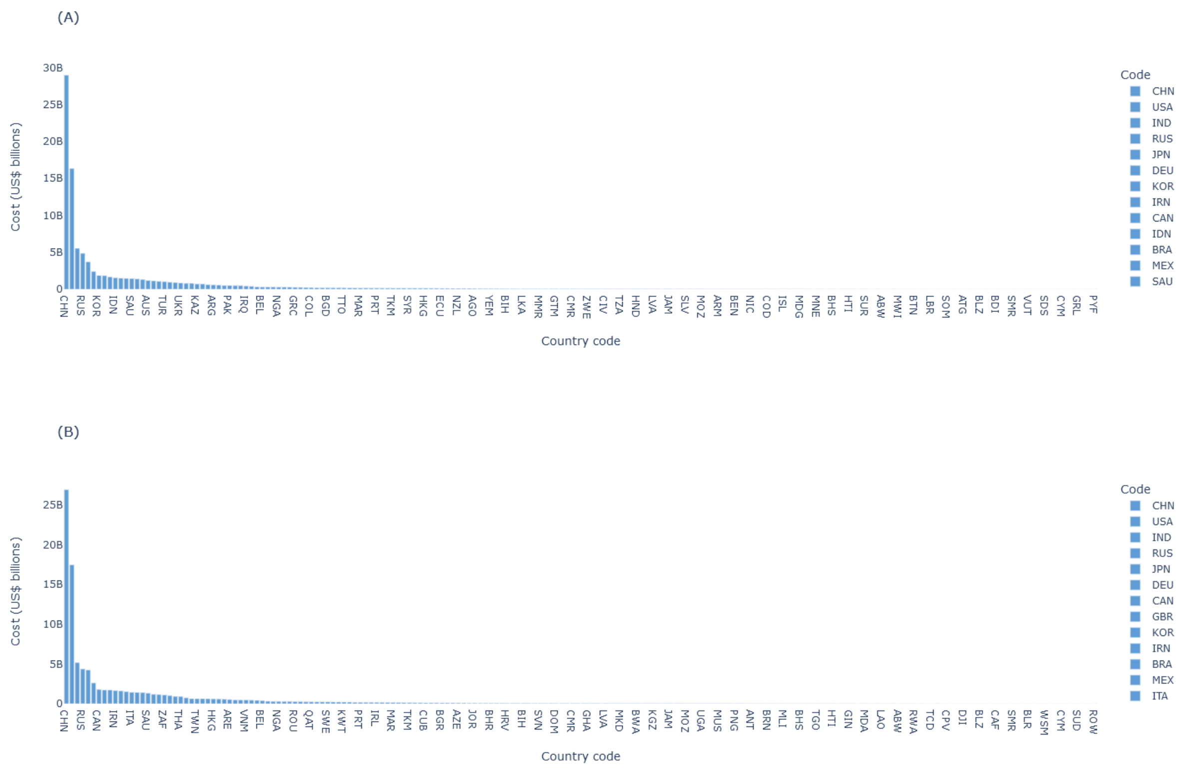
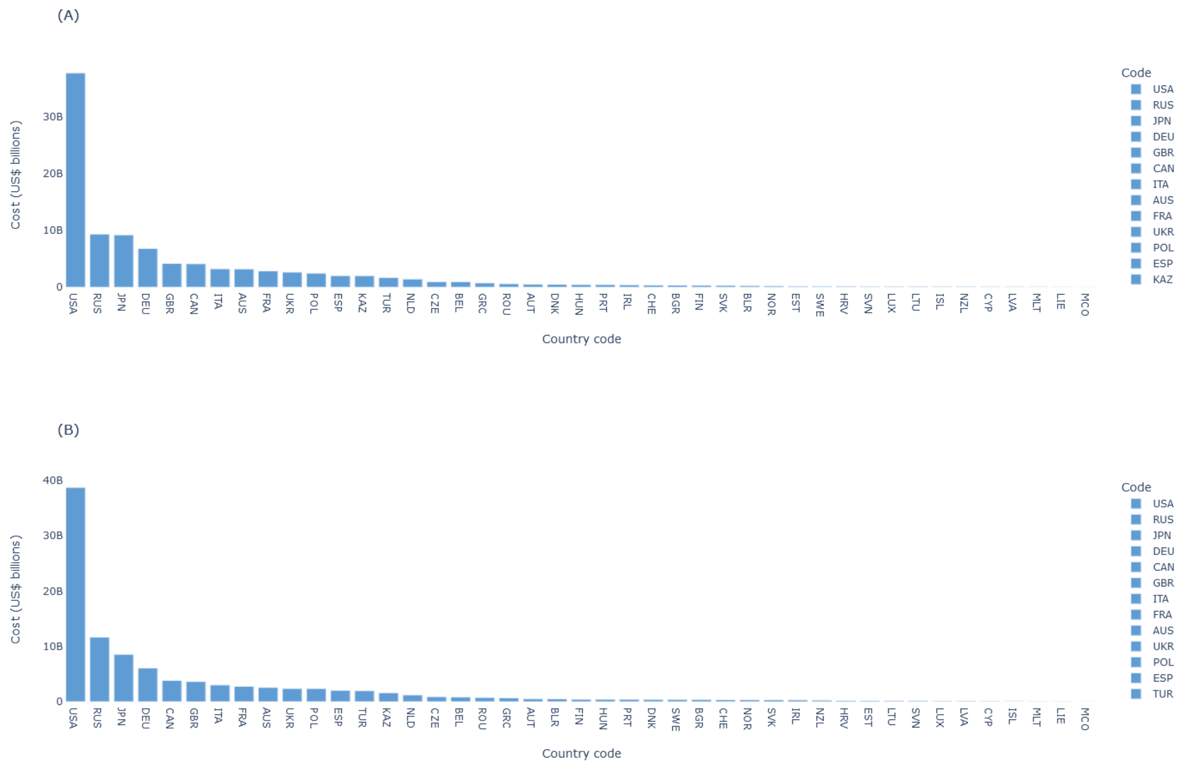



*Figure 28. Shares of the US$100 billion pledge according to the Polluter Pays Principle based on $CO_2$ emissions (kt), from the Eora-26 dataset between the years 2010–2015, where (A) Production-based emissions, (B) Consumption-based emissions*

Over the more recent 2010–2015 time-period, China trades place with the United States to become both the largest producer and consumer of $CO_2$ emissions, and China's share of the climate finance goal grows considerably under both accounting frameworks to US$29.0 billion under the PBA framework and US$26.9 billion under the CBA framework. While the difference between China's $CO_2$ emissions, under both frameworks, is higher over the 2010–2015 period than the 1990–2015 period, the difference is a relatively insubstantial US$0.2 billion.

It should be noted that a limitation of the Eora-26 dataset is that it does not include emissions estimates for the most recent eight years, from 2016–2024. If such data were available for this period, it is expected that China's climate finance obligation would increase under both accounting frameworks. While China's annual emissions growth has declined from 10% between 2002–2012 to 0.3% between 2012–2017 as it has entered a "new normal", China remains the largest annual $CO_2$ emitter (J. Zheng et al., 2019, p. 240). Since countries' climate finance obligations in the dashboard are based upon their cumulative emissions over a particular time-period, China's share of a finance goal would be expected to remain high, despite recent reductions in its emissions growth. However, the size of any country's climate finance obligation also depends on the trajectory of other countries' emissions accounts over the same time-period.

The following charts in Figure 29 apply the Polluter Pays Principle using UNFCCC GHG Inventories dataset for 42 Annex I Parties between 1990–2020. These charts can act as an example for how the US$100 billion climate finance goal – that developed countries pledged at COP15 – could be shared.



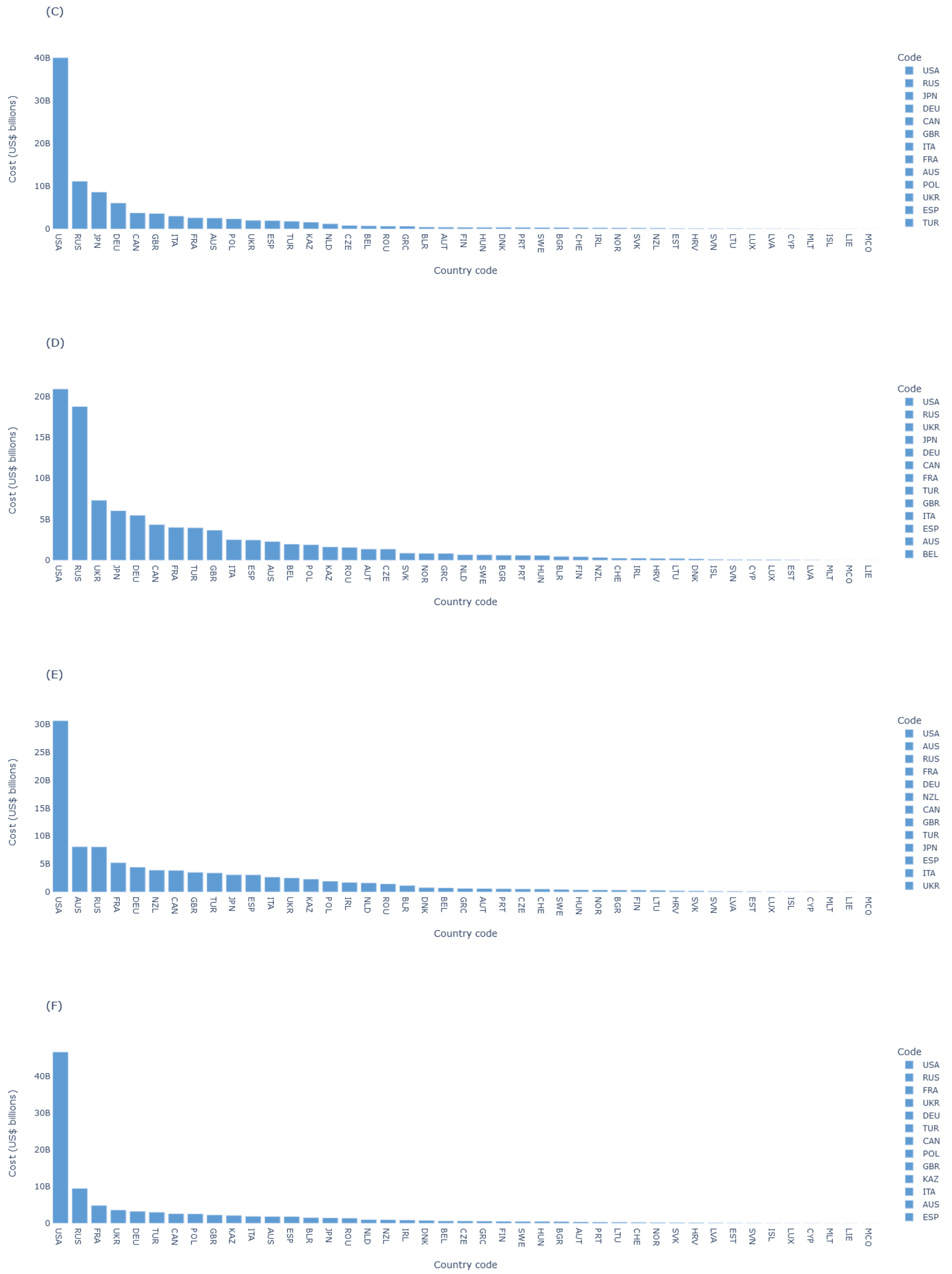



*Figure 29. Shares of the US$100 billion pledge according to the Polluter Pays Principle based on UNFCCC dataset, production-based emissions between 1990–2020, where: $CO_2$ emissions (in kt) from all sectors, including the LULUCF sector*

*$CO_2$ emissions (in kt) from all sectors except the LULUCF sector*

*$CO_2$ emissions (in kt) from the Energy sector only*

*$CO_2$ emission (in kt) from the Industrial Processes and Product Use sector*

*$CH_4$ emissions (in kt) from the Agriculture sector*

*$N_2O$ emissions (in kt) from the Agriculture sector*

Regardless of which sector is chosen, or whether the land use, land-use change, and forestry (LULUCF) sector is included or excluded, the United States is expected to pay the highest climate finance share, within the range of US$20–47 billion. This is a wide window of possible climate finance obligations and suggests that within a negotiating setting, the United States could be expected to care significantly about the type of sectors and GHGs which are used to determine its burden-sharing obligations under the Polluter Pays Principle.

#### *§4.3.3.2 Comparison with similar studies*

Studies which focus on applying a responsibility principle or indicator are of relevance when comparing the results of applying the Polluter Pays Principle. This is because responsibility is closely linked with causation and the Polluter Pays Principle asserts that those who have caused harm ought to pay for this in proportion to the amount of harm they caused. Therefore, studies which may not reference the Polluter Pays Principle explicitly, but mention responsibility, provide options for comparing the results of applying the Polluter Pays Principle within the SEFS dashboard.

As mentioned in §4.3.1.2, the Climate Equity Reference Calculator includes a Responsibility-capacity indicator. The Responsibility component of the indicator can be applied to emissions with three different start dates – 1850, 1950 and 1990 – which place decreasing weight on historical actions. However, the calculator's purpose differs from the purpose that the Polluter Pays Principle serves within the SEFS dashboard insofar as the calculator is concerned with allocating emissions out to 2030, instead of calculating financial costs for addressing climate change. Therefore, the calculator applies a responsibility principle, with links to the Polluter Pays Principle, but to answer a different question of allocating carbon budgets. For this reason, the results of the calculator are less directly comparable with those from the SEFS dashboard.

Another dashboard tool worth comparing Polluter Pays Principle applications with is the Fair Mitigation Finance Explorer. This was also used in §4.3.1.2 to compare the results of the Ability to Pay Principle. The explorer has two options for assessing responsibility, based on historical cumulative net anthropogenic fossil fuel and industry $CO_2$ emissions over two different time-periods: 1850–2019 and 1990–2019. It does not include net $CO_2$ from the land use, land-use change, and forestry (LULUCF) sector (Pachauri et al., 2022). The data comes from the Summary for Policy Makers of the Working Group III Contribution to the Intergovernmental Panel on Climate Change's (IPCC's) Sixth Assessment Report. The data is aggregated at the regional level and includes ten regions.

When the Responsibility indicator weight is set to 100% and the weights of the Capability and Need Indicators are set to zero, the North American (NAM) region is expected to supply the most mitigation finance, followed either by Europe (EUR) and then Eastern Asia (EAS), depending on whether the cost-effective investment need bounds are set to the lower or upper value. However, when the time-period between 1990–2019 is selected instead, the EAS region would be expected to contribute a far greater amount of climate mitigation finance. This aligns with findings from the SEFS dashboard in the way that, when later periods are prioritised so that emissions prior to 1990 are excluded, China is expected to become the highest payer of climate finance. However, Fair Mitigation Finance Explorer's regional-level aggregation prevents a less finely grained comparison from being done with the SEFS dashboard's applications of the Polluter Pays Principle.

Prompted by the 1997 Brazilian Proposal and a motivation to develop methodologies for calculating countries' contributions to global warming, several studies in the late 1990s and early 2000s also had a focus on responsibility for historical warming (den Elzen et al., 2005; den Elzen & Lucas, 2005). However, these studies use much older datasets, which do not include countries' GHG emissions or warming contributions in more recent years. For this reason, the results of these studies are less directly comparable with the results of applying the Polluter Pays Principle within the SEFS dashboard.

## §4.3.4 Discussion – All three financial burden-sharing principles

The SEFS dashboard can be used to answer the question of how the *costs* for addressing climate change should be distributed between countries. Very different allocations of climate finance can be observed when the three financial burden-sharing principles, as well as various metrics for operationalising them, are applied within the dashboard to answer this question. Some of the largest deviations in countries' climate finance obligations occur across applications of the same principle. This is the case for the Ability to Pay and Beneficiary Pays Principles, which are both operationalised with several different proxy metrics. In contrast, applications of the Polluter Pays Principle under different parameter prioritisations tend to produce results where countries' climate finance obligations fall within a more consistent range. Such varying climate finance obligations can appeal to differing notions of fairness.

The United States and China were found to be the two countries with the first and second highest climate finance obligations, across most applications of the principles. They are also the two countries which have featured strongly within climate negotiations, with significant power politics playing out between them, and climate policy increasingly becoming a source of geopolitical competition (Christoff, 2010). This is in terms of both countries shouldering costs for addressing climate change, as well as identifying future opportunities for innovation and market expansion that the issue presents for their economies. For instance, China's rapid deployment and transfer of solar photovoltaics has resulted in it becoming the dominant supplier of this technology (M. M. Jackson et al., 2021). This is providing opportunities for China to enter new markets so it can expand its Belt and Road Initiative and exert its geopolitical prominence, at the same time as supporting other countries to ramp up their climate mitigation efforts.

These two countries will now be taken as examples, to see how their climate finance obligations compare when different principles and metrics are applied within the SEFS dashboard. The results of applying these principles for the United States and China are presented in Table 28 below.

The following abbreviations appear in in Table 28 below.

| | |
|---|---|
| °C | Degrees Celsius |
| $CO_2$ | Carbon dioxide |
| Consump-based | Consumption-based accounting framework |
| GDP | Gross Domestic Product |
| GDPpc | Gross Domestic Product per capita |
| GHG | Greenhouse gas |
| GNI | Gross National Income |
| GNIpc | Gross National Income per capita |
| HDI | Human Development Index |
| kt | kilotons |
| Prod-based | Production-based accounting framework |
| TW | Total Wealth |
| TWpc | Total Wealth per capita |

| Acc. Framework | GHG | Metric | Time period | Climate finance obligations (US$ billions) | | Climate finance obligation rank | | Country rank (out of all countries) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | USA | China | USA | China | USA | China |
| - | - | GNI | 2021 | 25.2 | 18.8 | 1 | 4 | 1 | 2 |
| - | - | TW | 2018 | 24.7 | 21.1 | 2 | 2 | 1 | 2 |
| - | - | GDP | 2021 | 24.5 | 18.6 | 3 | 5 | 1 | 2 |
| Prod-based | $CO_2$ | °C | 1850-2014 | 22.4 | 10.6 | 4 | 9 | 1 | 2 |
| Consump-based | $CO_2$ | kt | 1990-2014 | 21.8 | 18.1 | 5 | 7 | 1 | 2 |
| Prod-based | $CO_2$ | kt | 1990-2014 | 21.0 | 20 | 6 | 3 | 1 | 2 |
| Prod-based | All | °C | 1850-2014 | 17.8 | 12.8 | 7 | 8 | 1 | 2 |
| Prod-based | $CO_2$ | °C | 1990-2014 | 17.1 | 18.2 | 8 | 6 | 2 | 1 |
| Prod-based | All | °C | 1990-2014 | 12.4 | 23.3 | 9 | 1 | 2 | 1 |
| - | - | TWpc | 2018 | 3.3 | 0.7 | 10 | 10 | 6 | 40 |
| - | - | GDPpc | 2021 | 2.0 | 0.4 | 11 | 13 | 9 | 69 |
| - | - | GNIpc | 2021 | 1.7 | 0.5 | 12 | 12 | 7 | 71 |
| - | - | HDI | 2021 | 0.7 | 0.6 | 13 | 11 | 21 | 79 |

*Table 28. Climate finance amounts and ranks under different principles and metric*

For the United States, it is different applications of the Ability to Pay Principle that result in the United States' largest and smallest shares of a climate finance goal. When the Ability to Pay Principle is applied with the GNI metric, the United States is expected to pay its greatest climate finance share of US$25.2 billion. In stark contrast, when the Ability to Pay Principle is applied with the HDI metric, the United States is expected to pay is smallest share of US$669 million. In contrast to applications of the Ability to Pay Principle, different applications of the Polluter Pays Principle result in the United States' 4–9$^{th}$ highest shares, within the range of US$12.4–22.4 billion.

For China, the picture is similar yet different in several ways. China's greatest climate finance share is US$23.3 billion. This is based on the Polluter Pays Principle, operationalised with the metric of warming (in °C) from $CO_2$, $CH_4$ and NOx emissions between 1990–2014. Like the United States, China is also expected to pay high sums under the GDP and GNI and Total Wealth metrics, which are used to operationalise both the Ability to Pay and Beneficiary Pays principles. However, China's country rank and climate finance share drop significantly in comparison to the United States when the GDP Per Capita, GNI Per Capita metrics are prioritised.

The varied results discussed in this section highlight how different combinations of parameters can affect countries' perceived responsibilities and obligations for addressing climate change, under the three financial burden-sharing principles. In §5.3.1, three international relations (IR) theories are described and drawn on to consider how these results might be used by countries in a negotiating context.

## §4.3.5 Section summary

This section (§4.3) has presented the results of applying the three financial burden-sharing principles within the dashboard to provide possible answers to RQ2, which is about distributing the costs of climate mitigation.

The United States and China bear the highest shares of climate finance goals under most principle applications. However, many countries' shares were found to vary substantially, depending on the particular metric that is used to apply the Ability to Pay and Beneficiary Pays Principles. The HDI metric gave the most even spread of climate finance obligations.

Compared with the other two financial burden-sharing principles, the Polluter Pays Principle is more complicated to apply because it requires the most information and that users make more choices. Results of applying the Polluter Pays Principle were most affected by the choice of historical time-period, GHGs, and which sectors are included. Differences in climate finance obligations under a

PBA or CBA accounting framework were not found to be as stark as anticipated for large players like the United States and China. However, allocating emissions under a CBA framework was only possible for one of three datasets used to apply the Polluter Pays Principle, and this dataset only covered the relatively brief and recent time-period from 1990–2015.

Challenges arose when seeking to compare the SEFS dashboard's results with other practical ethical assessments, which were found to be less directly comparable. This is because other assessments aggregated climate finance burdens or carbon budget allocations at the regional level, contained too small a sample size of countries, or used data which is now out of date. Another common divergence was that similar studies covered both allocating the costs of addressing climate change and future emissions rights within the same assessment. In contrast, the SEFS dashboard keeps these two domains separate, according to the typology presented in §2.7.

Additionally, several dashboard-style tools applied a development threshold, like a wellbeing or standard of living safeguard, to exempt low-income individuals from having an obligation to pay or reduce their emissions beneath levels that would impinge on their ability to meet their basic needs. This reflected a different interpretation of the Ability to Pay Principle than the one which has been applied within the dashboard, as mentioned in §2.6.1.3.

For these reasons, the SEFS dashboard presents an improvement on past studies in the way it traverses new terrain by facilitating analysis at the country-level and on a per gas basis, which enable more granular insights for the tool's target audiences. The incomparability of this approach, from a research verification perspective, means results cannot be checked against studies with a broader, regional focus. However, decisions were made to not compromise the tool's purpose and usefulness in the interests of comparability.

## §4.4 Distributing warming and emissions rights

This section (§4.4) presents and discusses answers to RQ3, which asks how rights to warm the planet might be fairly distributed between countries, without exceeding global temperature change targets. While the SEFS dashboard offers users the options to display distributions of both GHG emissions rights and warming rights, only the results of displaying warming rights will be discussed here since warming rights are the more novel concept.

Samples of results, according to applications of warming rights under the Equality-over-time and Grandfathering Principles, are discussed as answers to RQ3. However, before presenting the results of applying these principles, this section highlights two use cases for the application of principles related to the allocations of emissions rights: firstly, for evaluating the ethical adequacy of Nationally Determined Contributions (NDCs); secondly, for providing guidance for the initial allocations of emissions trading schemes (ETSs).

On the first of these, RQ3 has relevance to the Paris Agreement. Many countries' NDCs are pledges to achieve a certain absolute reduction in emissions by a particular date (King & van den Bergh, 2019). Such pledges implicitly follow a relative reduction form of the Grandfathering principle (Roser & Seidel, 2017). However, because countries commonly articulate their pledges in terms of the $CO_2e$ emissions metric, it is not clear how much of the overall Article 2 temperature targets these pledges will use up. The SEFS dashboard would provide a starting point for ethical analysis and scrutiny of countries' NDCs. With large assumptions and caveats, NDCs could be translated into temperature changes and then compared with results from the SEFS dashboard to judge whether countries are in fact doing their fair share, according to different ethical principles and different interpretations of fairness.

The second use case is for providing guidance for the initial allocations ETSs. Based on the concept of Pigouvian taxes, which internalise externalities, ETSs are a market-based form of environmental regulation which grant tradeable units or permits to polluters (Bertram, 1992; Rose & Tietenberg, 1993). ETSs – like the European Union Emissions Trading System (EU ETS) – are designed to mitigate GHGs and allocate allowances to polluting entities according to a form of moderate emissions grandfathering (ICAP, 2024; Knight, 2013). Initial allocations of emission entitlements under such schemes have traditionally been based upon practical approaches like benchmarking and auctioning or what is politically palatable, rather than what might be ethical (ICAP, 2024; Tietenberg, 2006). For instance, 95% and 90% of allowances were allocated freely in the first and second phases of the EU ETS. This was deemed to be the "political price for ensuring the participation of all member states in this multinational trading system" (Ellerman et al., 2016, p. 94). The SEFS dashboard presents one way in which initial allocations might be decided upon in ways that have forms of moral backing, with which real-world initial allocations might be compared.

## §4.4.1 The Equality-over-time Principle

There is a large literature which argues for distributing rights to emit GHGs on an equal per capita basis (Agarwal & Narain, 1991; Pan et al., 2022; van den Berg et al., 2020). As per the definition in Table 2, the Equal Per Capita Emissions Principle grants the same amount of emissions rights to everyone. However, because countries' populations are not static, it is unclear at which point in time Equal Per Capita entitlements ought to be allocated to individuals at a country-level basis. For once an allocation has been decided upon, there is a question of whether today's descendants ought to gain greater ability to pollute than was granted by way of emissions rights to their ancestors?

The pie chart in Figure 30 below shows what country-level shares of emissions rights would be for people alive in 2023, based upon an Equal Per Capita Emissions Principle.

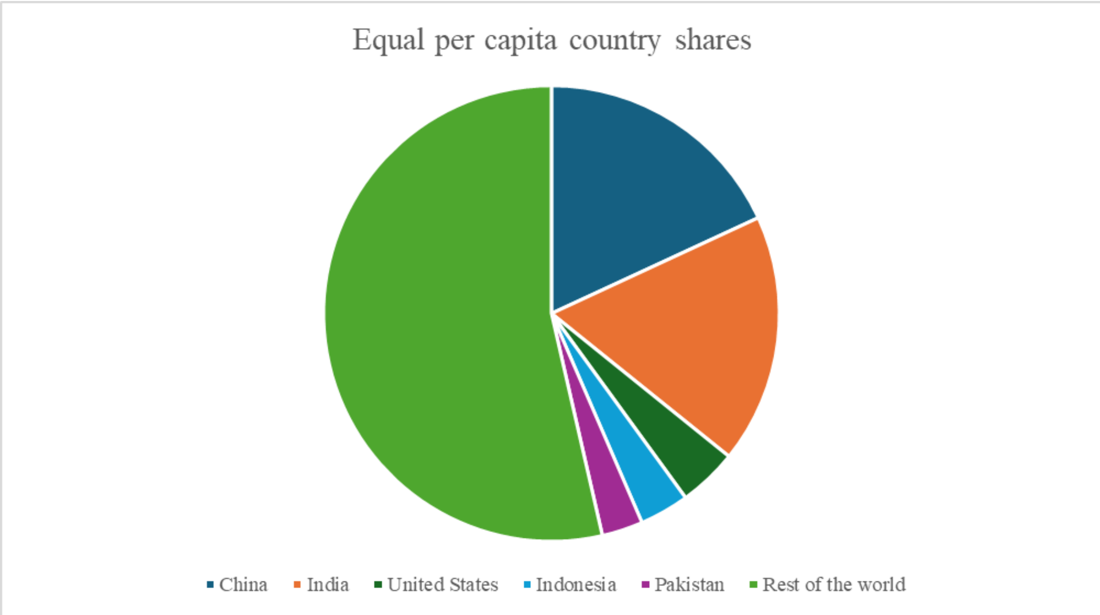



*Figure 30. Equal Per Capita Emissions shares based on country's 2023 populations*

Figure 30 reflects the world's population at a single snapshot in time. However, it could be argued that a purely equal per capita allocation of rights to emit based on some fixed point in time may disadvantage or advantage future populations. This is because the per capita allocation is fixed, yet populations may increase or decrease in the future, relative to other countries' populations. The implication is that population change could result in an under or over allocation of emissions rights, according to a static formulation of the Equal Per Capita Emissions Principle.

Figure 31 below shows how countries' populations may grow into the future. The concentric circles surrounding the central pie chart represent future generations. The three level expansion of people from the dark blue segment of the pie chart represents a country's increasing population, where the country's proportion of the world's population remains constant.

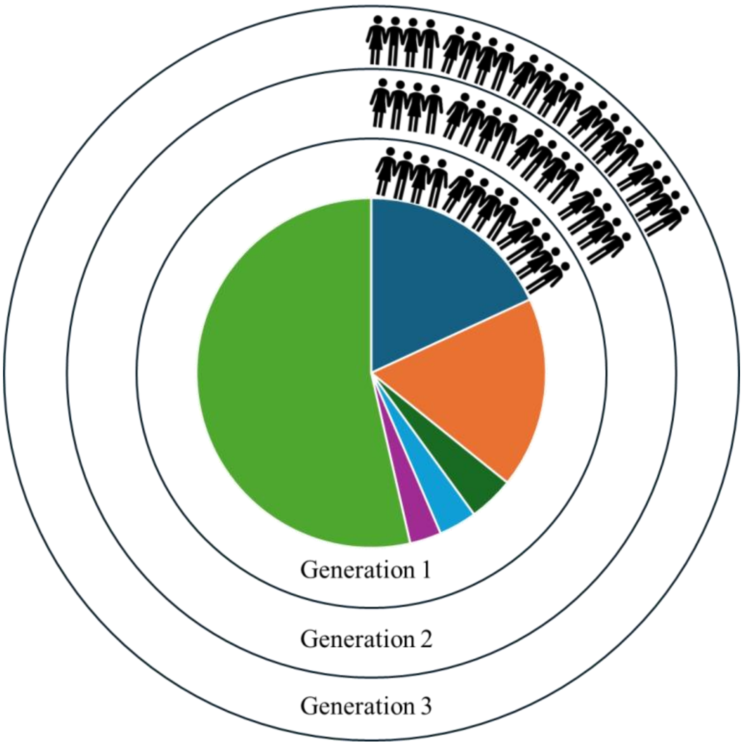



*Figure 31. Per capita shares of an emissions budget across generations*

However, in reality, countries like India and Nigeria have fast growing populations which are projected to increase significantly in the future (Gu et al., 2021; Ogunleye et al., 2018). For this reason, these countries' populations as proportions of the global population are also likely to increase as other countries' populations plateau or decline. The Equality-over-time Principle applied within the SEFS dashboard distributes warming rights between countries in a temporal way, which takes into account how countries' populations change over time.

### *§4.4.1.1 Results and discussion*

The SEFS dashboard includes options to allocate emissions and warming rights from multiple climate forcers. However, within this thesis, priority has been given to displaying and discussing the results of warming rights from $CO_2$ emissions only, for three reasons.

First, the long-lived, cumulative nature of $CO_2$ as a stock pollutant results in it persisting in the atmosphere for timescales that exceed human lifespans. For this reason, globally agreed temperature change constraints on $CO_2$-related warming extend over multiple generations. This is not the case for short-lived, flow pollutants like $CH_4$, where the warming effect can be undone on relatively short timescales of twenty years or less. Second, *warming rights* are a novel concept introduced in this thesis. To the researcher's knowledge, warming rights have not yet been explicitly discussed within the climate ethics literature. For this reason, warming rights were deemed more interesting to discuss than emissions rights. Finally, warming rights – expressed in °C – makes countries' allocations more relevant by putting them into the same metric as the Article 2 temperature targets.

The three stages of calculating the Equality-over-time Principle are described in charts in Figure 32, Figure 33, Figure 34 and Figure 35 below. The two charts in Figure 32 show the first step of applying the principle. Chart A displays 174 countries' historical warming use (in °C) from $CO_2$ emissions, whereas chart B provides a *zoomed in* picture of just the top fifty countries.

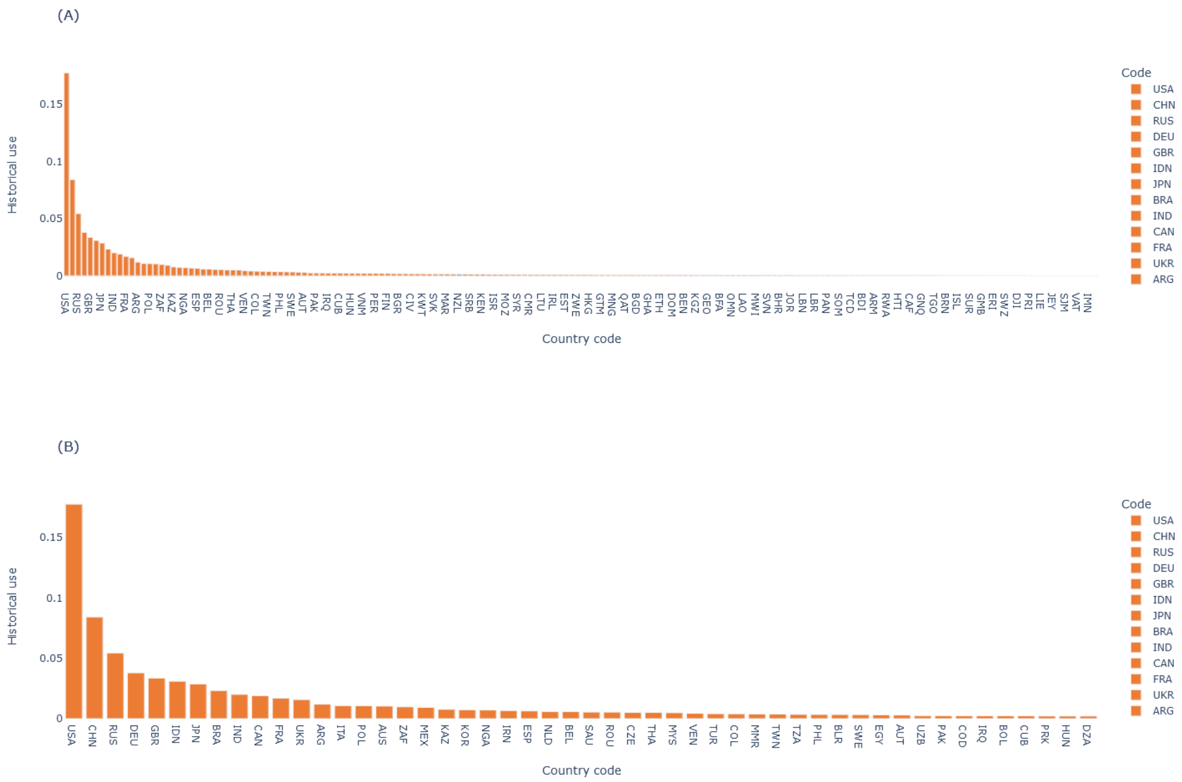



*Figure 32. Countries' historical warming use (°C) from $CO_2$ emissions between 1850–2014*

*(A) all countries, (B) top fifty countries*

Chart B shows that the United States was the greatest historical user of past warming. From its $CO_2$ emissions only, the United States warmed the Earth by 0.17°C over the 1850–2014 period. The United States is followed by China, Russia, Germany, Great Britain and Indonesia.

Next, the two charts in Figure 33 below show countries' cumulative historical per capita use of warming (in °C per person). This is the amount of warming that has been generated by countries, divided by each country's cumulative person-years – the sum of people alive in each year, for every year over the period of interest. As in Figure 32, chart A displays all 174 countries in the dataset, and chart B displays only the top fifty countries.

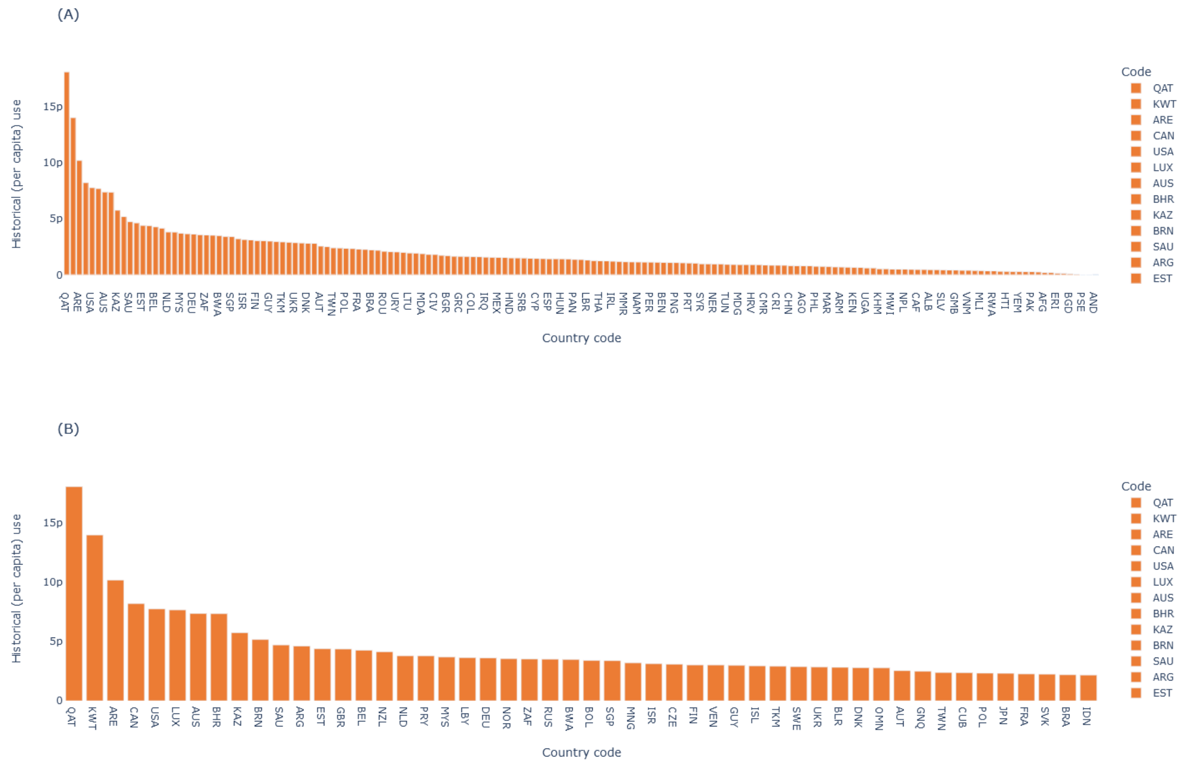



*Figure 33. Countries' historical cumulative per capita use of warming (°C) from $CO_2$ emissions between 1850–2014*

*(A) all countries, (B) top fifty countries*

Chart B in Figure 33 above, shows that Qatar is the country with the highest cumulative historical per capita use of warming from its $CO_2$ emissions, followed by Kuwait, the United Arab Emirates, Canada and Luxembourg. This result can be explained by Qatar's rapid economic transformation to a major oil and gas extracting and exporting economy, following discovery of the North Field gas reservoir in 1971 (Ibrahim & Harrigan, 2012; Tusiani & Johnson, 2023).

While not answering RQ3 specifically, charts A–C in Figure 34 below show how countries' ranks, based on their historical per capita warming use, have changed over three different time-periods. New Zealand (NZL), indicated by the blue bar, is taken as an example.

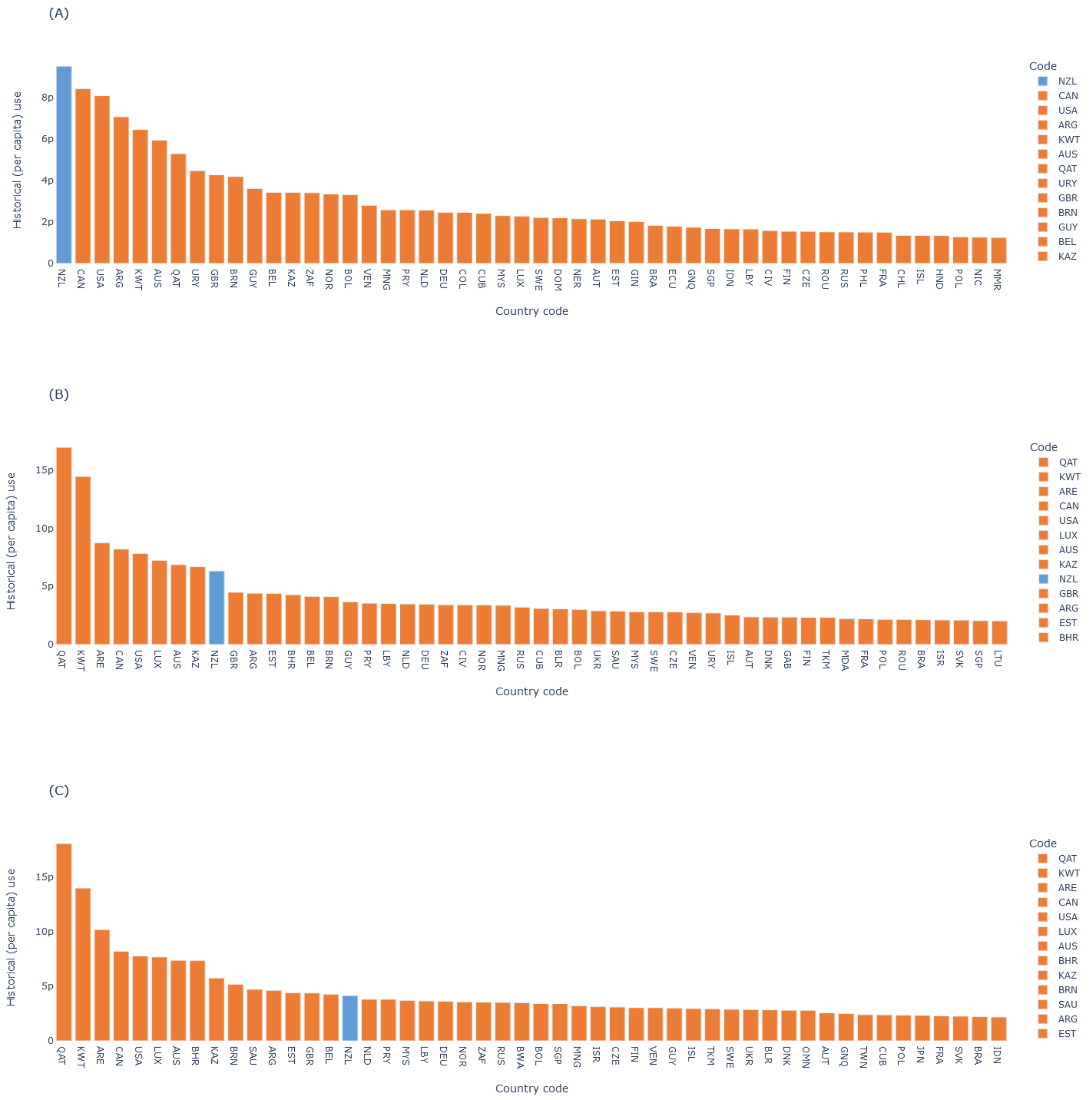


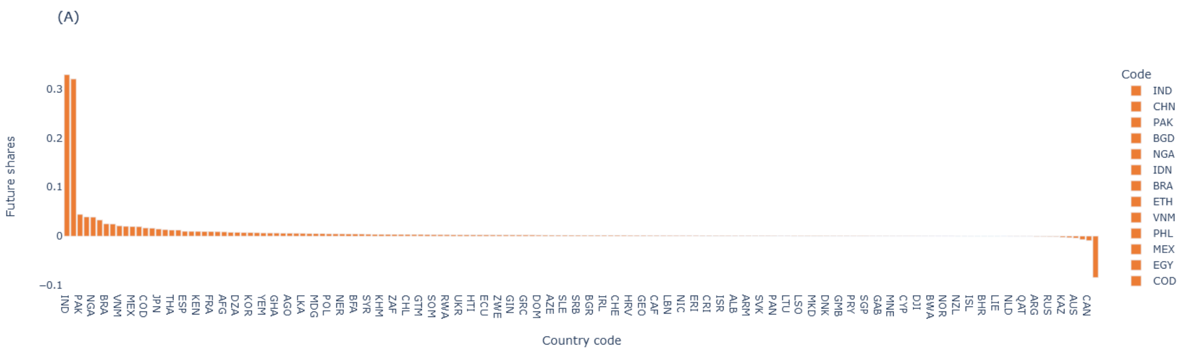

*Figure 34. Countries' cumulative historical per cumulative capita warming (°C) from $CO_2$ emissions*

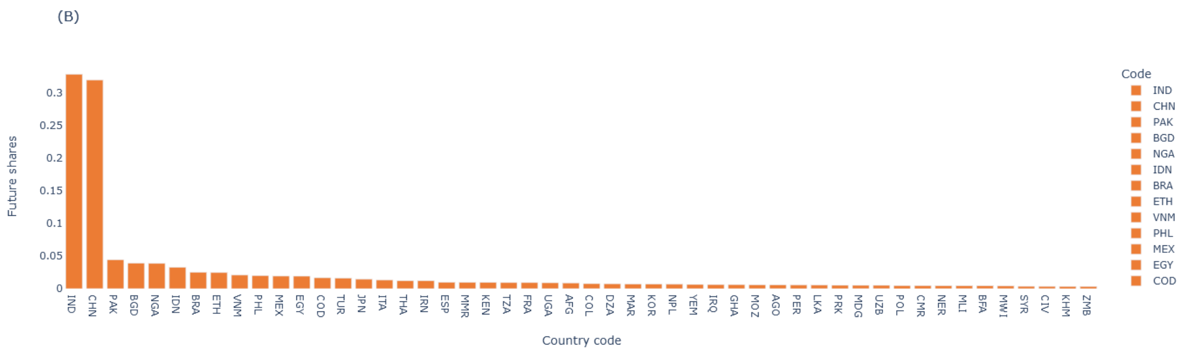
*(A) 1850–1960, (B) 1850–1990, (C) 1850–2014*

In chart A of Figure 34, when countries' warming contributions over the earliest time-period – 1850–1960 – are considered, New Zealand is the country with the highest cumulative historical per cumulative capita warming. New Zealand's high per capita emissions over the 1850–1960 time-period can be explained by New Zealand having a landmass with high forest cover and a relatively low population density. While many forests were cut down prior to European settlement in the early 17$^{th}$ century, this trend continued as large swathes of the country were cleared for "pastoral agriculture, cropping, horticulture, roads, and settlements" (Ausseil et al., 2011, p. 202; Ewers et al., 2006; Houghton & Nassikas, 2017).

In charts B and C, when the time-period is extended beyond 1960, three petrostates – Qatar, Kuwait and the United Arab Emirates – surpass New Zealand. These states continue to grow their per capita emissions relative to the next highest per capita warming countries – Canada, the United States, Luxembourg, and Australia – as can be seen in chart C. These results highlight that for countries like New Zealand, with low population densities and much forested land, contributions to warming over certain periods have been greater from land use change or conversions than the burning of fossil fuels. Whereas increased demand for fossil fuels since 1960 has played a dominant role in driving up the per capita warming of prominent petrostates.

Finally, the following four charts in Figure 35 below display countries' future warming rights, based on the Equality-over-time Principle. These take countries' historical warming use and historical populations between 1850–2014 into account, as well as countries' future populations, under a moderate population growth scenario, out to 2050. Chart A shows all 174 countries in the dataset, while charts B and C show only the top fifty and bottom fifty countries, respectively.



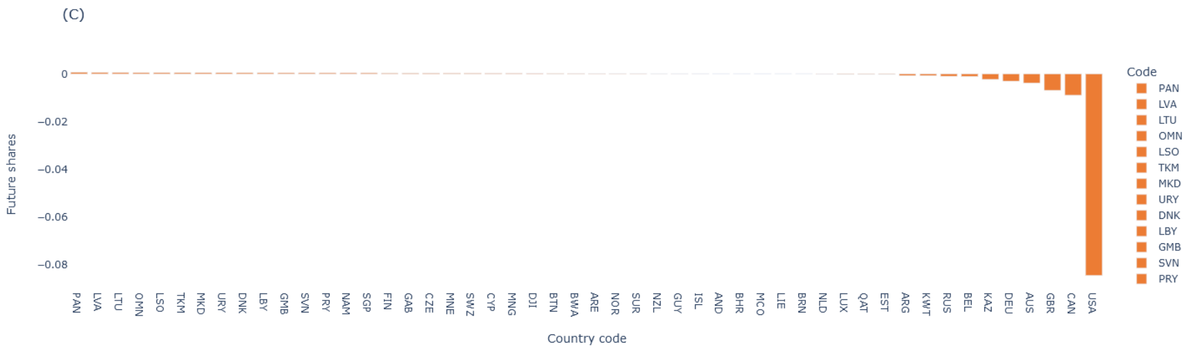



*Figure 35. Countries' future warming shares (°C) according to the Equality-over-time Principle based upon countries' historical cumulative $CO_2$ emissions and cumulative populations between 1850–2014 and future populations between 2015–2050*

*(A) all countries' past per capita warming use (B) all countries' future per capita shares*

Charts B and C of Figure 35 above show a zoomed in picture of countries' positive or negative warming rights. Positive warming rights reflect future amounts of a remaining global temperature target which countries have an ethical right to obtain. Negative warming rights indicate the level by which a country has already exceeded its fair share of warming, according to the Equality-over-time Principle. In an emissions rights sense, negative rights have been referred to as "carbon and climate debts" (Matthews, 2016, p. 60).

Chart B shows that the top five countries which receive the highest numbers of positive warming rights are India, China, Pakistan, Bangladesh, and Nigeria, according to the Equality-over-time Principle. Based on warming from these countries' $CO_2$ emissions between 1850–2014, and while remaining beneath the Paris Agreement's 2°C temperature target, these countries would be allocated 0.33°C, 0.32°C, 0.04°C, 0.04°C and 0.04°C of warming rights each. On the other hand, as shown in chart C, the top five countries deemed to have the greatest levels of warming debt are the United States, Russia, Germany, Great Britain, and Canada. These countries would receive obligations to undo their past warming by the following amounts: -0.084°C, -0.009°C, -0.007°C, -0.004°C, -0.003°C.

### *§4.4.1.2 Comparison with similar studies*

Four relevant studies have allocated emissions rights and carbon and climate debts at the country level on a per capita basis. These studies and their results will now be summarised and compared with those from the SEFS dashboard. The first study, by Matthews (2016), presents a new way of quantifying inequalities between countries, by calculating carbon and climate debts. This was done by considering national $CO_2$ emissions from fossil fuel combustion between 1990–2013, in the case of carbon debts; and national warming contributions from $CO_2$, $CH_4$, $N_2O$ and $SO_2$ emissions, in the case of climate debts. The study determined that climate debts amounted to 0.11°C between 1990–2010 and several of the same countries to those identified by the SEFS dashboard – the United States, Russia, and Canada – were found to be in climate debt. On the other hand, India, China, Bangladesh, Pakistan and Nigeria were all in climate credit.

A second study, by Hickel (2020), also sought to quantify the degree to which countries have overshot their fair shares of $CO_2$ emissions on a per capita basis. The study considered $CO_2$ emissions over two different time-periods: 1850–1969 and 1970–2015. Emissions were accounted for under the PBA framework for the first period and the CBA framework for the second period. Justification for the CBA framework during the second period was because the world has become more connected by global trade. The Hickel (2020) study found that the United States was responsible for a 40% excess of global $CO_2$ emissions and Annex I Parties were responsible for 90% of excess emissions. Both China and India were found to be within the boundaries of their fair shares, although China would overshoot its fair share soon.

Table 29 offers comparisons of the results in both studies with the closest possible comparisons of the Equality-over-time Principle in the SEFS dashboard.

| | Factor / Study | SEFS dashboard | Matthews (2016) | SEFS dashboard | Hickel (2020) |
|---|---|---|---|---|---|
| | Time period | 1990–2014 | 1960–2013<br>1990–2013 | 1850–2014 | 1850–2015 |
| | Way of expressing limit | 1.5*global emissions | Average per capita emissions | 1.5*global emissions | 350ppm |
| | Accounting framework | PBA | PBA | PBA | PBA (1850–1969)<br>CBA (1970–2015) |
| | Warming or emissions? | Warming (°C) | Warming (°C) | Warming (°C) | Emissions (Gigatonnes) |
| | Emissions from which activities | Fossil fuels and land use change | Fossil fuels and land use change | Fossil fuels and land use change | Fossil fuels only |
| | Which GHG? | $CO_2$ | $CO_2$ | $CO_2$ | $CO_2$ |
| **"Overshooters" (those in climate debt)** | 1 | United States | United States | United States | United States |
| | 2 | Canada | Russia | Canada | Russia |
| | 3 | Australia | Brazil | Great Britain | Germany |
| | 4 | Russia | Canada | Australia | United Kingdom |
| | 5 | Saudi Arabia | Germany | Argentina | Japan |
| **"Undershooters" (those in climate credit)** | 1 | India | India | China | India |
| | 2 | China | China | India | China |
| | 3 | Pakistan | Bangladesh | Bangladesh | Bangladesh |
| | 4 | Bangladesh | Pakistan | Pakistan | Indonesia |
| | 5 | Nigeria | Nigeria | Nigeria | Nigeria |

*Table 29. Comparing SEFS dashboard results with similar per capita studies*

These studies, for the most part, find similar so-called overshooters and undershooters, giving confidence in the results from the SEFS dashboard. Differences in parameter choices, such as time-period ranges, and the use of multiple accounting framework, as well as the exclusion of land use change in the Hickel (2020) study, could account for differences in the top five overshooters and undershooters.

The SEFS dashboard's approach of calculating historical cumulative per cumulative capita warming (see charts in Figure 34) as a precursor step in calculating the Equality-over-time Principle can also be compared with the results of a third study – Evans (2021b) – which quantified countries' historical per capita emissions as a perspective on countries' historical responsibility for climate change. However, the methods behind Evans (2021b) and the SEFS dashboard differ in significant ways.

The Evans (2021b) study calculated countries' per capita emissions for each year and then summed these values to obtain countries' historical per capita emissions. This would give a different result to the approach taken by the SEFS dashboard which instead divides a country's cumulative warming over the entire period of interest by the sum of that same country's annual populations over the same period, referred to as person-years. In this sense, the SEFS dashboard's Equality-over-time Principle is closer in its approach to the Hickel (2020) study.

Equations 31 and 32 below articulate how historical per capita emissions are calculated by Evans (2021b) and within the SEFS dashboard.

Evans (2021b) approach:

$$Cumulative\ per\ capita\ emissions_{Evans(2021b)} = \frac{E_{1850}}{P_{1850}} + \frac{E_{1851}}{P_{1851}} + \frac{E_{1852}}{P_{1852}} \dots \frac{E_{2021}}{P_{2021}} \quad \left[\frac{ktCO_2}{capita}\right] \tag{31}$$

Where:

- $E$ = $CO_2$ emissions in a given year. The year is indicated by the subscript following the $E$.
- $P$ = Population in a given year. The year is indicated by the subscript following the $P$.

SEFS dashboard approach:

$$Equality\ over\ time_{SEFS} = \sum \frac{W_{1850-2014}}{P_{1850} + P_{1851} + \cdots + P_{2014}} \qquad \left[\frac{°C}{personyear}\right] \tag{32}$$

Where:

- $W$ = warming from $CO_2$ emissions in °C.
- $P$ = Population in a given year. The year is indicated by the subscript following the $P$.

| | Factor / Study | SEFS dashboard | Evans (2021b) |
|---|---|---|---|
| | Time period | 1850–2014 | 1850–2021 |
| | Emissions or warming? | Warming (°C) | Emissions (tonnes) |
| | Accounting framework | PBA | PBA |
| | From which GHG? | $CO_2$ | $CO_2$ |
| | How is population considered? | Person-years | Sum of per capita emissions in each year |
| **Country rank** | 1 | ***Qatar*** | New Zealand |
| | 2 | Kuwait | ***Canada*** |
| | 3 | United Arab Emirates | ***Australia*** |
| | 4 | ***Canada*** | ***United States*** |
| | 5 | ***United States*** | Argentina |
| | 6 | ***Luxembourg*** | ***Qatar*** |
| | 7 | ***Australia*** | Gabon |
| | 8 | Bahrain | Malaysia |
| | 9 | Kazakhstan | Republic of Congo |
| | 10 | ***Brunei*** | Nicaragua |

*Table 30. Comparing SEFS dashboard results with Evans (2021b)*

Column two of Table 30 above shows the ten countries with the highest historical cumulative per cumulative capita warming from $CO_2$ emissions (in °C) over the 1850–2014 time-period and column three shows the top ten countries with the highest historical cumulative per capita $CO_2$ emissions (in tonnes) over the 1850–2021 time-period. Warming and emissions are both are attributed to countries under the PBA framework.

Countries which feature in the top ten of both the SEFS dashboard results and Evans (2021b) are indicated in **blue**. Differences could be explained by the inclusion of a further seven years of data in the Evans (2021b) approach, as well as the slight difference in calculations, stated previously. Additionally, Evans (2021b) notes that countries with populations beneath one million people are not included in the table. This means that several countries with small populations, but high per capita emissions – like Luxembourg, Guyana, Belize and Brunei – do not feature in the Evans (2021b) column of the table, but are present in **purple** in the SEFS dashboard column of the table.

The fourth study which has results that are of relevance to applications of the Equality-over-time Principle within the SEFS dashboard is a study by Pan et al. (2022). This study calculates shares of a remaining carbon budget (RCB) for 177 countries by allocating global cumulative GHG emissions of 2030 in $CO_2e$ over the 1990–2100 period to align with the 1.5°C Article 2 target. Both the PBA and CBA frameworks are used to apply an Equal Cumulative Per Capita Emissions (ECPCE) Principle. CBA emissions were calculated for the 1990–2015 period using the Eora-26 dataset. The results broadly conform with those from the SEFS dashboard in the sense that many large Annex I Parties would have exceeded their share of an emissions budget which equates to the 1.5°C temperature target. This means they are in carbon debt and would need to achieve negative emissions in the future.

### *§4.4.1.3 Population ethics and relevance of the repugnant conclusion*

Since the Equality-over-time Principle allocates warming rights across countries' changing populations, the Repugnant Conclusion – a fundamental challenge in modern population ethics – bears relevance. Conceived of by Derek Parfit, the Repugnant Conclusion compares different worlds based solely upon their aggregate level of well-being (Parfit, 1984). In the case of one world with few inhabitants that are well off and another world with many more inhabitants that are considerably worse off, the repugnant conclusion would view both worlds as equal. Parfit (2016) explains that "This conclusion seems repugnant, some people claim, because we cannot adequately imagine very large numbers" (pp. 110–111).

Rather than comparing the overall well-being of people in different worlds, RQ3 is focussed on determining how warming rights might be shared between countries' populations. However, researchers have drawn attention to past mistakes of other researchers, who conflated emissions and well-being by assuming that greater emissions will result in greater well-being (Q. Li & Chen, 2021; Steinberger & Roberts, 2010). On this logic, fixed warming targets would place limits on a population's collective level of well-being, where worlds with more people would receive less per person warming rights, resulting in less well-being per person.

While the *Distributing Rights* page of the dashboard does not explicitly encourage users to consider which world might be ethically better, the five different population growth scenario options for applying the Equality-over-time Principle would support such a comparison. This is because, if one were to evaluate the five scenarios under an aggregate well-being lens and it turned out that one of these had more people but less per person well-being, then the repugnant conclusion might be reached.

Taking India as an example, two population growth scenarios for calculating India's warming rights under the Equality-over-time Principle will be compared. Both are based on warming from India's historical $CO_2$ emissions between 1850–2014. The first population growth scenario, based on the first Shared Socioeconomic Pathway (SSP1) results in India and its projected 53.1 billion people that will be alive between 2015–2050 being allocated 0.1303°C of warming, or $2.45 \times 10^{-12}$°C per person. In contrast, population growth scenario 4 (SSP4) results in India and its projected 53.8 billion people that will be alive between 2014–2050 being allocated 0.1295°C of warming, or $2.41 \times 10^{-12}$°C per person. This demonstrates how, as a by-product of its approach for answering RQ3, the SEFS dashboard can enable different future worlds, with potentially different levels of per person well-being, to be analysed.

However, to reiterate, this research is not focussed moral assessments of different worlds based on their per person well-being. Interestingly, while the assumption that more emissions would support a greater level of well-being held credence in the past, it is less convincing in a world where increasing numbers of people are meeting their needs from renewable energy sources, without further contributing to the greenhouse effect. Therefore, an allocation of warming rights as a proxy for well-being is unlikely to be the most accurate indicator of different countries' aggregate levels of well-being.

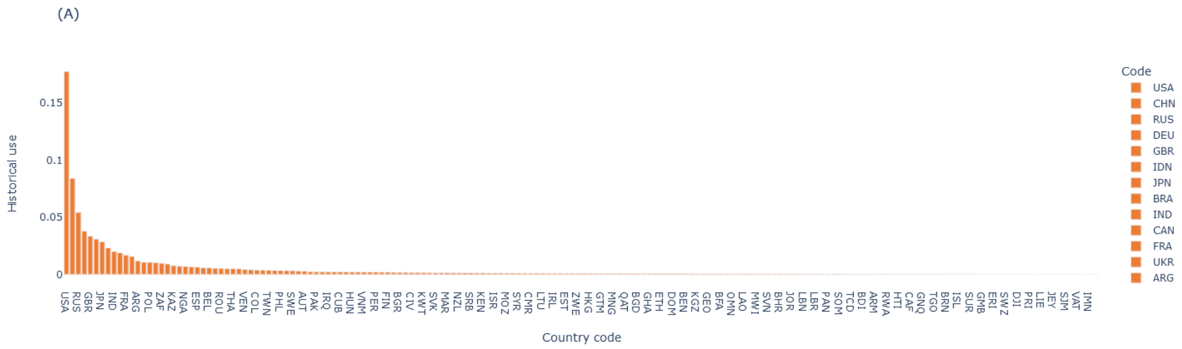
## §4.4.2 The Grandfathering Principle

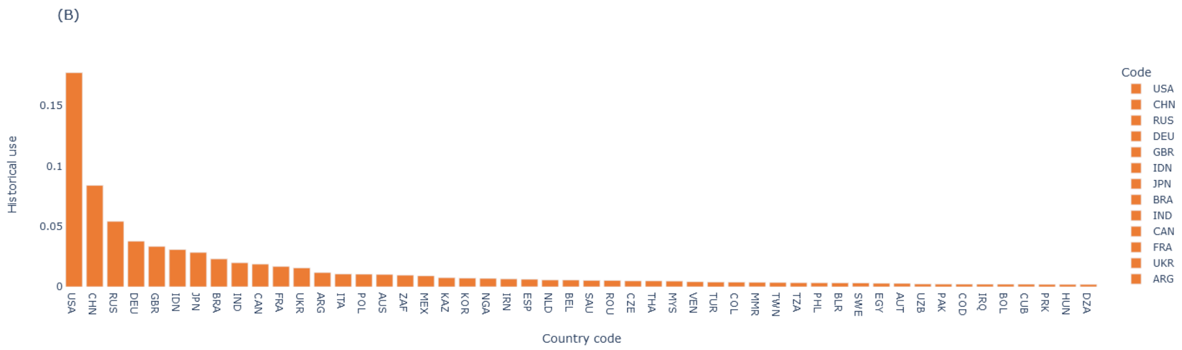
This section (§4.4.2) presents results of applying the Grandfathering Principle within the SEFS dashboard. Priority has again been given to presenting warming rights (in °C). It is important to point out that countries' cumulative warming from GHG emissions, over a particular time-period, are considered to be the basis for allocating future warming rights under the Grandfathering Principle. This approach differs from other studies and real-world instances of the Grandfathering Principle, which often take emissions amounts in a single year as the basis for future emissions reductions.

### *§4.4.2.1 Results and discussion*

The six charts in Figure 36 show countries' historical warming use over the full time-period – 1850–2014 – and from each of $CO_2$, $CH_4$ and NOx in turn. Charts A, C and E display all 174 countries' historical warming use. Charts B, D and F display only the top fifty countries from each of the immediately preceding charts to provide a more *zoomed in* view.

It is worth acknowledging here that the following charts are very close to those which appeared in Figure 17, where the difference is that those charts combined warming from each gas. In this section, warming from each gas is considered in isolation, starting with $CO_2$, followed by $CH_4$ and then NOx.



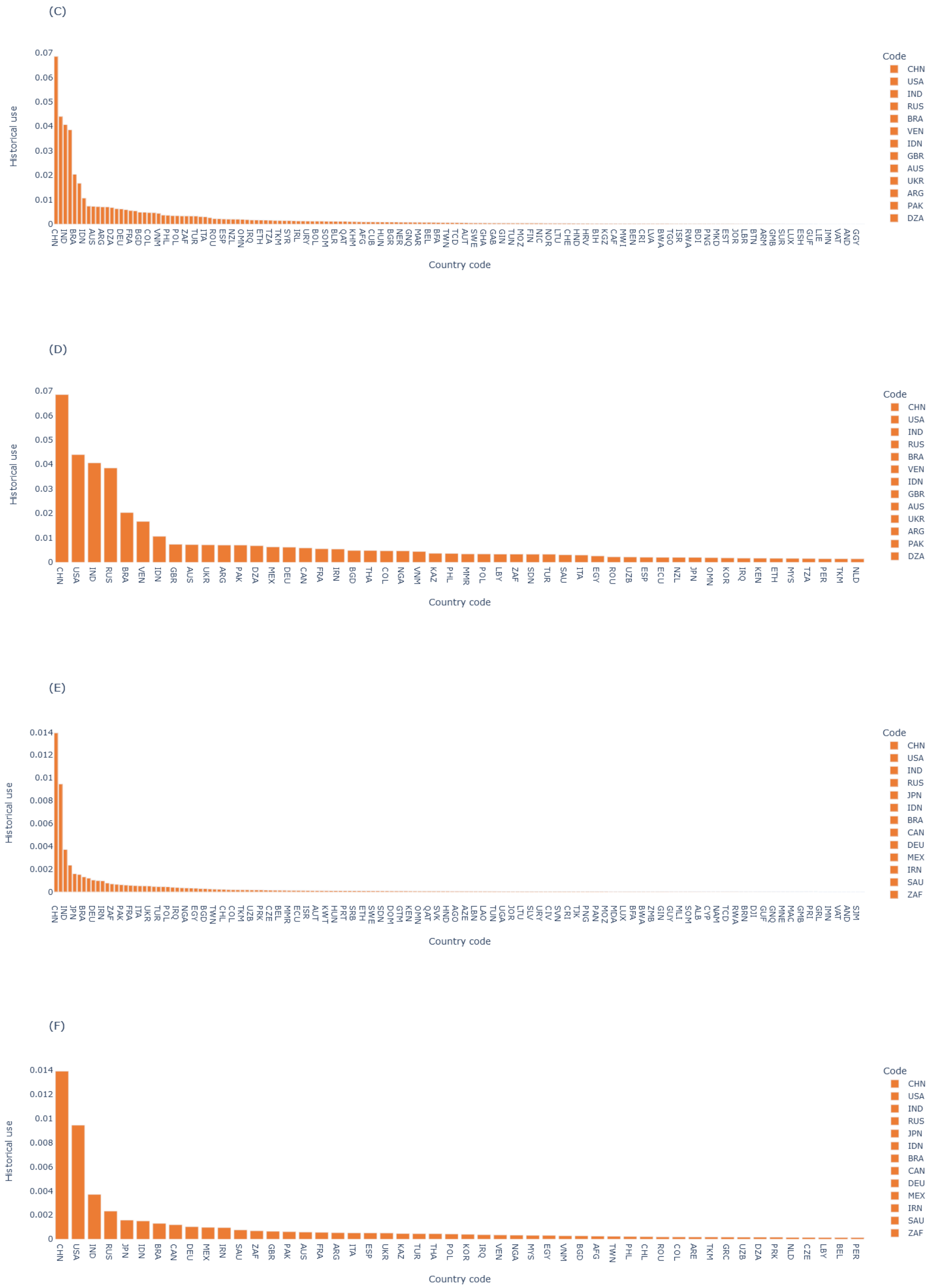



*Figure 36. Countries' warming shares (°C) under a Grandfathering Principle based on countries' emissions between 1850–2014 (A) all countries' $CO_2$, (B) top fifty countries' $CO_2$, (C) all countries' $CH_4$, (D) top fifty countries' $CH_4$, (E) all countries' NOx, (F) top fifty countries' NOx*

In Table 31 below, the top ten countries from each chart have had their *absolute* warming amounts converted into *relative* amounts, so that each country's warming from each gas is presented as a proportion of total warming from that gas, over the 1850–2014 time-period. These warming proportions are expressed as percentages in brackets after the country name.

| Rank | Warming from $CO_2$ emissions | Warming from $CH_4$ emissions | Warming from NOx emissions |
|---|---|---|---|
| **1** | United States (22%) | China (15%) | China (25%) |
| **2** | China (11%) | United States (10%) | United States (17%) |
| **3** | Russia (7%) | India (9%) | India (7%) |
| **4** | Germany (5%) | Russia (9%) | Russia (4%) |
| **5** | Great Britain (4%) | Brazil (5%) | Japan (3%) |
| **6** | Indonesia (4%) | Venezuela (4%) | Indonesia (3%) |
| **7** | Japan (4%) | Indonesia (2%) | Brazil (2%) |
| **8** | Brazil (3%) | Great Britain (2%) | Canada (2%) |
| **9** | India (3%) | Australia (2%) | Germany (2%) |
| **10** | Canada (2%) | Ukraine (2%) | Mexico (2%) |
| **Total warming over the 1850–2014 period** | 0.79°C | 0.45°C | 0.06°C |
| **This group of countries' proportion of overall warming** | 64% | 58% | 67% |

*Table 31. Relative warming contributions (all three climate forcers), 1850–2014*

The results in Table 31 show that ten countries accounted for 64% of historic warming from $CO_2$ emissions over the 1850–2014 time-period. In the case of distributing future warming rights under a Grandfathering Principle, these ten countries would obtain the same proportions of future warming constrained by a temperature change target. However, within this top ten countries, there are substantial differences between the warming that would be given to developed and developing countries. Six developed countries would collectively obtain 43% of future warming: the United States, Russia, Germany, Great Britain, Japan and Canada. Meanwhile, four developed countries would collectively obtain approximately half of this warming (21%).

The result is quite different in the case of allocating future warming rights based on historical relative warming from $CH_4$ and NOx. China and India would jointly be allocated 24% and 32% of future warming rights from $CH_4$ and NOx respectively. These countries would obtain significantly higher shares of $CH_4$- and NOx-related warming, than $CO_2$-related warming. However, $CH_4$-related warming is more temporary in nature, due to the GHG being short-lived.

Table 32 below combines warming contributions from $CO_2$, $CH_4$ and NOx for the five countries that have generated the most warming over the 1850–2014 time-period, in order to determine shares of future warming. Based on the Grandfathering Principle, the United States would inherit 18% of future warming, followed by China (13%) and Russia (7%).

| Country | Proportions of past warming and allocations of some future warming budget |
|---|---:|
| United States | 18% |
| China | 13% |
| Russia | 7% |
| India | 5% |
| Germany | 3% |

*Table 32. Countries' proportions of past warming*

While it can be useful to consider warming from different GHGs over the same time-period, it is also illuminating to consider how countries' warming contributions from the same GHG vary over different time-periods, relative to other countries. The charts in Figure 37 and Figure 38 display this information. Discussing these results will be the focus of the remainder of this section.

Charts in Figure 37 and Figure 38 cannot be generated by the SEFS dashboard in its current state. These charts were created from dashboard outputs so that countries' relative warming rights from different GHGs, over different time-periods, could be determined.

The charts display fifteen countries' historical warming use from $CO_2$ and then $CH_4$ over different time intervals. The countries displayed in these charts were the top fifteen contributors to warming over the 1850–1960 period. It is important to point out that all results in this section have a *relative* nature to them. This is because each bar reflects a country's warming as a proportion of the world's total warming, from a specific GHG and over a particular time-period. This means that while a country may have increased its $CO_2$ emissions during a particular time-period, if other countries have also increased their $CO_2$ emissions, the first country's absolute increase in emissions may be hidden by the collective size of these other countries' increases. In this sense, the results in Figure 37 and Figure 38 show the degree to which countries' *relative* historical warming contributions vary over different time-periods.

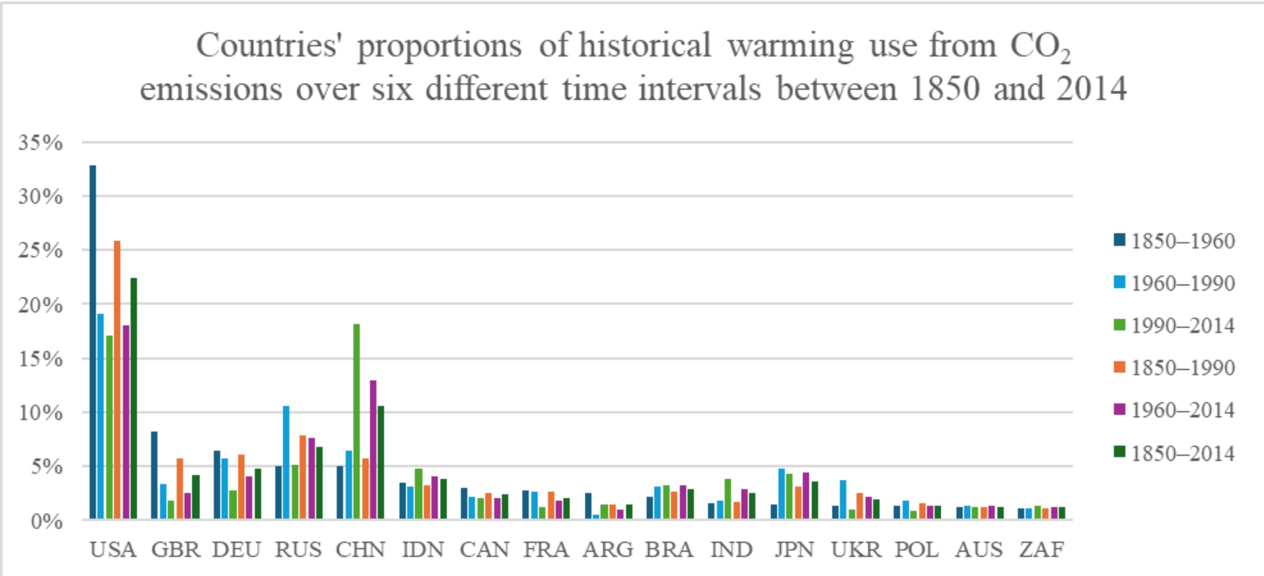



*Figure 37. Proportions of historical warming (from $CO_2$) over different time-periods*

Figure 37 shows the United States has been the greatest contributor to $CO_2$-related warming, accounting for between 17–33% of $CO_2$-related warming over all six time-periods. Russia and China account for the next highest shares of $CO_2$-related warming, accounting for between 5–11% and 5–18% respectively.

Early industrialisers like Great Britain, Germany, Canada, and France have similar proportions of $CO_2$-related warming. Their relative $CO_2$-related warming was higher over earlier time-periods – 1850–1960 and 1850–1990 – and is significantly lower over more recent time-periods – 1960–1990, 1960–2014 and 1990–2014. This can be explained these countries starting their processes of industrialisation much earlier than others (Abella et al., 2024). Then, since the 1990s and early 2000s, early industrialisers began decarbonising their domestic economies, and offshoring production to large developing countries like China as many of these countries began to industrialise (Baiocchi &

Minx, 2010; Y. Li & Hewitt, 2008). For instance, many large Latin American and Asian developing countries like Brazil, Argentina, China and India began undergoing their industrialisation journeys towards the end of the 20th century and developed large manufacturing industries (Szirmai, 2012). By 2014, the relative warming contributions over the 1850–2014 time-period of Brazil (3%) and Indonesia (5%) surpass most of the four early industrialisers: Great Britain (2%), Germany (3%), Canada (2%) and France (1%).

The $CO_2$-related warming profiles of Russia, Ukraine, and other Eastern European countries like Poland, which have their highest $CO_2$-related warming contributions relative to other countries over the 1960–1990 period, are distinctive. These distinctive profiles can be explained by the rapid industrialisation journey of the Union of Soviet Socialist Republics (USSR) which began from the early 1930s. This continued until the USSR's dissolution in 1991, when the post-communist economic crisis led to a significant reduction in industrial production and related emissions.

Conversely to Soviet and Eastern European countries, Argentina's lowest relative contribution to $CO_2$-related warming occurred during the 1960–1990 period. Deforestation practices, as opposed to the burning of fossil fuels, dominated Argentina's early contributions to warming (Gasparri et al., 2008). More recently, the expansion of Argentina's agricultural industry has resulted in significant land use conversions for soybean production.

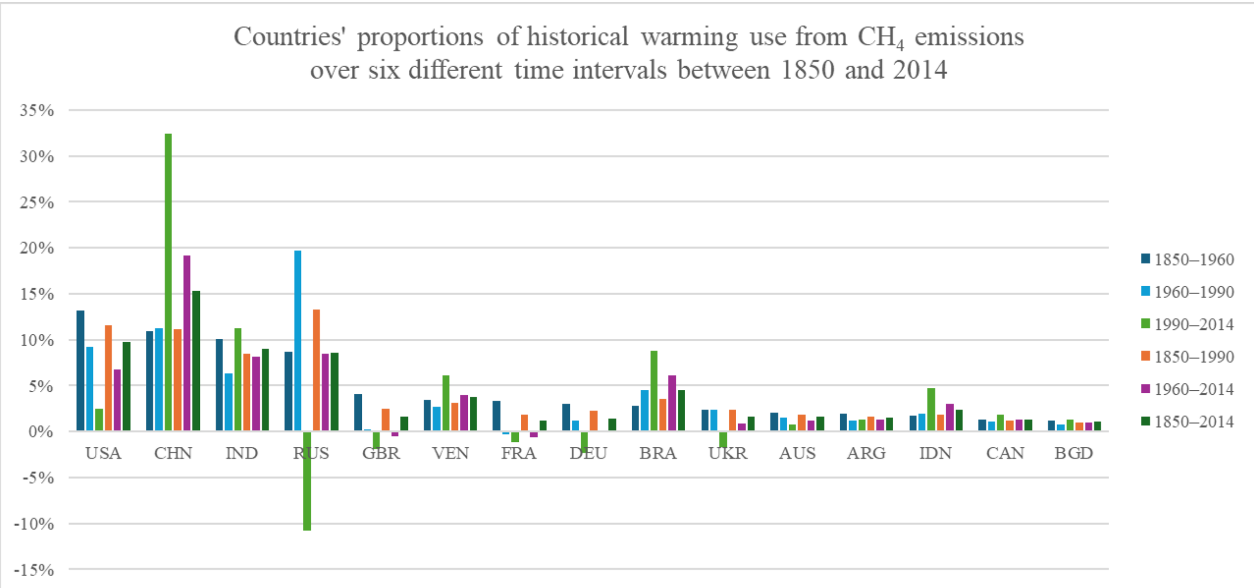



*Figure 38. Proportions of historical warming (from $CH_4$) over different time-periods*

Figure 38 above shows countries' relative contributions to $CH_4$-related warming over six time-periods. The United States and Russia contributed significantly to warming from $CH_4$ emissions over earlier periods. However, Russia's $CH_4$ emissions have had a net negative, or cooling effect, in the most recent time-period – 1990–2014. This can be explained by the USSR's large agricultural sector dramatically reducing in size following the collapse of the Soviet Union in 1991. Consequently, Russia's agricultural $CH_4$ emissions reduced by 17% between 1992 and 2000 (Schierhorn et al., 2019).

Other countries, like Great Britian, France, Germany and Ukraine, also display negative warming – or cooling – from their $CH_4$ emissions when the longest time-period – 1850–2014 – is considered. Great Britain and France also show negative $CH_4$-related warming over the 1960–2014 time-period.

These results highlight an important point: that certain countries have undone the warming of their past $CH_4$ emissions in recent time-periods. This can be explained by $CH_4$'s short-lived nature, which means its warming effect can be reversed within short timescales (Allen, Lynch, et al., 2018). These results also highlight the *temporary* nature of $CH_4$-related warming, as opposed the more permanent, long-lived warming from $CO_2$. The shift from $CH_4$-related warming to cooling can be explained by these countries' domestic economies moving away from activities which release $CH_4$ emissions.

The ability to reverse $CH_4$-related warming raises an interesting point about the allocation of warming rights under a Grandfathering Principle. If countries' have generated a cooling effect by undoing past warming from their $CH_4$-related emissions, then there is a question as to whether countries might inherit obligations to cool the planet under a Grandfathering Principle? To the researcher's knowledge, the possibility of inheriting cooling obligations under a Grandfathering Principle has not yet been discussed in the climate ethics literature.

A further question is whether globally agreed temperature change targets, like the Article 2 targets, should be disaggregated into targets for short-lived and long-lived warming. However, given the links between economic activities and GHGs, it may be too prescriptive to come up with how much warming ought to be allowed from different GHGs. Rather than specifying how much warming countries ought to receive from each type of GHG, a less prescriptive approach would be to specify overall warming rights (in °C), and let countries determine the GHG make up of this themselves. Countries like Ireland and New Zealand – with large amounts of temporary $CH_4$-related warming from their agricultural sectors – might be able to achieve cooling by reducing these emissions, which would leave them with more room for $CO_2$-related warming.

#### *§4.4.2.2 Comparison with similar studies*

A range of studies, similar in focus to the SEFS dashboard, distribute carbon budgets or allocate rights to emit according to the Grandfathering Principle (Robiou du Pont et al., 2017; Robiou du Pont &

Meinshausen, 2018; van den Berg et al., 2020). However, several of these studies combine the Grandfathering Principle with the equal per capita approaches, referred to as "blended sharing principles" (Raupach et al., 2014, p. 874; Williges et al., 2022). This renders the results of these studies less directly comparable with results from the SEFS dashboard which operationalises the Grandfathering Principle on its own.

A further important difference between the SEFS dashboard's application of the Grandfathering Principle and relevant studies is that one study excludes $CO_2$ emissions from LULCC, which the SEFS dashboard does include (Peters et al., 2015). Additionally, two relevant studies focus on a smaller number of countries, or aggregate emissions at the regional level and also analyse countries' NDCs and Intended Nationally Determined Contributions (INDCs) (Meinshausen et al., 2015; Peters et al., 2015). In its current form, the dashboard does not have functionality to assess countries' NDCs and INDCs. As indicated in the introduction to this section, a final important difference between the SEFS dashboard's application of the Grandfathering Principle and other studies is that the other studies allocate emissions rights based upon emissions in a single year. The Grandfathering Principle in the SEFS dashboard by contrast uses cumulative historical warming over multiple years as a basis for allocating future warming rights, where warming rights represents a novel contribution to the climate ethics literature.

Overall, results of applying the Grandfathering Principle within the SEFS dashboard tend to conform broadly with the results of similar studies, whereby in those studies many large, developed countries would inherit the lion's share of future rights to emit. However, the use of different metrics, data and methods – involving multiple principle combinations – renders results from these studies not directly comparable with the results of applying the Grandfathering Principle within the SEFS dashboard.

## §4.4.3 Section summary

The previous two sections (§4.4.1 and §4.4.2) have presented and discussed Equality-over-time and Grandfathering Principle applications within the SEFS dashboard, to answer RQ3. While the dashboard supports calculations of both future emissions rights and warming rights, only warming rights have been displayed and discussed since these are the more novel contribution.

The results of applying both principles show similarities with related studies from the climate ethics literature. However, the Equality-over-time Principle is a new principle that has not featured in other studies to date. For this reason, the results of applying this principle had to be compared with Equal Per Capita Emissions and ECPCE approaches, which used different datasets and performed slightly different calculations.

Similarly, there were limited opportunities to directly compare the SEFS dashboard's formulation of the Grandfathering Principle, which relied upon cumulative warming over multiple years, with relevant studies. Dataset differences and approaches which blended the Grandfathering Principle with other principles also rendered the SEFS dashboard's application of this principle less directly comparable with the existing literature.

The results of applying both principles were discussed in the context of historical events and the changing nature of countries' economies. Such information can help illuminate trends and variations in countries' historical warming contributions. Disruptive political events, like the collapse of the Soviet Union, can explain dramatic reductions in former Soviet countries' historical warming contributions, with implications for allocations of countries' future warming rights.

An interesting idea arose from a key finding that: several early industrialisers' $CH_4$ emission reductions over recent periods have had a net cooling effect. This provoked the idea that: countries could receive cooling obligations, under a Grandfathering Principle in more recent time-periods.

Finally, a policy implication of this work is that global temperature change targets could be separated into temporary and more permanent warming targets. The SEFS dashboard could therefore prompt debate about whether there is merit in treating the warming effect generated by short-lived and long-lived GHGs differently. However, prescribing temporary and permanent targets at the country-level may risk overstepping the bounds of national sovereignty, because of how countries' warming contributions from specific GHGs are so closely tied to activities underpinning their economies.

## §4.5 Chapter summary

Chapter 4 has presented and discussed samples of results from the SEFS dashboard as answers to the three RQs. Answers to RQ1 highlight the importance of time-period over which warming is considered, where most 19$^{th}$ to mid-20$^{th}$ century warming is attributed to early industrialising nations and large developing countries have come to dominate post-1990 warming contributions. While it is not expected to provide answers to such questions, the SEFS dashboard can enable explorations which support debates about which eras of anthropogenic warming ought to count. Perspectives on the concepts of excusable ignorance and inexcusable negligence, discussed in §2.6.1.1, are relevant to such debates and affect perceptions of country-level responsibility for causing climate change.

Answers to RQ2 highlight the very different distributions of climate finance that can result from applications of the Ability to Pay, Beneficiary Pays and Polluter Pays Principles within the SEFS dashboard. A lack of practical applications of the Beneficiary Pays Principle within the literature and substantial variations in some countries' climate finance obligations under both the Ability to Pay and Beneficiary Pays Principles has raised questions about the adequacy of proxy metrics, whether new data might need to be gathered, or the principles themselves revised.

Answers to RQ3 by way of the Equality-over-time Principle would see many large developing countries receiving future warming rights, with early industrialising nations having obligations to undo the warming of their historical emissions. Conversely, applications of the Grandfathering Principle paint an almost opposite view, where large, developed countries would inherit the lion's share of future warming rights. Additionally, charts created from dashboard outputs have revealed the potential for countries to inherit cooling obligations where their emissions of short-lived $CH_4$ have declined in recent time-periods.

Studies which seek to answer similar questions were found to have a regional-level focus, combine multiple principles or use different information. This made direct comparisons between these studies and the SEFS dashboard (in order to validate the research findings) difficult and highlights the more finely grained analysis and novel insights of this research project.

Results from the SEFS dashboard also highlight that there are no single answers to any of the three RQs. RQ1 answers depend on the choice of GHG and time-period over which warming is considered, while RQs 2 and 3 fall within the area of distributive justice. For these questions, a wider range of parameters influence the results. Ultimately, the dashboard can bring into clearer view the many value judgements which underpin choices when it comes to assessing countries' fair shares for addressing climate change. The pragmatist-positivist approach of this research has allowed for the results and discussion of them to be responded to in a pragmatist way. This supports the value pluralism of the results by acknowledging that a range of ethical perspectives exist.

# Chapter 5 Critical Review

## §5.1 Chapter overview

This chapter critically reflects on the research and describes options for extending the study that were identified during the research process, and which could be explored beyond the boundaries of this particular project. A critical evaluation of the research's scope and design and how the research was carried out is offered in §5.2.

Sections within §5.3 consider the research's relevance to other fields, and the benefits of the Science and Ethics of Fair Shares (SEFS) dashboard for its target audiences. International Relations (IR) theories are drawn on to hypothesise how these theories might engage with the dashboard and view inter-state behaviour, which principles might be argued for and why. This is followed by a discussion of the dashboard's ability to provide nuanced indications of countries' progress on addressing climate change and whether the dashboard is constrained by its focus on what might be ethically ideal, rather than practically useful.

Method-based and technical critiques of the research are the focus of §5.4. This includes reflections on how to incorporate future generations into applications of the principles (§5.4.1), a discussion of more sophisticated methods for calculating consumption-based emissions, and the possibility of combining multiple accounting frameworks to offer more nuanced perspectives on nation-state responsibility (§5.4.2). The technical critiques are concluded in §5.4.3, which echoes the limitations of using proxy metrics from Chapter 3 and questions whether new principles and datasets are needed.

Finally, §5.5 summarises the key themes of this chapter and reiterates the usefulness and importance of both the research and SEFS dashboard.

## §5.2 Research focus, scope and design

This section (§5.2) begins by evaluating the pragmatist-positivist approach to explain how positivism became less useful for dealing with varying definitions of ethical principles, leading to the exploration of more helpful paradigms (§5.2.1). Implications of the researcher's background and worldview are considered and discussed in §5.2.2, including the consequences of being amongst a climate elite and drawing on frameworks that have evolved from within this demographic. Limitations of the SEFS dashboard's sole focus on nation-states, given the growing importance of non-state and sub-state actors, are discussed in §5.2.3.

### §5.2.1 The pragmatist-positivist approach

As explained in Chapter 1 and Chapter 3, the paradigm which has guided this research is a pragmatist-positivist approach, which utilises the tools and methodologies of positivism but substitutes its objectivist commitments with a more a pragmatist approach to the ethics and its interaction with the science. For the most part, positivism was a useful paradigm for progressing the research, where research methods were of a positivist nature in that they involved manipulating quantitative data by using engineering-related techniques from the natural sciences.

However, several features of positivism made it less well suited to handling the plurality of perspectives on fairness that the SEFS dashboard helped uncover. For this reason, the pragmatist approach – which endorses paradigms and methodologies that offer useful perspectives, explanations and methods – allowed for the suspension of some of positivism's more rigid beliefs, without rejecting aspects of positivism that were useful for handling country-level information and building the SEFS dashboard. The pragmatist approach could therefore acknowledge that many different distributions of fairness can in fact exist at once, as opposed to each being treated as a generalisable moral law or truth.

The pragmatist approach was also helpful for guiding the research, where a purely positivist approach would have been ill-equipped to deal with definitions of ethical principles varying across different types of climate action and ethical principles taking different forms. For instance, in a mitigation context the beneficiary benefits from climate-causing actions, whereas in an adaptation context the beneficiary benefits from risk reduction measures (Farber, 2007; Page, 2012). Additionally, two formulations of the Ability to Pay Principle are distinguished between within the climate ethics literature. The first would expect everyone to bear costs, while the second would exempt those with limited financial capacity from bearing any costs (Roser & Seidel, 2017). There are also different forms of grandfathering: weak, moderate and strong (Knight, 2013; Roser & Seidel, 2017).

Varying understandings and definitions of different principles, as well as their relationships to accounting frameworks, marked points at which positivism became less helpful as a paradigm for dealing with these issues. At these points, interpretivism – which seeks to understand and explain social reality and human behaviour by investigating human experiences in the context of existing knowledge, cultural and contextual influences – presented an alternative paradigm for acknowledging a principle's multiple meanings (Crotty, 1998; Radnor, 2002). Rather than believing in the existence of discoverable, objective truths, interpretivism acknowledges the role that individuals play in constructing subjective forms of meaning as they actively interact with and make sense of the world (Radnor, 2002; Yanow & Schwartz-Shea, 2014). Since the principles assign responsibility differently in different contexts and have multiple formulations and meanings, interpretivism accommodates the ethical controversies that result from variable understandings of the principles, which are informed by individuals' unique values and experiences. It was at the points where principles' definitions and forms were found to vary that a pragmatist perspective was able to accommodate interpretivist ways of thinking, which were explored in order to reflect on principles' multiple meanings.

Following this interpretivist exploration, and in order to continue advancing the research, specific principle definitions were chosen and treated as fixed in order to continue their application in a positivist way. It is acknowledged that selections of different principle definitions and forms at these points may have resulted in principles being understood and operationalised in different ways, with different outcomes.

In summary, during the research process, positivism encountered a range of challenges. An overarching pragmatist approach enabled the use of positivist methods for progressing the research in so far as they were useful for achieving the research aims. However, despite the positivist nature of many of the research methods, the research questions (RQs) are ultimately responded to in a pragmatist way. This is because pragmatism enables a value pluralism by allowing for many possible answers to each of the RQs. The challenge of how to treat differing principle definitions and forms was not resolved within this research project. Rather, it marked positivism's unsuitability for handling principles' subjective meanings and highlighted points at which alternative paradigms, like interpretivism, have a role to play.

## §5.2.2 W.E.I.R.D research and identifying new principles

W.E.I.R.D – an acronym coined by Henrich et al. (2010) – has been used to refer to a lack of diversity within behavioural science research and question the validity of researchers drawing universal conclusions from studies carried out upon Western, Educated, Industrialized, Rich and Democratic (W.E.I.R.D) research participants.

This research is W.E.I.R.D in the sense that it is a product of ideas and frameworks which have emerged from within a W.E.I.R.D demographic of climate elites, which includes diplomats, negotiators and the wider international research and policymaking communities who have come to dominate understandings of climate change through a justice and equity lens. The research has also been carried out by a member of the W.E.I.R.D climate elite, a doctoral candidate based in a developed country (New Zealand). Consequently, the language and understandings that the research builds upon are characteristic of approaches recognised by this group. For instance, the ethical distributional principles applied in the SEFS dashboard have emerged out of Western ethical traditions and ideals.

Consequently, it could be argued that the SEFS dashboard may not engage satisfactorily with wider audiences because it does not incorporate ethical perspectives from a diverse range of cultures and traditions. This means that wider demographics, including Indigenous peoples and local communities (IPLCs), Least Developed Countries (LDCs), developing countries (non-Annex I Parties) and Economies in Transition (EIT) may not find their understandings of fairness reflected by principle applications.

However, as users engage with the dashboard and come to better understand the practical implications of applying different principles, they can be expected to obtain better understandings of each principle's conception of fairness. In this way, users can decide for themselves – by way of the technology-assisted wide reflective equilibrium (WRE) that the SEFS dashboard enables – whether or not they agree with each principle's underlying value judgements. Through interacting with the dashboard and interrogating their own conceptions of fairness, users may also find opportunities to identify different ethical principles – reflective of diverse cultural norms and understandings of fairness – which could further enrich equitable effort-sharing discussions. Such principles could be incorporated into future iterations of the tool.

### §5.2.3 Non-state and subnational actors as the unit of analysis

This research takes nation-states as its unit of analysis – specifically those 196 countries which are Parties to the United Nations Framework Convention on Climate Change (UNFCCC). However, some datasets in the SEFS dashboard also include tax havens and British and Danish territories like the Cayman and Faroe Islands. This explains why such places have made an appearance in the sample of results from the dashboard in §4.3.1.

This section focusses on assessing the feasibility of including non-state and subnational lenses within the SEFS dashboard. Arguably the SEFS dashboard's sole focus on nation-states is limited because other important non-state and subnational actors, including businesses, civil society, and regional and local governments, also bear responsibility. These actors have become of increasing interest to global climate governance scholarship, where multilevel and polycentric governance approaches recognise them, alongside nation-states, as agents of change who also have the ability to lead and pioneer stronger climate action (Wurzel et al., 2019). The growing influence and participation of non-state actors in international climate negotiations, as discussed in §2.3.4, and the large shares of global emissions that some of these actors account for, provide justifications for offering a non-state actor lens. For instance, research by the Carbon Majors Database found that just 100 companies, dubbed "Carbon Majors", accounted for 71% of the world's global industrial greenhouse gas (GHG) emissions between 1988 and 2015 (Griffin, 2017, p. 1). Scholars have since argued that such carbon majors ought to contribute significant amounts of climate finance towards loss and damage (Schleussner et al., 2023).

However, data limitations and gaps for non-state actors are a significant issue that has been highlighted by scholars (Hsu et al., 2019; UNEP, 2018). There are many datasets with varying levels of completeness, which do not provide comprehensive coverage of non-state actors that is consistent and comparable. While partnerships like the GHG Protocol and the Science Based Target initiative (SBTi) provide guidance to the corporate sector in the form of protocols and target setting manuals, reporting is voluntary and comprehensive coverage and consistency of information remains an issue (SBTi, 2023). At the municipal level, initiatives like C40 Cities and the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) provide guidance for cities to report their emissions (C40 Cities Climate Leadership Group et al., 2014). However, data gaps and inconsistencies are also significant limitations.

Two initiatives which present upcoming information streams that might fill data gaps and support assessments of the type that this thesis is concerned with, but for non-state actors, are the Taskforce on Climate-related Financial Disclosures (TCFD) and Taskforce on Nature-related Financial Disclosures (TNFD). The TCFDs and TNFDs are industry-led initiatives, established in 2015 and 2021 respectively, which encourage the corporate sector to assess and disclose climate- and nature-related risks to business (Mori & Mader, 2021; Redman, 2022). The Taskforces aim to shift the sector towards climate friendly and nature-positive ways of operating and provide greater guidance to investors about climate-related risk (Pierce, 2023). Since 2021, several countries, including New Zealand and the United Kingdom, have passed laws to mandate that companies within the financial services industry and other publicly listed companies carry out climate-related risk reporting, guided by the TCFD framework. Additionally, many firms around the world have adopted the framework and begun voluntarily reporting on such risks of their own accord.

In terms of calculating carbon budgets at the sectoral-level, climate ethics assessments have been carried out for the buildings, cement and electric utilities sectors (Habert et al., 2020; Rekker et al., 2022). However, one of these approaches first calculates national carbon budgets, suggesting that emissions estimates for nation-states are needed before non-state actors' fair shares can be determined (Habert et al., 2020).

An advantage of having used the environmentally extended input-output analysis (EE-IOA) technique to calculate countries' consumption-based emissions for the SEFS dashboard is that it can be used to calculate and assign consumption-based emissions at both the city and corporate level (Hertwich & Wood, 2018; Wiedmann et al., 2021). However, rather than differentiating between production- and consumption-based emissions, non-state actors' emissions are commonly referred to as scope 1 (direct emissions), scope 2 (upstream emissions), scope 3 (indirect emissions, or emissions associated with other inputs) (Stenzel & Waichman, 2023). The use of the EE-IOA technique, which can be readily applied to non-state actor information should it become available, would allow such information to be efficiently included in the SEFS dashboard.

A further type of non-state actor that could be incorporated in the dashboard is individual states or provinces of large federal countries, like the United States. Due to their relative size, economic influence and power, such countries could have their climate mitigation finance and warming rights shares allocated at the state, rather than the nation-state, level. This is because such countries are composed of multiple large states, which are themselves comparable to countries in terms of population size, landmass and economic output. For instance, in recent global economic analyses, the American state of California has commonly been ranked the fifth largest economy in the world, behind the United States, China, Germany and Japan (Vaziri, 2024). Three other American states – Texas, New York and Florida – have also been ranked amongst the top 20 global economies. Accounting for emissions at the state-level for federal countries could offer a complementary and beneficial non-state actor lens within the dashboard, once relevant datasets become available.

One challenge associated with taking nation-states as the unit of analysis is how to deal with border changes which present difficulties in attributing "past emissions to current nation states" (Grubb et al., 1992; Neumayer, 2000, p. 189). While the world as a whole has experienced a period of relative peace and the majority of country borders have endured since the second World War, the Soviet Union's collapse, Eritrea breaking away from Ethiopia in 1993, and South Sudan obtaining independence from the Republic of Sudan in 2011 are several examples of nation-state borders shifting as new countries have formed. However, since the majority of nation-states have maintained relatively consistent identities "as transgenerational entities" over time, difficulties in attributing responsibility for GHG emissions when nation-states' borders have changed is acknowledged yet considered a minor issue for the research, given the relatively few instances of this (L. H. Meyer & Sanklecha, 2017, p. 5).

While nation-states are not the only unit of analysis for apportioning climate change-related fair shares, the historical dominance and participation of these actors within international negotiating fora and the availability of relevant datasets for applying diverse ethical principles provided strong justifications for solely focussing on nation-states.

Despite the existence of studies which calculate sectoral-level carbon budgets, a lack of comprehensive, consistent data remains a limiting factor for offering ethical assessments of non-state actor's climate-related obligations. Additionally, principles which make sense at the nation-state level, like Equality-over-time, may not be as relevant for calculating non-state actors' warming rights, because population figures do not easily translate into a non-state actor context. For this reason, new principles may need to be designed that are better suited to non-state actors. Given the scope and time bounds of the research, bringing non-state actor data into the dashboard was not pursued. Nevertheless, incorporating a non-state actor lens once more information becomes available presents a possible future extension to the SEFS dashboard.

## §5.3 Relevance to other fields and practical usefulness

This section considers the research's relevance to the field of IR and how different theories might engage with the SEFS dashboard. Benefits the dashboard can bring for climate negotiators and policymakers are also discussed, followed by an evaluation of the real-world applicability of the research, in a field that evolves quickly, and where many viable solutions to the issue now exist. Finally, challenges of taking abstract ethical principles from philosophical to applied domains are discussed.

### §5.3.1 International Relations (IR) theories

This thesis has not engaged substantively with theories of IR. However, the dashboard's international focus means that the field of IR – which develops explanatory theories "to broaden and deepen our understanding of contemporary world politics" – might have useful contributions to make to this research (Burchill & Linklater, 1996, p. 13). Prominent IR theories, including different strands of realism, liberal institutionalism and constructivism, may have different ways of interacting with the dashboard and coming to predict the predominance of certain principles.

Realism theory, for instance, views nation-states as the primary actors within the international system. It believes nation-states behave rationally to achieve their goals and must increase their power in a zero-sum way in order to succeed (Burchill & Linklater, 1996; Nicholson, 1998). Realism views the international system as inherently anarchial, with an unequal distribution of power, where relations between states are best explained in terms of power politics (Griffiths et al., 2009).

Realism theory could predict the predominance of a Grandfathering Principle, where powerful early emitters like the United States and the United Kingdom negotiated emissions reduction targets to be in reference to a 1990 baseline under the Kyoto Protocol. This would have preserved the status quo by allowing future emissions to be in proportion to countries' prior levels. Realism theory would also accept climate adaptation-centric definitions of the Beneficiary Pays Principle, mentioned in §2.6.1.2, where the Beneficiary Pays approach is interpreted as the beneficiaries of climate action being expected to invest in those positive benefits.

A realism theory may also expect some limited use of the Polluter Pays Principle, whereby countries punish other countries for environmental harms that have crossed country borders. However, the theory would be sensitive to the challenges of implementation because an imposing of payments for pollution requires the successful exercise of power. This would be easier said than done in the international system of nation-states, where classical realism theory would draw attention to power imbalances trumping any appeals to ethically appropriate distributions of financial costs or warming rights because "the strong do what they can and the weak suffer what they must" (Thucydides, 2003). Finally, neorealism theory might refer to the anarchial structure and self-help system of states to explain that power politics will come to dominate nation-states' response to climate change (Waltz, 1979). As Schelling (1992) concluded: "the *developed* world has no self-interest in expensively curtailing carbon consumption and that the *developing* world cannot afford to incur economic penalties to slow the greenhouse effect" (p. 7).

Rather than assuming a self-help system of states, liberal institutionalism or liberal internationalism theory would take a less pessimistic view of nation-states' interactions with each other and efforts to address climate change. While still largely concerned with nation-states, liberal institutionalism theory also places high importance on institutions and believes in their potential, as legitimate political orders, to encourage successful cooperation amongst countries (Burchill & Linklater, 1996; Suhr, 1997). Liberal institutionalism may point to a near universal signing of the Paris Agreement and the endorsement of its ratchet mechanism as examples of nation-states cooperating to tackle climate change with growing levels of ambition, rather than inter-state interactions being dominated by combative power-struggles. Liberal institutionalism theory would also see benefit in engaging with the SEFS dashboard directly, to explore ethical distributions against which countries' real-world contributions could be compared. Traditional liberalism theory, which liberal institutionalism stems from, is highly optimistic about the potential for the international system to tend towards progress and achieve purposive change (Griffiths et al., 2009). In this sense, liberalist theories would see value in the SEFS dashboard's results as a means of encouraging greater efforts by countries in the real world as they aspire to tackle climate change ever more ambitiously.

A final IR theory – Constructivism – is concerned with understanding why and how certain norms spread and influence nation-state behaviour, to promote new values and socially acceptable practices (Acharya, 2004, p. 239). Constructivism theory focuses on a range of actors within world politics and their social interactions. It has a particular focus on the role that international institutions play, through their regulative and constitutive functions, in shaping nation-states' identities and interests over time (Griffiths et al., 2009). Constructivism theory views interactions between institutions and nation-states as mutually reinforcing and believes that nation-states behave and interact with other agents in ways that reflect their identity and how they choose to construct their national interest. Constructivism theory would highlight the norm-setting functions of the international climate regime, and the role its shifting axis of power have played in influencing China's emergent identity as a green energy leader. Constructivism scholars have found that "shared ideas about appropriate state behaviour had a profound impact on the nature and functioning of world politics" (Hoffmann, 2010, p. 3). Constructivism theory would therefore see engaging with the SEFS dashboard as a way to test norms that influence the development of the national interest.

Consideration will now be given to how the results presented in §4.3.4 – which compared the financial obligations of the United States and China under different parametrisations of the three financial burden-sharing principles – might be used within a diplomatic setting. This discussion will start with applications of the Polluter Pays Principle which American climate negotiators might choose to prioritise.

Assuming a realist IR theory, which expects countries to act in their own self-interest, in pursuit of geopolitical advantage, with motivations to minimise their climate finance obligations, we might expect American climate negotiators to argue for a baseline year of 1990, so that warming and emissions amounts from only the 1990–2014 time-period are included. This would make the United States' relative contribution to causing climate change smaller, owing to the larger warming contributions of latter industrialisers, like China, since 1990.

American negotiators might also argue for climate finance amounts to be allocated to countries under the PBA framework because the United States' CBA emissions are slightly higher than its PBA emissions, as shown in Figure 27 and Figure 28, while the opposite is true for China. Finally, American negotiators might choose to argue for the inclusion of warming contributions from multiple climate forcers, rather than exclusively focussing on $CO_2$. This is because the United States' contribution to climate change becomes smaller when all three climate forcers are included in climate finance obligation calculations. Whereas China's contribution becomes larger, due to its large $CH_4$ and NOx emissions, which have accounted for a greater share of China's overall warming contributions in recent time-periods.

In contrast to their American counterparts, and again under a realist IR theory, Chinese climate negotiators might argue for an earlier baseline year of 1850, to incorporate the warming from early industrialisation. They might claim that other early industrialisers must foot the bill for mitigating this warming, even if portions of it were unknowingly caused. Chinese negotiators are also likely to advocate for GHG emissions being assigned under a CBA framework, given that China's GHG accounts were found to be slightly lower under this framework than the PBA framework. They may also argue for a sole focus on $CO_2$ emissions, since China's climate finance contributions are lower when warming from other climate forcers are not included.

These hypothetical arguments highlight the importance of time horizon over which warming is considered, as well as whether emissions of all three climate forcers or just the main driver of climate change, $CO_2$, ought to be included. Choosing to allocate emissions to countries under a PBA or CBA lens also has important ramifications for the sizes of China's and the United States' relative contributions to causing climate change. These different ways in which the Polluter Pays Principle can be applied are all expected to be points of contention between the two most dominant players in climate negotiations.

However, if all countries were to negotiate and act along the lines of realist IR theory, this would result in all countries shifting responsibility and avoiding the costs of climate action. Moreover, the actual behaviour of nation-states cannot be fully explained by a simple self-interest. For instance, the 2014 bilateral agreement on climate change between the United States and China signalled the willingness of these countries to engage in negotiations more productively. This could mean that incentives may grow for countries to collaborate and work together, which is consistent with liberal institutionalism theory.

Ultimately, different IR theories see world politics and nation-state behaviour in different lights. Yet, realism, liberal institutionalism and constructivism would all find direct ways of engaging with the SEFS dashboard, to further test their theories. The SEFS dashboard presents a moralist perspective, to compare with IR theories, and brings transparency to the approach of considering country-level responsibility. It does this by showing how different combinations of parameters shift responsibility in different ways and bring to light that not everyone can avoid responsibility otherwise no mitigation of climate change will occur. Using the SEFS dashboard to engage and discuss different IR theories could add additional perspectives to a more nuanced deliberation and debate about what country-level ethical distributions of financial costs and warming rights associated with addressing climate change ought to be.

### §5.3.2 Enabling top-down assessments of country-level efforts

Regardless of how different IR theories explain nation-state behaviour and the functioning of world politics, there is benefit in using the SEFS dashboard as a yardstick against which to gauge countries' contributions towards addressing climate change. This is especially important as the architecture of international agreements has shifted away from the top-down structure of the Kyoto Protocol to the more bottom-up configuration of the Paris Agreement (Jacquet & Jamieson, 2016).

Under the Paris Agreement, countries are expected to pledge their own emissions reductions. However, it is difficult to assess what the resulting effect of these different reductions will be at a global level, as others have mentioned (Schulan et al., 2023). Different metrics being used at the global and national levels further complicates the issue. For instance, global climate goals of limiting warming to no more than 1.5°C and 2°C are expressed as temperature increases, whereas countries' Nationally Determined Contributions (NDCs) are often expressed in terms of Megatons or millions of tonnes of carbon dioxide equivalent ($CO_2e$) (UNFCCC, n.d.). This makes it challenging to track countries' progress and efforts towards addressing climate change in order to differentiate climate leaders from climate laggards (Liefferink & Wurzel, 2017; Wurzel et al., 2019).

The SEFS dashboard, while not able to assess the adequacy of specific NDCs in its current state, enables a top-down analysis for determining countries' climate finance obligations and warming rights. In this way, the SEFS dashboard moves a step closer towards being able to assess whether proposed NDCs are in line with countries' fair shares. It does this through allowing users to interrogate their own value judgements and notions of fairness while choosing different principles to apply, as they carry out a technology-assisted form of WRE. This can give dashboard users opportunities to gain insight into the implications of applying many perspectives of fairness in order to crystallise and articulate their own ethical intuitions about nation-state responsibility. This, in turn, could help people make informed and reflective contributions to global discussions about country-level responsibility for addressing climate change, while acknowledging the many views on the issue.

### §5.3.3 Relevance for policymakers

The SEFS dashboard can bring value for policymakers through supporting a better understanding of how nation-states' contributions to climate change have changed over time and what this could mean in terms of possible climate finance shares and warming rights. For instance, further analysis and interpretation of the results can reveal how climate change has been caused by different human activities to varying degrees in the past. This is evident for countries like New Zealand which had high historical per capita emissions due to the large clearing of forest that took place throughout pre- and post-European settlement as shown by the charts in Figure 34 of §4.4.1.1.

By encouraging policymakers to interact with the dashboard and seek to understand the different factors that contribute to countries' warming contributions, for instance, this could encourage policymakers to consider more deeply the type of activities that countries choose to engage in and the bearing these activities may have on nation-states' contributions to furthering climate change in the future.

## §5.3.4 Real-world applicability of the research

Climate change research is a field which is evolving rapidly. Solutions to the issue now take many forms from behavioural change policies, carbon prices, government subsides, public-private partnership-based investment in climate-related research, nature-based solutions, renewable energy development and deployment, as well as geoengineering techniques like solar radiation management (SRM) and carbon dioxide removal (CDR) (Fawzy et al., 2020; Moriarty & Honnery, 2022; Nielsen et al., 2021). Moreover, countries are likely engaging in many of these different solutions, to varying degrees, at the same time.

Now that the research project has been completed, it is apparent that the research forms a starting point from which future research can be built upon to capture the different ways that countries are simultaneously engaging in making climate change worse, mitigating it, and alleviating its effects. A sample of future research questions and possible data sources that offer more sophisticated ways of reflecting countries' climate-related efforts are listed in Table 33 below. Taking all of this information into account would enable a more nuanced approach for determining countries' fair shares for addressing climate change.

| Area | Question | Possible data source | Further information | Link to data, reports |
|---|---|---|---|---|
| Climate finance<br>Mitigation<br>Renewable energy | What are countries' financial investments towards renewable energy research and development? | BloombergNEF (published by Statista) | | https://www.statista.com/statistics/799098/global-clean-energy-investment-by-country/ |
| Climate finance<br>Mitigation<br>Renewable energy | What are countries' financial investments towards renewable energy deployment? | Global Energy Monitor<br>(Global Solar Power Tracker)<br>(Global Wind Power Tracker) | | https://globalenergymonitor.org/projects/global-solar-power-tracker/<br><br>https://globalenergymonitor.org/projects/global-wind-power-tracker/ |
| Mitigation<br>Renewable energy | At what rate are countries' renewable energy capacity and deployment growing? | Global Energy Monitor | | https://globalenergymonitor.org/ |
| Climate finance<br>Fossil fuels | What are countries' financial investments towards maintaining a fossil fuel industry (including subsidies)? | Global Energy Monitor<br>(Global Coal Plant Tracker)<br><br>International Monetary Fund | Global Coal Plant Tracker Summary Tables<br><br>IMF Fossil Fuel Subsidies Data: 2023 Update (report) | https://globalenergymonitor.org/projects/global-coal-plant-tracker/summary-tables/<br><br>https://www.imf.org/en/Publications/WP/Issues/2023/08/22/IMF-Fossil-Fuel-Subsidies-Data-2023-Update-537281 |
| Indirect mitigation | What are countries' contributions towards indirect mitigation? | | | |
| Climate finance<br>Adaptation | What are countries' contributions towards climate finance and climate adaptation finance, in particular? | International Monetary Fund<br><br>Climate Policy Initiative<br><br>Climate Policy Initiative | IMF finance (report)<br><br>Global Landscape of Climate Finance 2023 (report)<br><br>State and trends in climate adaptation finance 2023 (report) | https://www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2023/<br><br>https://www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2023/ |
| Mitigation | What are countries' avoided emissions? | GHG protocol | Estimating and reporting avoided emissions (report) | https://ghgprotocol.org/estimating-and-reporting-avoided-emissions |
| Governance<br>Policy<br>Climate leadership | Which countries are showing the greatest levels of climate policy innovation and entrepreneurship? | World Bank<br><br>UNFCCC Technology Executive Committee (TEC) | Reality Check: Lessons from 25 policies advancing a low-carbon future (report)<br><br>Good practices and lessons learned on the setup and implementation of National Systems of Innovation (report) | https://openknowledge.worldbank.org/entities/publication/3770b59a-617f-4636-8aa1-adbe6db7db34<br><br>https://unfccc.int/news/harnessing-national-systems-of-innovation-for-climate-action |
| Governance<br>Policy<br>Climate leadership | What signs are there of countries' public and private sectors working together to address climate change (moonshot example)? | | | |

*Table 33. Sample of future questions*

Related to the opening point in this section (§5.3.4) about climate change research being a field that moves quickly, political scientist Leah Stokes has argued that 75% of the climate problem can now be solved by clean electricity and electrification (Bioneers, 2023; Stokes, 2020). Using clean electricity and electrification to decarbonise economies is becoming more realistic as countries like New Zealand reach an "electrification tipping point," where the financial case for people to electrify their homes and cars to reduce living costs and cut emissions is strong (Ellison et al., 2024, p. 3).

However, as more countries begin reaching such tipping points, the adequacy of existing financial burden-sharing principles for determining country-level fair shares of climate finance may come under scrutiny. For instance, as the transition towards cleaner forms of energy accelerates, the Beneficiary Pays Principle may place greater financial obligations on large emerging economies like Venezuela, Iran and Mexico. These countries have recently increased their fossil fuel use substantially and in an era when switching towards cleaner forms of energy was less financially viable than it is today. In contrast, many early industrialising countries may be further ahead on their clean energy transition and if benefits from climate causing actions are only considered over recent time-periods, early industrialising countries would face lower burdens than emerging economies. This could result in the Beneficiary Pays Principle becoming ethically contestable when emerging economies bear higher burdens simply because they decarbonised after early industrialisers. For this reason, the Beneficiary Pays Principle may become susceptible to the implausibility critique that the Grandfathering Principle has faced (see §2.6.2.1), which describes how the principle affords a temporal priority without moral justification (Jamieson, 2010).

## §5.3.5 Going from the philosophical to the applied

Climate ethicists and developers of tools, similar in purpose and functionality to the SEFS dashboard, have grappled with a tension that exists between the philosophical and the applied. This can be described as finding a balance between what might be ethically ideal and what might be most realistic or practically useful against a backdrop of power asymmetries. This is articulated by Baer et al. (2010):

> *"Ethicists considering climate change have – appropriately, we believe – framed their questions in terms of what might actually be feasible, not merely what is ideal. Of course, the relationship between the 'ideal' and the 'practical' is a dialectical one. Both will change over time, influenced by each other; individuals at any one time may agree on one and disagree on the other" (p. 217).*

Put another way, tools like the SEFS dashboard face the challenge of being too far removed from reflecting what might be practically possible for countries, in their absolute focus on what nation-states' ethical obligations ought to be. This has the potential to render them less valuable.

The *ought-implies-can* principle, commonly attributed to Immanuel Kant, is of relevance and worth discussing here. Like many ethical principles, ought-implies-can is open to interpretation and philosophers have argued about the meaning that Kant intended by this principle. Philosophers like Robert Stern (2004) have analysed different ways in which the principle has been used to evaluate agents' moral obligations in different contexts. Based on Stern's analysis and understanding of what Kant meant by this principle, it would be excessively demanding for an agent to bear moral duties which are beyond that agent's capacity. This is summarised by the following translation from Kant's *Religion Within the Boundaries of Mere Reason*, shared in Stern (2004): "duty commands nothing but what we can do" (p. 54).

The ought-implies-can principle is of relevance to the SEFS dashboard because of the way the dashboard calculates nation-states' moral obligations for addressing climate change. In its current state, the dashboard does not place any feasibility bounds on the range of possible ethical solutions. This means that financial obligations might be beyond countries' capacities, and quantities of warming rights might be inadequate. The impractical implications of the United States being in warming debt under applications of the Equality-over-time principle, and not having a right to future warming, is an example of this.

An adherence to the ought-implies-can principle would mean limiting what could plausibly be asked of states. However, it would be difficult to discern where such feasibility constraints lie to distinguish between what would and would not be plausible for states. In other words, states *could* stop releasing GHG emissions, however this would likely have disastrous consequences for their populations. The ought-implies-can principle raises questions of what reasonable expectations to place on countries would look like and whether strict readings of the SEFS dashboard's results remain useful if countries could be expected to act beyond their capacities. This is where the Grandfathering Principle may have more practical appeal.

# §5.4 Method-based reflections and technical issues

This section (§5.4) focuses on several method-based and technical aspects of the research. First, §5.4.1 discusses the intergenerational challenge that climate change presents and reflects on the complexities of applying principles in ways which take a futurist dimension into account. In §5.4.2 a more detailed formulation of countries' consumption-based emissions is briefly discussed, as well as the possibilities of adding and combining multiple accounting frameworks to reflect more nuanced perspectives on responsibility. With new datasets becoming available, the prospects of this are encouraging and present possible extensions to the research and SEFS dashboard. Finally, §5.4.3 discusses limitations the SEFS dashboard inherits by using proxy metrics.

### §5.4.1 Incorporating future people in principle applications

While significant distributive issues and injustices exist between countries' efforts to address climate change in the present, these also exist across time, between generations. Some moral and political philosophers have argued that these *inter*-generational injustices have the potential to play more significant roles than *intra*-generational ones. Gardiner (2006) describes the challenge that future generations face as a

> *"temporal fragmentation of agency … in principle, spatially fragmented agents may actually become unified and so able really to act as a single agent; but temporally fragmented agents cannot actually become unified, and so may at best only act as if they were a single agent" (p. 404).*

Climate change's unique features, including the dispersal of its effects over time, make it a new class of collective action problem, what Gardiner (2016) refers to as "the tyranny of the contemporary" (p. 8). This describes how advantages from fossil fuel use – like cheap energy – that past and current generations obtain outweigh incentives to reduce perils that future generations will face from historical fossil fuel use. The result could have a compounding effect, where subsequent generations similarly choose to "live large" and have little interest in curbing the emissions that will adversely affect their descendants (p. 26).

A risk of taking nation-states as the unit of analysis within the SEFS dashboard, without regard for nation-states' future persons, is that attention is not given to climate change's temporal dimension. This has the potential to advantage present persons above future people. Knight (2013) also alludes to these intergenerational issues when articulating how the Grandfathering Principle grants rights to emit without explicitly taking current and future generations into account.

> *"Rights to initial acquisition, which have initial intuitive support because they are equally held by all, lose that support when we consider current and future generations. They are excluded from such rights because there is nothing left in common to acquire. Their entitlements are influenced by what they inherit, for which they can claim no credit" (p. 415).*

One way that a greater balance can be struck between present and future people is by including projected future populations in calculations which apply the principles. The Equality-over-time Principle is the only principle in the SEFS dashboard with an explicitly futurist dimension in the sense that future population figures have been incorporated by basing allocations of warming rights on how countries' populations will shift over time.

In contrast, although applications of the Beneficiary Pays and Ability to Pay Principles with per capita metrics do take countries' relatively recent populations into account, this is only at a single point in time. Adding a futurist dimension to these principles would be difficult because information about countries' anticipated levels of future financial capacity for the Ability to Pay Principle, or the benefit that future humans might derive from the emissions of their predecessors for the Beneficiary Pays Principle, would have to be estimated. It is unclear how this could be done and is anticipated to be a deeply complicated and near impossible task, akin to predicting what countries' future circumstances would be.

For instance, a country's ability to pay in the future will be partially dependent on what natural capital it has at its disposal to turn into goods and trade with other nations. Additionally, climate change's future physical impacts, at a local level, are uncertain and these too could impact countries' built and natural environments, and financial positions. For instance, impacts that the August 2022 Pakistan floods had on the country's infrastructure and financial capacity would have been difficult to predict with certainty in advance (Nanditha et al., 2023). However, such information would be important to include in calculations which reflect nation-states' future capacities to contribute towards addressing climate change under an Ability to Pay Principle.

To summarise, aside from the Equality-over-time Principle, a futurist dimension has not been incorporated into calculations for determining distributions of climate finance and warming rights, under the SEFS dashboard's other four principles: Polluter Pays, Beneficiary Pays, Ability to Pay and Grandfathering. Projected measures of a country's future situation would be necessary for making these principles incorporate a focus on future generations. However, this would be difficult to do.

## §5.4.2 Consumption-based emissions and accounting frameworks

A significant early part of the research involved learning how to calculate consumption-based emissions. The Eora-26 dataset was identified as one which would enable consumption-based emissions to be calculated for 189 countries between 1990–2015, by using the Leontief inverse to carry out EE-IOA. The consumption-based emissions which appear in the SEFS dashboard have been calculated according to the industry-by-industry approach, where the same emissions intensity value is applied to all commodities within that industry. This means that different commodities, with very different emissions intensities – like wool and meat within the agricultural sector – can have the same emission factor applied to them. Using a commodity-by-industry approach, in contrast, would provide more accurate estimates of consumption-based emissions because specific emissions intensity values for different products would be used.

However, calculating consumption-based emissions according to a commodity-by-industry approach was not pursued as part of this research project because of the additional complexity involved in working with the Full Eora dataset, instead of the simpler Eora-26 one. Moreover, the original industry-by-industry approach was deemed sufficient for satisfying the research aims. However, a commodity-by-industry approach for calculating countries' consumption-based emissions could be incorporated into future iterations of the tool by applying the approach to the Full Eora dataset.

While investigating how to calculate consumption-based emissions, a range of other accounting frameworks and models were encountered, including the income- or extraction-based accounting and value-added frameworks (Lazarus & Erickson, 2013; Tukker, Pollitt, et al., 2020). Countries' income-based emissions can be calculated using the Ghosh model, or supply-side input-output model, set out in Miller and Blair (2009). The Ghosh model, like the Leontief model (defined in §3.6.2), presents a means of carrying out EE-IOA. A key difference between the two is that the Leontief model assumes fixed *input* coefficients and is described as a demand-side model, whereas "fixed *output* coefficients are assumed in the supply-side [or Ghosh] model" (Miller & Blair, 2009, p. 544).

The Ghosh model's assumption "that output distributions are stable in an economic system", resulted in physical interpretations of the model drawing criticism in the early 1980s because of its theoretical flaws (Guerra & Sancho, 2011; Miller & Blair, 2009, p. 544; Oosterhaven, 1988, 1989). Criticisms focused on how transmission of primary input increases in one sector result in output increases in all sectors that buy from that single sector, without there also being increases in primary inputs in those sectors. This makes the model implausible. A reinterpretation of the Ghosh model as a price model by Dietzenbacher (1997) to focus on prices, rather than physical quantities, resolved these issues.

In summary, the Leontief and Ghosh models both represent flows of goods and services throughout an economy but differ in their supply- or demand-side focus. Theoretical assumptions underlying the Ghosh model have been challenged, however its reinterpretation from a supply-driven model – which focussed on physical quantities – to a price model, helped overcome these issues. Implementing the Ghosh model to calculate countries' income-based or extraction-based emissions was identified as a piece of potential future work early in the research and not pursued further, in part because of an awareness that the Ghosh model had suffered criticism. However, recent studies have used the method and restored confidence in this approach (Cheng et al., 2023; Liang et al., 2017). Using the Ghosh model to carry out EE-IOA on the Eora-26 dataset presents one way of calculating countries' income- or extraction-based emissions.

Alternatively, new extraction-based emissions datasets emerged in early 2024. These have been developed and put online by Robbie Andrew from Oslo's Center for International Climate and Environmental Research (CICERO). The data is available for download here: https://robbieandrew.github.io/GCB2023/extraction.html. The dataset currently includes information for 123 countries and the total world. Future releases will improve on these initial estimates. While this data has not yet been included in the dashboard, an obvious next step would be to include it to broaden how responsibility for emissions can be allocated to countries. The extraction-based accounting perspective could also present a warming-dependent way of applying the Beneficiary Pays Principle (as discussed in §3.7.4). Since, it could be argued, that fossil fuel-rich countries benefit financially from extracting fossil fuels and putting these into supply chains.

Finally, in §2.5.3, the Economic Benefit Shared Responsibility (EBSR) scheme – a hybrid approach which combines the production-based and consumption-based accounting (CBA) frameworks – was discussed. The rationale for this scheme was that it took a more nuanced view of responsibility, by acknowledging that benefits accrue to both producers and consumers throughout value chains. Combining multiple accounting frameworks allows limitations of using single frameworks to be overcome. While there is currently no option within the SEFS dashboard to merge multiple accounting frameworks, the ability to display countries' GHG emissions information under different combinations of two accounting frameworks and ethical principles already presents a novel contribution to the climate ethics literature. However, including a feature to weight countries' emissions under multiple accounting frameworks would offer even more nuanced perspectives on nation-state responsibility for addressing climate change and would be another novel contribution and direction for future research.

## §5.4.3 Data issues and the prevalence of proxy metrics

Chapter 3 described the various datasets used in this research, including the limitations, and issues they suffer from. This section will continue this discussion, with a particular focus on the use of *proxy* metrics for applying the Ability to Pay and Beneficiary Pays Principles.

The prevalence of proxy metrics in similar climate ethics assessments is indicative of a current lack of appropriate data for applying ethical distributional principles and reflects a challenge that comes with applying ethical principles to the complex use-case of climate. It also means that this research project's investigation of countries' fair shares has been limited by the most appropriate data that was found to be available, as mentioned in §2.6.1.5.

While proxy metrics will not provide the most accurate approximations of the principles, they are what is currently available for use. However, a disadvantage of relying on proxy metrics for principle applications is that they risk distorting how countries' contributions to climate change, and the level of obligation they bear for addressing it, are perceived. For instance, the Total Wealth metric for applying the Beneficiary Pays Principle may become an even poorer proxy for the benefits derived from historical GHG emissions as climate change progresses. This is because, as countries decarbonise their energy sectors, they will increasingly be able to grow greater amounts of wealth and meet their energy-related needs in ways that do not also see them obtaining benefit from climate causing actions.

This raises further questions about whether the principles themselves are adequate, whether new principles are needed which could make better use of data that has been collected to date, and whether new datasets need to be created which better reflect each principle. The consideration of ethical principles' ease of application in §2.6 also raised the question of whether there may be a bias towards those principles which are most straightforward to apply, which could risk distorting climate ethics assessments by unnecessarily reducing the scope of principles that are included.

The exercise of developing the SEFS dashboard has helped identify current data gaps and could prompt social scientists to collect more adequate data in the future, which better capture the essence of the principles and limit the potential for moral assessments to be restricted to only those principles which are most readily applicable today. When such data becomes available, the infrastructure of the dashboard is already in place to incorporate the data and further support country-level comparisons and analysis.

The proxy metric issue has prompted further thinking about what new information social scientists could gather to create new datasets. Examples of helpful information could include financial amounts that countries have invested in climate mitigation measures like renewable technologies, and measures which more specifically capture the benefits that countries have derived from historical fossil fuel extraction and use within their borders. This information could improve the SEFS dashboard by allowing principle applications to align more closely with the essence of the principles by better reflecting country-level contributions – both positive and negative – towards the global climate mitigation effort.

# §5.5 Chapter summary

Chapter 5 has critically evaluated aspects of the research. Reflections can broadly be grouped into three categories: those that focus on the research scope and design, and how it has been carried out (§5.2); those which consider the SEFS dashboard's relevance to other academic disciplines and level of usefulness to its target audiences (§5.3); and those which are more method-based and technical (§5.4). Many of the method-based reflections reveal directions for further study and ways to expand the SEFS dashboard in the future which are elaborated on in §6.6.

However, the SEFS dashboard's reliance on proxy metrics remains a significant limitation, which highlights the challenge of applying ethical principles to answer questions of distributive climate justice. The proxy metrics issue has raised further questions, including whether different data should be collected to enable more appropriate operationalisations of the principles?; or whether the principles themselves should be disregarded and new ones, based on currently available data, be used instead? The possibility of climate ethics assessments being biased towards those principles which are most straightforward to apply is a further consideration, which new datasets could also help address.

Putting the proxy metrics issue aside, the SEFS dashboard provides its users with greater clarity about how nation-states have contributed to climate change at various points in time. It can also encourage (often) implicit value judgements, underlying notions of equity and responsibility, to be seen as users consider varied perspectives – including those of IR theories – about how climate change could be addressed by countries. The process of developing the SEFS dashboard has also illuminated complexities that come with carrying out multidisciplinary research and taking abstract ethical principles from the philosophical to the applied. Inadequacies of currently available datasets have revealed a need for social scientists to gather new information and climate ethicists to revise or develop alternative ethical principles that can help inform burden-sharing discussions, as climate change and ways of tackling it continue to evolve.

# Chapter 6 Conclusion

> *"Interpretations of fairness concepts are likely to diverge . . . Attempts to find a single authoritative and consensual formula are therefore unlikely to be of broad interest. What is much more likely to be of interest are comprehensive assessments of contributions to climate change: What is for example Canada's contribution to climate change, viewed from a plurality of perspectives? ... Do they depend critically on certain key choices, or do they more or less hold under a range of different interpretations?"*
>
> *(Skeie et al., 2017, p. 2)*

## §6.1 Research topic and its importance

This thesis began by outlining the importance of equity and responsibility as concepts within the international climate regime and climate ethics literature. A timeline of international diplomacy efforts in Chapter 2 revealed how understandings of these concepts amongst the international climate policymaking community have varied and different interpretations of the Common But Differentiated Responsibilities and Respective Capabilities (CBDR-RC) principle have been sources of contention between countries, leading to a developed/developing country divide. This exposed a need to make the principle more practically useful for international climate negotiators and policymakers by applying lower-level regulative principles with factual information.

To meet this need, this research has calculated countries' fair shares for addressing climate change according to applications of five lower-level regulative principles. A tangible output of the research is the Science and Ethics of Fair Shares (SEFS) dashboard. This is a bespoke tool, built to facilitate the research inquiry and inform deliberation and debate amongst the tool's target audiences who discuss equitable effort-sharing approaches at the international level: climate negotiators and policymakers.

The SEFS dashboard has offered a means of bringing five ethical principles to life, so that these communities can explore the implications for countries once the principles are quantified with real-world, country-level information. Through its novel combination of datasets, the SEFS dashboard enables swift analysis across specific variables, including countries' historical warming information, accounting frameworks and ethical principles to determine countries' fair shares of climate finance goals and remaining warming rights.

Research which provides greater clarity on what country-level mitigation efforts ought to be from an ethical standpoint and moves towards enabling global goals to become translatable to the country-level will be beneficial for supporting the international climate policy community in their burden-sharing discussions. This thesis has built the case for developing dashboard-style tools to shed light on country-level equity and responsibility in relation to questions of distributive climate justice.

## §6.2 Research gaps and aims

While several independent dashboard-style tools and climate ethics assessments do exist, these were found to have a less granular focus and did not offer opportunities to consider a wide breadth of scientific and ethical parameters, as well as lower-level regulative principles that could help make interpretations of the CBDR-RC principle more specific. Similar tools were also found to combine ethical principles in a form of hybrid equitable assessment, symptomatic of adhering to the moral objectivism of a positivist worldview. Additionally, several tools demonstrated instances of conceptual confusion when conflating related, yet distinct, ethical domains by confusing distributions of financial costs and rights to emit greenhouse gases (GHGs). These different tools were discussed in §2.6.5, and Table 6 compared them with each other, and the SEFS dashboard, to highlight the particular gaps that the SEFS dashboard fills.

This thesis has sought to address such gaps by providing country-level assessments on a per gas basis and offering a wider range of variables across climate science and ethics domains. The research aims have been investigated by way of three research questions (RQs), with answers to RQ1 providing assessments of countries' historical warming contributions and supplying starting points for answers to RQ2 and RQ3, which focused on allocations of financial costs and warming rights. Presentation of the results in Chapter 4 is clear about the ethical principles that underpin each analysis and how the overarching worldview of positivism with pragmatist characteristics has moderated the positivist belief in there being a single form of objective truth to each RQ.

## §6.3 Main results and contributions

Through this research's combination of diverse datasets and a spectrum of ethical principles, the SEFS dashboard enables a technology-assisted Wide Reflective Equilibrium (WRE) to prompt greater consideration of nation-states' responsibilities for addressing climate change. This fills a gap, identified by Helms (2024), of there being relatively few explicit applications of WRE, despite it being considered a fundamental means of ethical justification.

The dashboard's ability to filter country-level contributions on a per gas basis also offers a more finely grained analysis than that provided by similar tools presented in Table 6. Many of these tools convert multiple GHGs into the carbon dioxide equivalent ($CO_2e$) metric, which has been problematic for reasons previously outlined in §2.4.1. The ability to focus on individual climate forcers revealed the importance of considering short-lived and long-lived climate forcers separately. Methane ($CH_4$)-centric applications of the Grandfathering Principle raised the possibility of certain countries inheriting cooling obligations if, over the time-period of interest, their $CH_4$ emissions had reduced.

Additionally, the discussion of warming rights is a novel concept which has not yet been seen in the climate ethics literature, where an advantage of applying principles with warming-related information is that results can be expressed in the same temperature terms as the Paris Agreement's Article 2 targets.

The novel Equality-over-time Principle has been designed to explicitly capture climate change's intergenerational dimensions by distributing carbon dioxide ($CO_2$) emissions across past and projected future populations. This has heeded calls from applied ethics practitioners to make the Equal Per Capita Emissions Principle more sophisticated.

Finally, the climate justice typology presented in §2.7 is a novel means of differentiating between the two related ethical domains captured by RQ2 and RQ3. As well as providing answers to the RQs, the research prompted further philosophical questions along the way. These have theoretical implications and are discussed further in §6.4.

## §6.4 Practical and theoretical implications of research findings

The research findings have practical and theoretical implications for a wide range of stakeholders, including international climate negotiators, policymakers and researchers which will now be discussed.

By providing a broad spectrum of ethical principles to represent a range of moral perspectives, the SEFS dashboard enables its users to carry out their own experiments or intuition tests in a form of technology-assisted WRE. This can help climate negotiators and policymakers better comprehend what aligning with a certain ethical principle can mean when data is applied in practice and allow them to refine their ethical intuitions by compelling them to think through the implications of concrete principle applications. In this way, the WRE enabled by the dashboard can support a more formalised cognitive process for establishing good judgements to better feed into discussions and debates.

The SEFS dashboard's ability to filter country-level contributions under different accounting frameworks and on a per gas basis offers a more finely grained analysis of nation-state-level responsibility for climate change than similar tools with a regional focus. This is particularly beneficial for the target audiences of international climate negotiators and policymakers, who are concerned with the contributions of nation-states.

The SEFS dashboard's explicit focus on countries' contributions to historical global warming is an example of using climate science knowledge to enlighten answers to ethical questions and practical policy-related decisions. Using the dashboard to demonstrate countries' warming on a per gas basis has revealed the benefit of considering short-lived and long-lived climate forcers separately. Applications of the Grandfathering Principle and considerations of country-level warming from individual climate forcers over different time-periods allowed the dashboard to highlight the temporary nature of the warming generated by short-lived GHGs, like $CH_4$, and how this can be reversed on relatively short timescales. This raised further questions of real-world policy relevance, such as whether a Grandfathering Principle applied over time-periods when countries' $CH_4$-associated warming has fallen might result in those countries obtaining cooling obligations, rather than warming rights. This information could feed into policy decisions about where financial investments in mitigation efforts might best be directed to acknowledge variations in the levels of warming permanence generated by different GHGs.

Basing applications of the Equality-over-time and Grandfathering Principles upon countries' historical *warming* contributions, rather than *emissions*, is a novel contribution to the climate ethics literature, where ethical distributions of warming rights have not yet been explicitly discussed. An advantage of focussing on warming rights is that this puts countries' contributions to climate change into the same metrics as the Paris Agreement Article 2 temperature targets, making it possible to analyse what fair distributions of country-level effort might be in terms of these global goals.

The development of a new version of the Equal Per Capita Emissions Principle – Equality-over-time – presents a more sophisticated means of distributing emissions rights than approaches found in the literature and takes scientific knowledge of GHG properties into account. This principle's design, which includes warming from $CO_2$ emissions only, acknowledges $CO_2$'s persistence in the atmosphere by distributing the gas's cumulative warming effect across past and future people. In this way, climate science knowledge about how different GHGs warm the Earth in different ways has been used to inform the principle's design and application. Distribution of warming rights across historical and projected populations also reflects a type of intergenerational fairness, a feature which other ethical principles do not explicitly incorporate, as discussed in §5.4.1.

A conflation of ethical domains, which had been observed in similar climate ethics assessments, motivated the development of a climate justice typology to support the research inquiry by clearly separating the two related, yet distinct, ethical areas that RQ2 and RQ3 are concerned with. The typology's clear distinction of costs- and rights-related questions could help other applied ethics practitioners avoid the conceptual confusion present in similar practical ethical assessments.

Finally, the research's pragmatist-positivist approach allowed for the exploration of additional paradigms, like interpretivism, where a purely positivist perspective would have been ill-equipped to acknowledge and engage with the multiple meanings of different principles and accounting frameworks. The pragmatist characteristics of the approach also prevented an adherence to the kind of moral objectivism that a purely positivist approach would take towards the ethics component of the research. In this way, the research's pragmatist characteristics supported an ethical pluralism and the acknowledgement that a range of ethical perspectives exist. This combining of paradigms, so that the research is predominantly positivist in nature, with pragmatist characteristics, could provide a helpful approach for other researchers to follow when carrying out interdisciplinary climate-related work, which seeks to traverse climate science and ethics topics.

## §6.5 Limitations of the study

It is worth reiterating that the SEFS dashboard is experimental in nature and should be viewed as a proof-of-concept for how climate-related information could be presented, and how answers to questions of distributive justice at the level of nation-states, can be studied. Nevertheless, the dashboard's use of multiple datasets has resulted in it acquiring limitations associated with these, with implications for how results are viewed by target audiences.

First, the Community Emissions Data System (CEDS) and Houghton and Nassikas (2017) datasets used to answer all three RQs do not include emissions and land use change estimates beyond 2014. This means the ~0.26°C of human-induced warming which has occurred since 2014 has not been captured in the dashboard's results, assuming recent estimates of a 0.26°C per decade rate of warming for the 2014–2023 period (Forster et al., 2024). Additionally, the Eora-26 dataset does not include countries' consumption-based emissions before 1990. These are significant limitations because the inclusion of post-2014 and pre-1990 emissions could result in very different pictures of country-level responsibility. Future iterations of the tool could incorporate more recent emissions and land use change estimates by stitching together datasets to cover these time-period gaps.

A second limitation is the research's focus on warming from GHG species and one short-lived climate forcer (SLCF) only. As explained in §2.2, a range of other radiatively active species, including prominent aerosols and aerosol precursors, can have significant climatic effects. Sulphur dioxide ($SO_2$) emissions – from countries' power sectors and which produce sulphate ($SO_4$) aerosols – have detrimental effects on local air quality, as well as a significant short-term cooling effect on the global climate, known as "masking" (Y. Zheng et al., 2020, p. 220). For this reason, several studies have included sulphate aerosol emissions in calculations of national or regional contributions to global climate forcing and temperature change (Andronova & Schlesinger, 2004; Matthews et al., 2014; Ward & Mahowald, 2014). While developed countries' $SO_2$ and sulphate aerosol emissions began to fall from the 1970s due to these countries' power sectors introducing clean air standards, many developing countries' aerosol emissions are yet to fall (Wang et al., 2015; Y. Zheng et al., 2020). This means that, were aerosol emissions to be included in calculations for applying warming- and emissions-dependent principles, China's obligations would likely be significantly lower. However, it is not clear that the relatively short-term cooling from aerosol emissions ought to cancel out or decrease countries' obligations for addressing the long-lived warming from their $CO_2$ emissions. In other words, countries' aerosol emissions could be included in future iterations of the tool, but it is not obvious that such offsets in warming ought to alleviate countries from bearing responsibilities that are associated with their $CO_2$-related warming, which will persist over longer time periods than the masked cooling of their aerosol emissions.

A third limitation is the research's reliance on proxy metrics to operationalise the Ability to Pay and Beneficiary Pays Principles. This has the potential to diminish the perceived usefulness of the SEFS dashboard for international negotiators and policymakers, as discussed in §5.4.3. Future work could focus on considering how these principles might be operationalised in ways that are more reflective of each principle's meaning from the theoretical climate ethics literature as discussed towards the end of the next section (§6.6).

# §6.6 Recommendations for future research

This section (§6.6) presents possible directions for extending the research which were identified during the research process and alluded to in earlier chapters of this thesis.

While RQ2 has focussed solely on finding fair allocations of financial resources for climate mitigation, the three financial burden-sharing principles could also be applied to the two other types of climate action mentioned in §1.3 and §2.6.1: climate adaptation and loss and damage. Fair allocations of finance for measures which adapt to the effects of climate change and compensate victims of climate-related harms will be of ongoing significance to the international climate policymaking community, given the specific focus on climate finance at the 29th Conference of the Parties (COP29) and the establishment of a Loss and Damage Fund as part of COP28. The focus of RQ2 could also be shifted in another way; rather than identifying countries' climate finance burdens, RQ2 could consider how financial resources ought to be distributed to receiving countries.

Given that climate ethicists have advocated for merging of ethical principles to create hybrid views, future iterations of the SEFS dashboard could weight and combine ethical principles as mentioned in §2.6.3. This would give users the opportunity to combine multiple principles like the Responsibility Capability Index of the Climate Equity Reference Calculator or apply percentage weightings to the Responsibility, Capacity and Need Principles in Fair Mitigation Finance Explorer (discussed in §2.6.5). In a similar way, the dashboard could also include options to combine multiple accounting frameworks in the vein of the Economic Benefit Shared Responsibility scheme, discussed in §2.5.3. However, this work would not be without the technical and philosophical challenges that come with combining factors in a dashboard. For instance, there are many different ways that principles and accounting frameworks could be weighted, all of which would introduce further value judgements.

In §2.4, two different methods for calculating countries' historical contributions to global warming were identified. The first method utilises an emissions metric and a climate metric in a bottom-up-fashion, while the second method uses a simple climate model (SCM) in a top-down way to run modified *leave-one-country-out* experiments. Only results from the second method were presented and discussed in §4.2.1 of this thesis. A future piece of research could include the first method within the SEFS dashboard so that both approaches could be compared with one another.

Including the first method for calculating countries' historical contributions to global warming would also support an obvious extension to the research: to include functionality which enables comparisons between ethical allocations of countries' warming rights with the Nationally Determined Contributions (NDCs) that countries have pledged. Two ethical assessments, presented and discussed in §2.6.5, have been developed to evaluate the ambition of country-level efforts, expressed by their NDCs. However, both assessments have been criticised for their untransparent methodologies. Therefore, including features to compare countries' real-world NDCs with warming rights allocations under different ethical principles in more transparent ways could fill this gap.

Finally, to address the current limitation of relying on proxy metrics for applying the Ability to Pay and Beneficiary Pays Principles, discussed in §5.4.3 and §6.5, a future piece of work could involve devising novel metrics and collecting new information to better reflect the essence of these principles. The Beneficiary Pays Principle could also be applied in warming-centric ways by using the extraction-based accounting framework, as discussed in §5.4.2. This work would also reduce the risk of principle applications becoming a source of moral bias, where ethical assessments favour the use of those principles that are easily applied. The emergence of new datasets, and use of accounting frameworks for applying ethical principles would support more comprehensive climate ethics assessments and mitigate against the potential for assessments' scopes being unnecessarily reduced.

## §6.7 Final remarks

As a contribution to applied ethics, this study has demonstrated the value in carrying out interdisciplinary research to generate new insights into nation-state level responsibility for climate change, as the world seeks to address this wicked challenge. By utilising SCM outputs, EE-IOA and operationalising ethical principles in ways which reflect properties of GHGs and explicitly capture intergenerational dimensions, the SEFS dashboard and its results provide a range of perspectives on equitable effort-sharing that will be of interest to groups that extend beyond the academic audience of this thesis.

While communities of climate ethicists and moral and political philosophers have advanced their thinking on many ethical issues that climate change raises since the early 1990s, there remain few independent assessments which explicitly apply the three financial burden-sharing principles and the Grandfathering Principle on its own. The process of answering the three RQs has revealed challenges that accompany the practical application of such ethical principles, including datasets with different country and time-period coverage, variable information adequacy and a lack of suitable metrics for applying the Ability to Pay and Beneficiary Pays Principles. Principles facing greater challenges in terms of their ease of application raised the possibility of whether there may be a moral bias towards those principles like the Polluter Pays and Grandfathering, which are more readily applied with data that is already available. This could unnecessarily restrict climate ethics assessments.

By acknowledging these challenges and illuminating separations between how ethical principles are understood and debated in the abstract versus how they can be applied in practice, this research strengthens the case for more deeply considering how these principles should be applied. It has been argued that consideration ought to be given as to whether new data needs to be gathered to better represent the principles, or whether the principles themselves are inadequate and need revising in the face of data constraints.

Consequently, this project calls for greater collaboration between communities of climate scientists, economists, ethicists, and social scientists in the future. Closer engagement between communities of ethicists and the producers of physical and social science will help build better understandings of the principles so that necessary data to support their operationalisation can be generated. This will strengthen the climate ethics literature as a whole by enabling theory to better inform practice, and vice versa. In turn, this will benefit international climate negotiators and policymakers in the real world, who will continue discussing equitable effort-sharing approaches for addressing climate change as the issue progresses.

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# Appendices

## Appendix A: R code for transforming data into a column-wise format

```
# Getting total wealth data into column-wise format

# Setting working directory
setwd("C:/Users/...")

# Clearing variables
rm(list=ls())

library(tidyverse)
library(tidyr)

wide_data <- read.csv("wealth_indicators.csv", header=TRUE)

new_tidy_data <- pivot_longer(wide_data, `X`:`X.23`, names_to =
"Year", values_to = "Value")
```

# Appendix B: Dictionary of ISO codes and country names

| # | Country | Code | # | Country | Code | # | Country | Code | # | Country | Code |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Aruba | ABW | 31 | Bolivia | BOL | 61 | Comoros | COM | 91 | Micronesia, Fed. Sts. | FSM |
| 2 | Afghanistan | AFG | 32 | Bolivia (Plurinational State of) | BOL | 62 | Cabo Verde | CPV | 92 | Gabon | GAB |
| 3 | Angola | AGO | 33 | Brazil | BRA | 63 | Cape Verde | CPV | 93 | UK | GBR |
| 4 | Albania | ALB | 34 | Barbados | BRB | 64 | Costa Rica | CRI | 94 | United Kingdom | GBR |
| 5 | Andorra | AND | 35 | Brunei | BRN | 65 | Cuba | CUB | 95 | United Kingdom of Great Britain and Northern Ireland | GBR |
| 6 | Netherlands Antilles | ANT | 36 | Brunei Darussalam | BRN | 66 | Curacao | CUW | 96 | United Kingdom of Great Britain and Northern Ireland (the) | GBR |
| 7 | UAE | ARE | 37 | Bhutan | BTN | 67 | Cayman Islands | CYM | 97 | Georgia | GEO |
| 8 | United Arab Emirates | ARE | 38 | Botswana | BWA | 68 | Cyprus | CYP | 98 | Guernsey | GGY |
| 9 | United Arab Emirates (the) | ARE | 39 | Central African Republic | CAF | 69 | Czech Republic | CZE | 99 | Ghana | GHA |
| 10 | Argentina | ARG | 40 | Central African Republic (the) | CAF | 70 | Czechia | CZE | 100 | Gibraltar | GIB |
| 11 | Armenia | ARM | 41 | Canada | CAN | 71 | Germany | DEU | 101 | Guinea | GIN |
| 12 | American Samoa | ASM | 42 | Channel Islands | CHA | 72 | Djibouti | DJI | 102 | Gambia | GMB |
| 13 | Antigua | ATG | 43 | Switzerland | CHE | 73 | Dominica | DMA | 103 | Gambia (the) | GMB |
| 14 | Antigua and Barbuda | ATG | 44 | Chile | CHL | 74 | Denmark | DNK | 104 | Gambia, The | GMB |
| 15 | Australia | AUS | 45 | China | CHN | 75 | Dominican Republic | DOM | 105 | The Gambia | GMB |
| 16 | Austria | AUT | 46 | Ci¿½te d'Ivoire | CIV | 76 | Dominican Republic (the) | DOM | 106 | Guinea-Bissau | GNB |
| 17 | Azerbaijan | AZE | 47 | Cote dIvoire | CIV | 77 | Algeria | DZA | 107 | Equatorial Guinea | GNQ |
| 18 | Burundi | BDI | 48 | Cote d'Ivoire | CIV | 78 | Ecuador | ECU | 108 | Greece | GRC |
| 19 | Belgium | BEL | 49 | Côte d'Ivoire | CIV | 79 | Egypt | EGY | 109 | Grenada | GRD |
| 20 | Benin | BEN | 50 | Cameroon | CMR | 80 | Egypt, Arab Rep. | EGY | 110 | Greenland | GRL |
| 21 | Burkina Faso | BFA | 51 | Congo (Democratic Republic of the) | COD | 81 | Eritrea | ERI | 111 | Guatemala | GTM |
| 22 | Bangladesh | BGD | 52 | Congo (the Democratic Republic of the) | COD | 82 | Western Sahara | ESH | 112 | French Guiana | GUF |
| 23 | Bulgaria | BGR | 53 | Congo, Dem. Rep. | COD | 83 | Spain | ESP | 113 | Guam | GUM |
| 24 | Bahrain | BHR | 54 | Dem. Rep. Congo | COD | 84 | Estonia | EST | 114 | Guyana | GUY |
| 25 | Bahamas | BHS | 55 | Democratic Republic of Congo | COD | 85 | Ethiopia | ETH | 115 | Hong Kong | HKG |
| 26 | Bahamas, The | BHS | 56 | DR Congo | COD | 86 | Finland | FIN | 116 | Hong Kong SAR, China | HKG |
| 27 | Bosnia and Herzegovina | BIH | 57 | Congo | COG | 87 | Fiji | FJI | 117 | Hong Kong, China (SAR) | HKG |
| 28 | Belarus | BLR | 58 | Congo (the) | COG | 88 | France | FRA | 118 | Honduras | HND |
| 29 | Belize | BLZ | 59 | Congo, Rep. | COG | 89 | Faroe Islands | FRO | 119 | Croatia | HRV |
| 30 | Bermuda | BMU | 60 | Colombia | COL | 90 | Micronesia (Federated States of) | FSM | 120 | Haiti | HTI |

| # | Country | Code | # | Country | Code | # | Country | Code | # | Country | Code |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 121 | Hungary | HUN | 151 | Lao PDR | LAO | 181 | Republic of North Macedonia | MKD | 211 | Philippines (the) | PHL |
| 122 | Indonesia | IDN | 152 | Lao People's Democratic Republic | LAO | 182 | TFYR Macedonia | MKD | 212 | Palau | PLW |
| 123 | Isle of Man | IMN | 153 | Lao People's Democratic Republic (the) | LAO | 183 | Mali | MLI | 213 | Papa New Guinea | PNG |
| 124 | India | IND | 154 | Laos | LAO | 184 | Malta | MLT | 214 | Papua New Guinea | PNG |
| 125 | Ireland | IRL | 155 | Lebanon | LBN | 185 | Myanmar | MMR | 215 | Poland | POL |
| 126 | Iran | IRN | 156 | Liberia | LBR | 186 | Montenegro | MNE | 216 | Puerto Rico | PRI |
| 127 | Iran (Islamic Republic of) | IRN | 157 | Libya | LBY | 187 | Mongolia | MNG | 217 | Korea (the Democratic People's Republic of) | PRK |
| 128 | Iran, Islamic Rep. | IRN | 158 | Saint Lucia | LCA | 188 | Northern Mariana Islands | MNP | 218 | Korea, Dem. People's Rep. | PRK |
| 129 | Iraq | IRQ | 159 | St. Lucia | LCA | 189 | Mozambique | MOZ | 219 | North Korea | PRK |
| 130 | Iceland | ISL | 160 | Liechtenstein | LIE | 190 | Mauritania | MRT | 220 | Portugal | PRT |
| 131 | Israel | ISR | 161 | Sri Lanka | LKA | 191 | Mauritius | MUS | 221 | Paraguay | PRY |
| 132 | Italy | ITA | 162 | Lesotho | LSO | 192 | Malawi | MWI | 222 | Gaza Strip | PSE |
| 133 | Jamaica | JAM | 163 | Lithuania | LTU | 193 | Malaysia | MYS | 223 | Palestine | PSE |
| 134 | Jersey | JEY | 164 | Luxembourg | LUX | 194 | Namibia | NAM | 224 | Palestine, State of | PSE |
| 135 | Jordan | JOR | 165 | Latvia | LVA | 195 | New Caledonia | NCL | 225 | West Bank and Gaza | PSE |
| 136 | Japan | JPN | 166 | Macao | MAC | 196 | Niger | NER | 226 | French Polynesia | PYF |
| 137 | Kazakhstan | KAZ | 167 | Macao SAR | MAC | 197 | Niger (the) | NER | 227 | Qatar | QAT |
| 138 | Kenya | KEN | 168 | Macao SAR, China | MAC | 198 | Nigeria | NGA | 228 | Romania | ROU |
| 139 | Kyrgyz Republic | KGZ | 169 | St. Martin (French part) | MAF | 199 | Nicaragua | NIC | 229 | Rest of World | ROW |
| 140 | Kyrgyzstan | KGZ | 170 | Morocco | MAR | 200 | Netherlands | NLD | 230 | Russia | RUS |
| 141 | Cambodia | KHM | 171 | Monaco | MCO | 201 | Netherlands (the) | NLD | 231 | Russian Federation | RUS |
| 142 | Kiribati | KIR | 172 | Moldova | MDA | 202 | Norway | NOR | 232 | Russian Federation (the) | RUS |
| 143 | Saint Kitts and Nevis | KNA | 173 | Moldova (Republic of) | MDA | 203 | Nepal | NPL | 233 | Rwanda | RWA |
| 144 | St. Kitts and Nevis | KNA | 174 | Moldova (the Republic of) | MDA | 204 | Nauru | NRU | 234 | Saudi Arabia | SAU |
| 145 | Korea | KOR | 175 | Madagascar | MDG | 205 | New Zealand | NZL | 235 | Sudan | SDN |
| 146 | Korea (Republic of) | KOR | 176 | Maldives | MDV | 206 | Oman | OMN | 236 | South Sudan | SDS |
| 147 | Korea (the Republic of) | KOR | 177 | Mexico | MEX | 207 | Pakistan | PAK | 237 | Senegal | SEN |
| 148 | Korea, Rep. | KOR | 178 | Marshall Islands | MHL | 208 | Panama | PAN | 238 | Singapore | SGP |
| 149 | South Korea | KOR | 179 | Macedonia, FYR | MKD | 209 | Peru | PER | 239 | Svalbard and Jan Mayen | SJM |
| 150 | Kuwait | KWT | 180 | North Macedonia | MKD | 210 | Philippines | PHL | 240 | Solomon Islands | SLB |

| # | Country | Code | # | Country | Code | # | Country | Code |
|---|---|---|---|---|---|---|---|---|
| 241 | Sierra Leone | SLE | 271 | Tï¿½rkiye | TUR | 301 | Vanuatu | VUT |
| 242 | El Salvador | SLV | 272 | Turkey | TUR | 302 | Samoa | WSM |
| 243 | San Marino | SMR | 273 | Turkiye | TUR | 303 | Kosovo | XXK |
| 244 | Somalia | SOM | 274 | Türkiye | TUR | 304 | Yemen | YEM |
| 245 | Serbia | SRB | 275 | Tuvalu | TUV | 305 | Yemen, Rep. | YEM |
| 246 | South Sudan | SSD | 276 | Taiwan | TWN | 306 | South Africa | ZAF |
| 247 | Sao Tome and Principe | STP | 277 | Taiwan, China | TWN | 307 | Zambia | ZMB |
| 248 | Sudan | SUD | 278 | Taiwan_Province of China | TWN | 308 | Zimbabwe | ZWE |
| 249 | Suriname | SUR | 279 | Tanzania | TZA | | | |
| 250 | Slovak Republic | SVK | 280 | Tanzania (United Republic of) | TZA | | | |
| 251 | Slovakia | SVK | 281 | Tanzania, United Republic of | TZA | | | |
| 252 | Slovenia | SVN | 282 | Uganda | UGA | | | |
| 253 | Sweden | SWE | 283 | Ukraine | UKR | | | |
| 254 | Eswatini | SWZ | 284 | Uruguay | URY | | | |
| 255 | Eswatini (Kingdom of) | SWZ | 285 | United States | USA | | | |
| 256 | Swaziland | SWZ | 286 | United States of America | USA | | | |
| 257 | Sint Maarten (Dutch part) | SXM | 287 | United States of America (the) | USA | | | |
| 258 | Seychelles | SYC | 288 | USA | USA | | | |
| 259 | Syria | SYR | 289 | Former USSR | USR | | | |
| 260 | Syrian Arab Republic | SYR | 290 | Uzbekistan | UZB | | | |
| 261 | Turks and Caicos Islands | TCA | 291 | Holy See | VAT | | | |
| 262 | Chad | TCD | 292 | Saint Vincent and the Grenadines | VCT | | | |
| 263 | Togo | TGO | 293 | St. Vincent and the Grenadines | VCT | | | |
| 264 | Thailand | THA | 294 | Venezuela | VEN | | | |
| 265 | Tajikistan | TJK | 295 | Venezuela (Bolivarian Republic of) | VEN | | | |
| 266 | Turkmenistan | TKM | 296 | Venezuela, RB | VEN | | | |
| 267 | Timor-Leste | TLS | 297 | British Virgin Islands | VGB | | | |
| 268 | Tonga | TON | 298 | Virgin Islands (U.S.) | VIR | | | |
| 269 | Trinidad and Tobago | TTO | 299 | Viet Nam | VNM | | | |
| 270 | Tunisia | TUN | 300 | Vietnam | VNM | | | |

# Appendix C: Modified code from Callahan and Mankin (2022)

```
species_subtract = ["CH4", "NOx", "CO2"]
hist_emissions_subtract = xr.DataArray(np.zeros((niso,len(species_subtract))+hist_emissions.shape),
                                        coords=[iso,species_subtract,time,species],
                                        dims=["iso","species_subtract","time","species"])
#Adding in species being subtracted variable above

# first load hist emissions
hist_emissions_subtract[:,:,:,:] = np.broadcast_to(hist_emissions,(niso,len(species_subtract))+hist_emissions.shape)

# now loop and subtract emissions for each country over the relevant years
for ii in np.arange(0,len(iso),1):
    country = iso[ii]
    for jj, sub_sp in enumerate(species_subtract):
        hist_emissions_subtract[ii,jj,:,0] = hist_emissions[:,0]

        for ss in np.arange(3,len(species),1): # we'll do CO2 separately
            sp = species[ss]
            if sp == sub_sp:  # this line used to be: if sp in anthro_sp:
                print(sp)
                national_shares_spp = xr.open_dataarray(loc_emissions_shares+"CEDS_National_"+sp+"Emissions_Yearly_Shares_"+accounting+"_"+str(y1_shares)+"-"+str(y2_shares)+".nc")
                hist_emissions_subtract[ii,jj,shares_yr_overlap,ss] = hist_emissions[shares_yr_overlap,ss]*(1 - national_shares_spp.loc[country,:].values)
            else:
                hist_emissions_subtract[ii,jj,shares_yr_overlap,ss] = hist_emissions[shares_yr_overlap,ss]
```

```
        if sub_sp == "CO2":
            # CO2-fossil
            hist_emissions_subtract[ii,jj,shares_yr_overlap,1] =
hist_emissions[shares_yr_overlap,1]*(1 - shares_co2.loc[country,:].values)

            # CO2-landuse
            #hist_emissions_subtract[ii,shares_yr_overlap,2] =
hist_emissions[shares_yr_overlap,2]*(1 - shares_co2.loc[country,:].values)
            co2_lulcf_country =
co2_lulcf.loc[country,y1_shares:y2_shares].values
            if len(co2_lulcf_country[~np.isnan(co2_lulcf_country)]) ==
len(co2_lulcf_country):
                hist_emissions_subtract[ii,jj,shares_yr_overlap,2] =
co2_lulcf.loc[:,y1_shares:y2_shares].sum(dim="iso") - co2_lulcf_country
            else:
                hist_emissions_subtract[ii,jj,shares_yr_overlap,2] =
co2_lulcf.loc[:,y1_shares:y2_shares].sum(dim="iso")
        else:
            hist_emissions_subtract[ii,jj,shares_yr_overlap,1] =
hist_emissions[shares_yr_overlap,1]
            hist_emissions_subtract[ii,jj,shares_yr_overlap,2] =
hist_emissions[shares_yr_overlap,2]


…

T_subtract =
xr.DataArray(np.zeros((niso,len(species_subtract),len(time),nrun)),
                          coords=[iso,species_subtract,time,run],
                          dims=["iso_attr","species_subtract","time","fair
_run"])

for ii in np.arange(0,nrun,1):

    if ((ii == 0) | (np.mod(ii,5)==0)):
        print(ii)
```

```
    for jj in np.arange(0,niso,1):
        country = iso[jj]
        for kk, sub_sp in enumerate(species_subtract):
            C, F, T_subtract[jj,kk,:,ii] =
fair_scm(emissions=hist_emissions_subtract[jj,kk,:,:].values,
                                                natural=hist_natural_emiss
ions,
                                                F_solar=hist_solar_forcing
,
                                                F_volcanic=hist_volcanic_f
orcing,
                                                r0=r0_ens[ii],rc=rc_ens[ii
],rt=rt_ens[ii],
                                                tcrecs=tcrecs_ens[ii,:])

…

T_subtract.name = "temperatures"
t_sub_df_fair_runs = T_subtract.to_dataframe()
t_sub_df =
t_sub_df_fair_runs.groupby(["iso_attr","species_subtract","time"]).mean()
t_sub_df.to_csv('temp_outputs_NJI.csv') # this line used to be
t_sub_df.to_csv('temp_outputs_modified.csv')
```

# Appendix D: List of Eora-26 sectors

| # | Eora-26 sector |
|---|---|
| 1 | Agriculture |
| 2 | Fishing |
| 3 | Mining and Quarrying |
| 4 | Food & Beverages |
| 5 | Textiles and Wearing Apparel |
| 6 | Wood and Paper |
| 7 | Petroleum, Chemical and Non-Metallic Mineral Products |
| 8 | Metal Products |
| 9 | Electrical Machinery |
| 10 | Transport Equipment |
| 11 | Other Manufacturing |
| 12 | Recycling |
| 13 | Electricity, Gas and Water |
| 14 | Construction |
| 15 | Maintenance and Repair |
| 16 | Wholesale Trade |
| 17 | Retail Trade |
| 18 | Hotels and Restaurants |
| 19 | Transport |
| 20 | Post and Telecommunications |
| 21 | Financial Intermediation and Business Activities |
| 22 | Public Administration |
| 23 | Education, Health and Other Services |
| 24 | Private Households |
| 25 | Others |
| 26 | Re-export & Re-import |

# Appendix E: R code for calculating countries' consumption-based emissions

```
# This R script reads in the following files and calculates
countries'
# consumption-based GHG emissions

# Below are the set of steps to follow
# 1. Read in Q_subset matrix, T matrix and FD matrix
# 2. Calculate output vector by summing rows of T matrix
# 3. Calculate direct intensity vector, f
# 4. Create technical coefficient matrix, A
# 5. Calculate total intensity vector, F
#     a) Calculate identity matrix, I = . . . (use in-built R
function)
#     b) Calculate Leontief inverse, L = (I - A)^-1
#     c) Multiply L by direct intensity vector, f
# 6. Calculate total upstream emissions, E (E = F * FD)

# Setting working directory
setwd("C:/Users/...")

# Clearing variables
rm(list=ls())

library(dplyr)
library(purrr)
library(plyr)
library(magrittr)
library(stringr)
library(fst)
library(itertools)
library(matlib)
library(matrixcalc)
library(tibble)
library(phonTools)
```

```
library(stringr)
library(reshape2)
library(reshape)
library(data.table)
library(tibble)
library(dplyr)
library(tidyr)


####################################################################
############

# Steps 1 & 2: Read in Q_subset matrix, T matrix and FD matrix, and
generate y_out vector

####################################################################
############

# Q labels
Q_labels <- read.delim("labels_Q.txt", header=FALSE)
# Checking that third column is filled entirely with NAs
sum(is.na(Q_labels[,3]))
Q_labels <- Q_labels[,-3]

# T labels
T_labels <- read.delim("labels_T.txt", header=FALSE)
# Checking that fifth column is filled entirely with NAs
sum(is.na(T_labels[,5]))
T_labels <- T_labels[,c(-2,-3,-5)]
T_labels <- t(T_labels)

# FD labels
FD_labels <- read.delim("labels_FD.txt", header=FALSE)
sum(is.na(FD_labels[,5]))
FD_labels <- FD_labels[,c(-2,-3,-5)]
FD_labels <- t(FD_labels)
```

```
# Combine T labels and FD labels
TandFD_labels <- cbind(T_labels, FD_labels)
rownames(TandFD_labels) <- NULL

# IPCC categories
IPCC_desc <- read.csv("PRIMAP_categories.csv", header=TRUE)
# Country codes and countries
Country_codes <- read.csv("Country_codes.csv", header=TRUE)

years <- sort(c("2015", "2014", "2013", "2012", "2011", "2010",
"2009", "2008", "2007", "2006", "2005", "2004", "2003", "2002",
"2001", "2000", "1999", "1998", "1997", "1996", "1995", "1994",
"1993", "1992", "1991", "1990"))

list_of_files <- list.files(path = "C:/Users/.../Eora Files for R",
pattern = NULL, all.files = FALSE,
                            full.names = FALSE, recursive = FALSE,
                            ignore.case = FALSE, include.dirs =
FALSE, no.. = FALSE)

# Identify files with Q matrix
find_Q_files <- str_detect(list_of_files, "bp_Q.txt")
Q_files <- sort(list_of_files[which(find_Q_files == TRUE)])

# Identify files with a T matrix
find_T_files <- str_detect(list_of_files, "bp_T.txt")
T_files <- sort(list_of_files[which(find_T_files == TRUE)])


# Identify files with a FD matrix
find_FD_files <- str_detect(list_of_files, "bp_FD.txt")
FD_files <- sort(list_of_files[which(find_FD_files == TRUE)])

#i = 23 #This is for the year 2012

for (i in 1:26) {
```

```
  # Getting Q matrix
  # Q matrix
  Q_matrix <- read.table(Q_files[i], header=FALSE, sep="\t")
  # Checking for NA values
  which(is.na(Q_matrix))

  # Taking relevant rows of Q_labels matrix and using this to index
and take the
  # relevant rows of the Q matrix
  Q_labels_sub <- Q_labels[grepl(pattern="PRIMAPHIST",
Q_labels[,1]), ]
  Q_labels_sub[,2] <- gsub("[|]","",Q_labels_sub[,2])

  # Now just have 54 rows (there are 18 rows for each of the three
main GHGs)
  Q_labels_sub2 <- Q_labels_sub[grepl(pattern = "MAPCO2|CH4|N2O",
Q_labels_sub[,2]), ]
  # Now just taking the total values for each of the GHGs
  Q_labels_subset <- Q_labels_sub2[grepl(pattern =
"TOTALexcludingLULUCF", Q_labels_sub2[,2]), ]
  Q_subset_rows <- row.names(Q_labels_subset)
  # Getting total values for each of the GHGs for the entire Q
matrix
  Q_matrix_subset = Q_matrix[Q_subset_rows, ]

  Q_labels_factor <- Q_labels_subset[, 2]
  Q_labels_factor
  Q_labels_factor <- t(data.frame(lapply(Q_labels_factor,
type.convert), stringsAsFactors=FALSE))
  Q_labels_factor
  rownames(Q_labels_factor) <- NULL

  # Adding in initial column which specifies which greenhouse gases
are being used
  Q_matrix_subset_final = cbind(Q_labels_factor, Q_matrix_subset)

  # Getting T matrix
```

```
  T_matrix <- read.table(T_files[i], header=FALSE)

  # Checking for NA values
  which(is.na(T_matrix))

  # Getting FD matrix
  FD_files[2]
  FD_matrix <- read.table(FD_files[i], header=FALSE)

  # Checking for NA values
  which(is.na(FD_matrix))

  # Calculating total output vector, y_out
  T_matrix_y_out<-rowSums(T_matrix)

  # Calculating output vector from Final Demand, y_out_FD
  FD_matrix_y_out <-rowSums(FD_matrix)

  y_out_vector <- T_matrix_y_out + FD_matrix_y_out
  y_out_vector

  y_out_vect_modified <- y_out_vector

  # Modifying the y_output vector by replacing zero entries with
ones
  y_out_vect_modified[which(y_out_vect_modified==0)] <- 0.01


####################################################################
############

  # Step 3: Calculate direct intensity vector, f


####################################################################
############
```

```
  # We are going to keep the CH4, CO2 and N2O values separate

  f_CH4 <- Q_matrix_subset_final[1,-1] / y_out_vect_modified
  f_CH4_vec <- as.vector(f_CH4,mode='numeric')

  f_CO2 <- Q_matrix_subset_final[2,-1] / y_out_vect_modified
  f_CO2_vec <- as.vector(f_CO2,mode='numeric')

  f_N2O <- t(Q_matrix_subset_final[3,-1] / y_out_vect_modified)
  f_N2O_vec <- as.vector(f_N2O,mode='numeric')

#######################################################################
############

  # Step 4: Create technical coefficient matrix, A


#######################################################################
############

  a_matrix <- sweep(T_matrix[,-4916], 2, y_out_vect_modified, FUN =
'/')

  # Identify rows of y_out vector that have zeros and remove the
relevant columns
  # from the a_matrix

  indices <- which(y_out_vector==0)
  a_matrix_without_zeros <- a_matrix[-indices,-indices]
  cols <- colnames(a_matrix_without_zeros)
  rows <- rownames(a_matrix_without_zeros)

#######################################################################
############

  # Step 5: Calculate total intensity vector, F
```

```
####################################################################
############

  I <- diag(dim(a_matrix_without_zeros)[1])
  a <- a_matrix_without_zeros
  A <- I - a

  Leontief_inv <- solve(A)

  cols <- colnames(Leontief_inv)
  rows <- rownames(Leontief_inv)

  row.names(Leontief_inv) <- cols
  colnames(Leontief_inv) <- rows

  #Now add columns which had been removed back in

  a_columns_to_insert_later <- a_matrix[,indices]
  a_rows_to_insert_later <- a_matrix[indices,]

  A_new <- as.data.frame(matrix(0, nrow = dim(a_matrix)[1], ncol =
dim(a_matrix)[2]), row.names=NULL, col.names=NULL)
  A_new[indices,] <- a_rows_to_insert_later
  A_new[,indices] <- a_columns_to_insert_later
  A_new[cols,rows] <- Leontief_inv

  A_new_matrix <- as.matrix(A_new)

  F_CH4 <- f_CH4_vec%*%A_new_matrix
  F_CO2 <- f_CO2_vec%*%A_new_matrix
  F_N2O <- f_N2O_vec%*%A_new_matrix

####################################################################
############

  # Step 6: Calculate total upstream emissions, E (E = F * FD)
```

```
########################################################################
############

  FD_matrix_new <- t(as.matrix(FD_matrix_y_out))

  E_CH4 <- (F_CH4*FD_matrix_new) #*25
  E_CO2 <- F_CO2*FD_matrix_new
  E_N2O <- (F_N2O*FD_matrix_new) #*298


  # Now make a matrix with the FD labels:

  final_df <- rbind(T_labels[1,],T_labels[2,],E_CH4,E_CO2, E_N2O)
  row.names(final_df) <- c("Country","Industry","CH4_kt", "CO2_kt",
"N2O_kt")

  final_df_transposed <- t(final_df)
  row.names(final_df_transposed) <- NULL
  colnames(final_df_transposed) <- c("Country","Industry","CH4_kt",
"CO2_kt", "N2O_kt")

  final_df_transposed <- data.frame(final_df_transposed)

  New_df <- cbind(final_df_transposed[1:2],
stack(final_df_transposed[3:5]))
  colnames(New_df) <- c("Country","Industry","Value","Gas")
  df <- New_df %>% separate(Gas, c('Gas', 'Metric'))

  Year <- data.frame(rep(years[i],dim(df)[1]))
  colnames(Year) <- c('Year')

  fin_df <- cbind(df,Year)

  write.table(fin_df, "fin_df.csv", sep = ",", row.names = FALSE,
col.names = !file.exists("fin_df.csv"), append = T)
```

```
  print(i)
}
```