THE ECONOMIC RETURNS OF DECARBONIZING THE GLOBAL POWER SECTOR

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Master of Science

by

Yuktha Bhadane

May 2025

ABSTRACT

This thesis examines the economic returns of decarbonizing the global power sector. Using data from 79,797 operational power plants across 156 countries, I quantify both costs and benefits through 2035 and 2050, globally and for countries. The methodology extends the Coasian approach to all fossil fuels in electricity generation. The findings challenge the widespread belief that just climate action is too expensive. With a social cost of carbon of $190/tCO_2$, net benefits reach $11.0 trillion by 2035 and $50.4 trillion by 2050. Notably, just 3.3% of total costs come from compensating fossil fuel owners, shifting the focus to mobilizing capital as the main challenge. While 45 countries see positive returns from self-financing by 2035, others need cross-border climate finance. This analysis transforms climate finance from a perceived zero-sum game into a positive-sum opportunity. Rather than charity, investments from developed to developing countries generate returns of 180-1457%. The findings demonstrate that power sector decarbonization represents both a solution to climate change and a compelling economic opportunity. These results provide policymakers with rigorous economic rationale to accelerate energy transition investments.

BIOGRAPHICAL SKETCH

Yuktha Bhadane was born in Pune, India. She received her BSc. Economics from the University of London under the academic direction of the London School of Economics & Political Science in 2022. Her undergraduate studies were completed at the Indian School of Business and Finance. In 2020, she co-founded a sustainable lifestyle enterprise in India. Bhadane served as the G20 Secretariat Young Professional at United Nations Women during India's G20 Presidency in 2023. Following that, she moved to the US to pursue an MS in Applied Economics & Management at Cornell University. Her research interests include climate finance, blended finance investment strategies, and implementation mechanisms addressing the climate crisis.

Dedicated to my grandfather, *Pappa*, who worked in the mines to educate himself and changed the fate of generations to come, including mine.

ACKNOWLEDGEMENTS

I express my immense gratitude to my advisor, Alissa Kleinnijenhuis for introducing me to climate finance. What began as a teaching assistantship has become the field I aspire to excel in, thanks to Alissa's inspiring commitment to the climate crisis. Thank you for the Big Thinking discussions.

I am grateful to Professor Turvey who supported me throughout this masters program. He patiently heard my half-baked ideas, been kind as I found my way and made me think. Thanks to Professor Tobin for opening the world of financing deals through his teaching and committee support.

Central to this thesis is our research group. I thank Rudy Tanin and Farhad Panahov, with whom I learned the most. The Forward Analytics team, Moritz Baer and Mathis Greussing have been generous with their time and the dataset.

Being a Teaching Assistant made this degree possible. Thank you Professor Stephen Shu, Professor Justin St. Juliana and Professor Robert Howarth for the opportunity to learn and assist in your classes, and to the staff for their support.

I would be remiss to not acknowledge my friends without whom I would have probably packed my bags to India in week 6. Shashwat, Karishni, Devesh, Kapil, Amlan, Tanuj, Neil, Shanthanu, Rewa and Kasim, thank you for making Ithaca a home. To my MS AEM friends - Maddie, Lillian, Wenqi, Shreya, Kashvi, Anamay, I am glad problem sets brought us together.

My academic dreams sprouted from my parents' sacrifices and belief. This harvest is as much yours as mine. I am grateful to my brother, Dada, my lifelong light, and to my partner Sidd, who has been my rock and reason these past years.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Climate change represents the defining challenge of our time, with the power sector accounting for 34% of global CO_2 emissions. Despite widespread consensus on the urgent need for decarbonization, progress remains insufficient to meet Paris Agreement targets. This thesis examines the economic returns of transitioning from fossil fuels to renewable energy in the global power sector, challenging the persistent narrative that climate action entails prohibitive economic costs.

Using granular asset-level data for 79,797 operational power plants across 156 countries, I quantify both the costs and benefits of power sector decarbonization through 2050. The methodology builds upon the Coasian framework established in "The Great Carbon Arbitrage" by Adrian, Bolton, and Kleinnijenhuis (2022), while expanding its application from coal to all fossil fuels in electricity generation. This approach enables a comprehensive economic assessment that captures opportunity costs to fossil fuel owners and workers, investment requirements for replacement renewables, and climate benefits from avoided emissions.

The findings reveal substantial positive economic returns across multiple scenarios. When considering a social cost of carbon (SCC) of \$190/tCO_2, the net benefits of global power sector decarbonization reach \$50.4 trillion by 2050, with costs of \$24.2 trillion significantly outweighed by benefits of \$74.6 trillion. With an SCC of \$1056/tCO_2 that better accounts for climate tipping points, net benefits increase to \$360 trillion. Perhaps most significantly, direct opportunity costs to fossil fuel owners represent just 3.3% of total transition costs, challenging the common perception that compensating incumbent interests poses the primary financial barrier.

These results demonstrate that decarbonizing the power sector is not merely an environmental imperative but a compelling economic opportunity. However, the findings also reveal significant implementation challenges. While 67 countries show positive returns from self-financing their own transitions by 2050, others require cross-border climate finance to achieve positive economic returns. Through blended finance arrangements where public capital leverages private investment, I find that climate finance from developed to developing countries generates economic returns of 180-1457%, depending on SCC valuation.

This thesis makes three key contributions to the literature. First, it provides the first comprehensive, comparable country-level estimates of both the costs and benefits of power sector decarbonization, addressing a critical gap in standardized methodologies. Second, it quantifies the economic returns to various cross-border climate finance arrangements, demonstrating that financing developing countries' energy transitions serves the economic self-interest of developed nations. Third, it challenges conventional wisdom about transition barriers by quantifying the costs attributable to fossil fuel asset stranding (just 3.3%), revealing that the primary challenge is not compensating incumbent stakeholders but rather mobilizing and effectively deploying capital for renewable energy infrastructure at speed and scale.

The analysis proceeds as follows. Chapter 2 reviews the scientific consensus on climate change and assesses existing literature on power sector decarbonization finance. Chapter 3 details the data sources and methodological framework. Chapter 4 presents the results on costs, benefits, and economic returns across different financing scenarios. Chapter 5 discusses implementation barriers and potential solutions, particularly the role of climate clubs and blended finance in mobilizing capital at scale.

CHAPTER 2

LITERATURE REVIEW

This chapter examines the scientific and economic foundations that frame the imperative for the decarbonization of the power sector. The review starts with an exploration of the scientific consensus on climate change and its implications for rapid action. Following that, it establishes why the power sector represents a critical focus for climate mitigation efforts, examining both its emissions profile and economic transformation opportunities. The review then critically assesses the existing literature on the decarbonization finance of the power sector, revealing significant methodological gaps. Finally, I examine Adrian et al.'s Great Carbon Arbitrage framework, which provides the foundation that I extend in this thesis to develop a comprehensive economic analysis of the decarbonization of the power sector.

2.1 Tipping Points: The Imperative for Rapid Decarbonization

In 1958, Charles David Keeling began measurements at Mauna Loa Observatory that provided unequivocal evidence of rising atmospheric CO_2 levels, establishing what is now known as the Keeling Curve—one of the most iconic datasets of climate science (Weart, 1997).

The scientific consensus on climate change has strengthened dramatically over decades. The language of the Intergovernmental Panel on Climate Change (IPCC) has evolved from their 1990 statement that ”The greenhouse effect is real; it is a well understood effect” to their 2001 acknowledgment of ”discernible human influence on global climate,” culminating in their 2023 conclusion that ”Human activities... have unequivocally caused global warming”[1].

Despite this scientific clarity, policy progress has lagged considerably. The year 2024 was recorded as Earth’s hottest in modern history (NASA, 2025), with atmospheric CO_2 reaching levels not seen in over two million years.

Climate systems are non-linear, which introduces substantial policy challenges. Rockström et al. (2009)’s planetary boundaries framework identifies climate change as one of nine critical boundaries with potential tipping points—thresholds beyond which abrupt and possibly irreversible system changes occur (Lenton et al., 2008). Recent evidence suggests that several tipping points may be approaching critical thresholds[2], including the Atlantic Meridional Overturning Circulation, West Antarctic Ice Sheet, and the Amazon rainforest (Ripple et al., 2023; Rockström et al., 2023).

Stocker et al. (2024) highlight a scientific divide between ”tippists”, who argue that tipping points are ubiquitous in the non-linear climate dynamics, and ”linearists”, who argue for more gradual changes[3]. The authors propose focusing on

[1] This evolution in language reflects the strengthening scientific consensus as observational evidence accumulated and climate models improved in their explanatory power.

[2] These observed anomalies are occurring faster than many earlier climate models predicted, suggesting potential underestimation of climate sensitivity in previous modeling efforts.

[3] ”Linearists” emphasize the climate system’s complexity and dissipative elements that might prevent large-scale instabilities. Thus, suggesting comprehensive models would show more gradual changes.

High Impact-Low Likelihood (HILL) events to bridge this divide, shifting focus to potential impacts regardless of underlying dynamics.

What remains undisputed is that economically viable solutions already exist. Renewable energy costs have plummeted (solar PV by 85%, wind by 55%) over the past decade (IPCC, 2023), making clean energy cost-competitive or cheaper than fossil alternatives in many markets. [4]Therefore, the science is clear and there are solutions.

2.2 Power Sector: A Central Focus for Decarbonization

The power sector represents the largest source of global CO_2 emissions, which makes it a critical focus for climate mitigation efforts (IPCC, 2023; M. Crippa et al., 2024). Despite growing awareness and clean energy deployment, fossil fuels continue to dominate new energy demand, driving emissions to record levels in recent years (IEA, 2024).

Historically, concerns about fossil fuel emissions date back more than a century. Arrhenius (1896) theorized that burning coal would lead to atmospheric CO_2 accumulation, predicting a gradual rise in temperatures. However, the actual pace of CO_2 accumulation has vastly exceeded Arrhenius' expectations. Current levels

[4]These cost declines have been driven by technological learning, economies of scale, and policy support mechanisms, demonstrating how targeted interventions can accelerate sustainability transitions.

of 410 ppm represent not just a deviation from pre-industrial conditions, but also an unprecedented state not seen in more than two million years (IPCC, 2023).[5]

Beyond environmental damage, these impacts create substantial economic losses and threaten energy security itself, creating a dangerous feedback loop. As per World Energy Outlook 2024 Report (IEA, 2024), "extreme weather events, intensified by decades of high emissions, are already posing profound energy security risks", highlighting the inextricable link between climate action and energy security.

Despite this troubling trajectory, the dramatic evolution of renewable energy technologies suggests a potential positive tipping point. The IPCC (2023) documents substantial cost decreases between 2010-2019 in solar energy (85%), wind energy (55%), and lithium-ion batteries (85%), making renewables the cheapest energy option in many regions (IPCC, 2023). Simply put, "It is now cheaper to save the world than destroy it" (Rathi, 2024). The IEA (2024) confirms this economic shift, noting that investment flows to clean energy projects are approaching USD 2 trillion annually, almost double the combined investment in new oil, gas and coal supply.

The power sector therefore represents both the greatest challenge and the greatest opportunity in addressing climate change. Although technological and economic barriers are falling rapidly, implementation gaps remain, particularly

[5] This rapid increase in atmospheric CO_2 has occurred primarily over the last century, with approximately half of cumulative anthropogenic CO_2 emissions occurring in just the past 30 years.

in developing economies where clean energy investment lags despite representing the majority of future demand growth (IEA, 2024).[6] These gaps shed light on the need for actionable frameworks that can accelerate deployment and overcome persistent barriers to implementation.

2.3 Existing Literature on Power Sector Decarbonization

According to the IEA's World Energy Investment Report, global energy investment is set to exceed US$3 trillion in 2024, of which US$2 trillion will go to clean technologies (IEA, 2024).[7] While clean energy investments have increased, emissions attributable to the energy sector continue to rise, reaching a record high of 37.8 $GtCO_2e$ (IEA, 2025). This divergence between investment growth and emission trends raises critical questions about the adequacy and targeting of current financing approaches.

Despite reports mapping investment needs by Montague, Raiser, and Lee (2024)[8] and Climate Policy Institute (2023), a critical gap remains in standardized methodologies to estimate climate finance requirements, both globally and for in-

[6]This implementation gap is often driven by a combination of factors including financing constraints, policy uncertainty, grid integration challenges, and institutional capacity limitations rather than technological or economic barriers.

[7]The IEA defines "clean technologies" as non-fossil fuel technologies across the whole energy system that contribute to achieving net-zero emissions, including renewable power, nuclear, grids, storage, low-emission fuels, efficiency improvements, and end-use renewables and electrification.

[8]Organisation for Economic Co-operation and Development (OECD), Environment Working Paper No. 245

dividual countries. The existing literature on the decarbonization finance of the power sector tends to be country or region-specific, with significant methodological inconsistencies that hinder comparative analysis.

These inconsistencies are particularly evident in Nationally Determined Contributions (NDCs)[9] that are submitted to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat under the Paris Agreement 2015. Pauw et al. (2018) demonstrate that NDCs lack transparency and comparability and that countries rarely provide sufficient evidence on the financial requirements to implement climate commitments. Their analysis reveals significant variations in reporting approaches, with some NDCs completely omitting cost estimates or methodological details, creating a systemic gap between developing countries' stated financial needs and developed countries' commitments.

Isah, Egli, Schmidt, and Stünzi (2025) provide further evidence of this standardization gap, analyzing 251 NDCs and finding significant variation in specificity that cannot be easily explained by economic factors.[10] While countries are improving in reporting financial details—with quantification increasing from 60% in the first NDCs to 74% in the updated NDCs —the estimated climate finance needs (more than US$600 billion annually by 2030) significantly exceed current

[9]NDCs are national climate action plans where a country outlines its plan to reduce GHG emissions to meet the Paris Agreement global goal of limiting temperature rise to 1.5C and adapt to the impacts of climate change.

[10]Isah et al. (2025) developed a Climate Finance Needs Specificity framework that categorizes NDCs into three levels: no estimate, low specificity (only total figures), and high specificity (at least one sectoral estimate). Their analysis found that while 60% of countries provided some financial estimates in first NDCs, many lacked sectoral detail or methodological transparency.

pledges.

Country-specific examples illustrate these methodological challenges. Indonesia's NDC commits to unconditionally reduce greenhouse gas emissions by 29% by 2030, estimating approximately US$246 billion for the decarbonization of its power sector (Ministry of Environment and Forestry, Government of Indonesia, 2021). However, their methodology focuses primarily on current capital expenditure needs without adequately addressing operating costs or providing granular project level details. The report acknowledges these limitations, noting that "consideration may need to be given to developing future capital expenditure and operating expenditures" and that their estimates are conservative.

Similarly, India's latest Biennial Report has a power sector-specific target. It aims to achieve "about 50 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030" (Ministry of Environment, Forest and Climate Change, Government of India, 2024). However, no quantification of the financing requirements is provided. Additionally, this target raises methodological concerns regarding the distinction between installed capacity and generation capacity.[11] Aiming to evenly distribute installed capacity between fossil and non-fossil sources does not lead to an even mix of electricity generation. Thus, the power sector in India may remain heavily skewed toward fossil fuels

[11]Generation capacity equals total installed capacity multiplied by the capacity factor. This distinction matters because renewable energy sources typically have significantly lower capacity factors than fossil fuel plants. Hunt and Bloomfield (2024) found that onshore wind capacity factors in India generally range between 0.2-0.4 and solar capacity factors between 0.18-0.22, compared to the 0.7-0.9 capacity factors typical of fossil fuel plants.

due to these capacity factor differentials.

Methodological weaknesses in financial planning mirror broader issues in setting climate targets. Rogelj et al. (2023) evaluate the credibility of net-zero climate targets by examining their legal status, implementation planning, and alignment with near-term emission reduction policies. Their analysis reveals that, when considering only highly credible targets, global warming is projected to reach 2.4°C by 2100, significantly exceeding the Paris Agreement goals. Their findings indicate that approximately 90% of the net-zero targets lack sufficient credibility, highlighting a critical gap between the climate pledges and the implementation of policies.

Clearly, countries need better sectoral climate finance estimates. In this thesis, I use a robust methodology that builds on the Great Carbon Arbitrage (Adrian et al., 2022) framework to estimate the global and country-specific costs, benefits and the economic returns of decarbonizing the power sector.

2.4 The Great Carbon Arbitrage

It has been a common belief that with increasing energy demands, phasing out coal would be costly and that replacing coal with renewable energy would be too expensive. The Great Carbon Arbitrage (Adrian et al., 2022) paper challenged this by demonstrating a net gain of US$85 trillion to be realized from phasing out coal (production) and replacing it with renewables.

The paper calculates the cost of replacing coal with renewable energy, and the social benefit of phasing out coal, to obtain a net gain of the energy transition. They achieve this by taking a Coasian approach instead of a Pigouvian one. While the Pigouvian approach focuses on determining the marginal social cost of carbon (SCC) to tax emissions efficiently, the Coasian approach seeks to determine the total net benefit from a large reduction in CO_2 emissions and how this benefit could be split among the contracting parties.[12]

The authors rigorously measure the benefits of phasing out coal as the average social cost of carbon multiplied by the quantity of avoided emissions. They conservatively estimate the average SCC at $80 per ton of CO_2, based on Pindyck's (2019) survey study. Their baseline scenario follows the Network for Greening the Financial System (NGFS) Net Zero 2050 pathway, comparing it to a business-as-usual Current Policy Scenario. This approach estimates that phasing out coal would prevent approximately 1,425 gigatons of CO_2 emissions.

The costs are calculated as the sum of two components: (1) the opportunity costs of coal, which include the missed free cash flows of coal companies calculated using data from 2,027 coal companies with 6,590 coal plants worldwide, and (2) the investment costs of building renewable energy capacity including 50% solar PV, 25% onshore wind, and 25% offshore wind. The authors incorporate

[12] This methodological distinction is significant as it shifts from pricing individual units of pollution to valuing the total economic benefit of a systemic transition, allowing for more comprehensive cost-benefit analysis of large-scale climate action.

Wright's Law to model learning curves showing how renewable energy costs decrease over time as cumulative capacity increases,[13] with documented learning rates of 20% for solar, 5% for onshore wind, and 3% for offshore wind.

Using granular data from Asset Resolution on coal production at the plant level, the authors estimate that the present value of the benefits from avoided coal emissions is approximately $114.04 trillion, while the present value of costs is only $29.03 trillion (just $50 billion in opportunity costs and $28.98 trillion in investment costs). This results in a net gain of $85.01 trillion, representing about 1.3% of the current world GDP annually until 2100. The authors conduct extensive sensitivity analyses, finding that even with lower SCC estimates of $61.4/tCO_2$, the net gain would still be $59 trillion.

The authors also break down climate financing needs by geography and development status, finding that approximately $29 trillion would be required globally to finance the transition from coal to renewables, with 46% in Asia, 18% in Europe, 13% in North America, 13% in Australia and New Zealand, 8% in Africa, and 2% in Latin America and the Caribbean. They propose that most of this funding could come through blended finance arrangements (See section3.5.1) where public funds leverage private capital at a ratio of approximately 1:9, requiring only about $2.9 trillion in public funds.

Furthermore, they analyze country-level costs and benefits, finding that most

[13] Wright's Law, sometimes called the learning curve or experience curve, describes how production costs decrease as a function of cumulative production. In renewable energy, it explains why costs have fallen so dramatically as global installed capacity has increased. See section 3.4.2

countries would benefit from a global coal phase-out even without cross-country compensatory transfers. Their analysis also addresses the broader societal costs, including compensation for lost wages of coal workers ($275 billion) and retraining costs ($7 billion), which they find to be small relative to the overall gains.

The Great Carbon Arbitrage provides a compelling framework that directly informs my methodology. By demonstrating the substantial net economic benefit of $85 trillion from phasing out coal and replacing it with renewables, Adrian et al. (2022) establishes that what was once viewed primarily as an environmental imperative is also economically advantageous. Their Coasian approach, calculating both the costs of replacing coal with renewables and the benefits of avoided emissions, provides the methodological foundation upon which I build my analysis of fossil fuel power plant phase-outs, with both approaches revealing that the benefits of transition far outweigh the costs when properly quantified.

I extend this Coasian approach to a broader power sector transition, using similar calculations for investment costs in renewables and opportunity costs of fossil fuel plants, while incorporating updated data and additional renewable technologies. Both methodologies highlight that the financial benefits of avoided emissions substantially outweigh the costs of transition, creating a true "arbitrage" opportunity that can benefit both global climate goals and economic development.

CHAPTER 3

DATA & METHODOLOGY

This chapter presents the comprehensive data sources and methodological framework utilized to examine the economics of decarbonizing the global power sector. This thesis employs a granular, asset-level approach built on carbon budget-consistent Net Zero (1.5°C) scenario analysis to assess the costs, benefits, and economic returns of transitioning from fossil fuels to renewable energy. The analysis integrates data from multiple authoritative sources, including Forward Analytics' global power plant database, Network for Greening the Financial System (2023) emission pathways, Bloomberg L.P (2024) data, various IEA Reports and Economic Research Institute (ERI) Salary Assesor. Methodologically, this research extends the Coasian framework established in the Great Carbon Arbitrage to develop country-level estimates of both climate benefits and transition costs.

3.1 Data

This research uses a new granular data set from Forward Analytics with global coverage of power plants at the asset level. The dataset has the following attributes for each power plant:

- Asset name
- Direct owner

- Location (longitude and latitude)
- Country
- Power type (oil, coal, gas, solar, wind, hydropower, bioenergy, nuclear)
- Power type-specific subtype (e.g., for coal: bituminous, sub-bituminous; for wind: onshore, offshore)
- Capacity (in MW)
- Emission intensity (in kg of CO_2e per TJ)[1]
- Heat rate
- Capacity factor (country and technology-type specific)
- Activity (in MWh)
- Status (announced, shelved, cancelled, pre-permit, construction, operating, retired)
- Start year, planned retirement year, retirement year.

The global dataset contains a total of 125,915 power plants, of which 79,797 are operational; see Table 3.1 with the global summary statistics of the 2023 Forward Analytics power sector data.

[1]We use the 20 year global warming potential (GWP) of methane emissions for a conservative estimate as the 100 year GWP dramatically underplays this level of warming. This is consistent with NY State's NY Climate Leadership & Community Protection Act of 2019 (See https://www.nysenate.gov/legislation/bills/2019/S6599)

Table 3.1: Global summary statistics of power sector data.

	Plants (#)	%	Capacity (GW)	%	Used Cap. (GW)	Elec. (TWh)	%	Emissions ($GtCO_2e$)	%	Energy[2] (%)	Total[3] (%)
Coal	6823	8.6	2281.3	24.7	1138.8	9976.0	29.5	10.08	71.2	27.0	24.2
Gas	8043	10.1	1931.8	20.9	884.8	7751.0	22.9	3.41	24.1	9.1	8.2
Oil	1159	1.5	152.8	1.7	67.7	593.5	1.8	0.64	4.5	1.7	1.5
Other	78	0.1	8.8	0.1	4.1	35.5	0.1	0.03	0.2	0.1	0.1
Solar	38589	48.4	915.8	9.9	126.4	1107.1	3.3	0.0	0.0	0.0	0.0
Wind	19048	23.9	1108.1	12.0	241.1	2111.9	6.3	0.0	0.0	0.0	0.0
Hydropower	3430	4.3	2195.3	23.7	898.7	7872.2	23.3	0.0	0.0	0.0	0.0
Geothermal	384	0.5	15.8	0.2	12.0	104.8	0.3	0.0	0.0	0.0	0.0
Bioenergy	1679	2.1	86.1	0.9	42.4	371.7	1.1	0.0	0.0	0.0	0.0
Nuclear	564	0.7	550.4	6.0	441.3	3865.9	11.4	0.0	0.0	0.0	0.0
Fossil+[4]	16103	20.2	4374.7	47.3	2095.4	18356.0	54.3	14.16	100.0	37.9	34.0
Renewables+[5]	62015	77.7	4785.4	51.8	1719.4	15061.9	44.6	0.0	0.0	0.0	0.0
Total	79797	100.0	9246.2	100.0	3857.3	33789.6	100.0	14.16	100.0	37.9	34.0

When plant-level power sector activity data with their emission intensity is aggregated,[6] the estimate for global power sector emissions of 14.2 Gt, is comparable. It closely aligns with the 2023 estimates from authoritative sources such as Statista (15.1 Gt) and the 2024 UN Emission Gap Report (15.1 Gt).[7] This alignment in aggregate statistics gives me confidence that these global granular plant-level data are reliable.

[2]Energy (%): as a % of total Energy-related CO_2e emissions (37.4 Gt)

[3]Total (%): as a % of total CO_2e emissions (41.6 Gt).

[4]Fossil+ includes all fossil fuels plus other sources.

[5]Renewables+ includes all renewables plus nuclear.

[6]Specifically the multiplication at the plant-level is: annual CO2 (in million tonnes) = capacity * capacity factor * heat rate (in Btu per kWh) * emission factor (kg of CO2 per TJ) * 9.2427 x 10^{-12}.

[7]The slight differences between power sector emission estimates stem from differences in: (1) the estimated capacity factor, (2) the emission factors which are sometimes asset-specific, sometimes technology specific depending on availability of data; and (3) the coal methane CO_2e emissions (which the Forward Analytics data shows for both global warming potential (GWP) of 20 and 100 years - which drives total emissions)

In Figures C.1-C.6 in Appendix C, regional breakdown of the power sector statistics (i.e., for Asia, Africa, Europe, North America, Latin America and the Caribbean, and Australia and New Zealand) is presented. In Figure 4.2, I display the top 25 countries by power sector emissions and their emission breakdown. In Figure 4.3, I show these countries' relative emission contributions within their respective regions.

Business-as-Usual and Carbon-Budget Consistent Net-Zero Scenarios For projecting emission and energy pathways, I rely on the scenarios developed by Bolton and Kleinnijenhuis (2025). They use the Network for Greening the Financial System (NGFS) GCAM 6 model as the foundation for projections through 2050. These scenarios provide energy, emissions, and economic statistics broken down by country and power sector energy type in 5-year intervals, with linear trends extrapolated between intervals to create annual data series. Bolton and Kleinnijenhuis developed a methodology to adjust standard net-zero scenarios to ensure cumulative emissions until 2050 remain within the 1.5°C 50% carbon budget as of January 2024. This adjustment is critical as standard net-zero scenarios do not necessarily limit cumulative emissions to the remaining carbon budget. I adopt their "1.5°C 50% Carbon Budget Consistent Net Zero 2050" scenario that avoids reliance on unproven large-scale negative emissions technologies after 2050.

Renewable investment costs and land use I take into consideration how investment costs in renewable technologies tend to drop as a function of global cumulative deployment through "experience curves" or learning-by-doing effects. In Table 3.2, I summarize my renewable data on investment costs, learning rates, depreciation rates, and lifetimes. For land and sea space constraints for building renewables, I adopt the methodology and data from Bolton and Kleinnijenhuis (2025), who utilize datasets from FAOSTAT Land Cover and Marine Regions.

Fossil fuel opportunity costs The opportunity cost of phasing out fuel fuels early consist of the expected discounted missed cash flows to power sector owners from closing their operations early; as well as could be said to more broadly incorporate missed income to power sector workers and their retraining costs. To estimate missed free cash flows, I use data of Bloomberg Finance LP in combination with Forward Analytics data. For missed wages, I use data found in IEA (2023) World Energy Employment Report and data of the Economic Research Institute (ERI) Salary Assessor[8]. I estimate retraining cost based on data from Louie and Pearce (2016).

Air Pollution Benefits For the economic benefits from reduced air pollution when phasing out fossil fuels, I adopt the methodology and data compiled by Bolton and Kleinnijenhuis (2025). Their approach integrates high-resolution (1km

[8]The IEA (2023) World Energy Employment Report also uses ERI's private and employer provided estimates. See https://cdn.erieri.com/help/SA/SAMethodUS.pdf detailed methodology here

× 1km) PM2.5 concentration data with country-specific disease mortality rates, population distribution estimates, and value-of-statistical-life (VSL) figures. This comprehensive framework enables quantification of avoided mortality and morbidity resulting from the reduction in air pollutants associated with fossil fuel combustion. By monetizing these health benefits, I incorporate this significant co-benefit into the overall economic assessment of decarbonization pathways.

3.2 Methodology

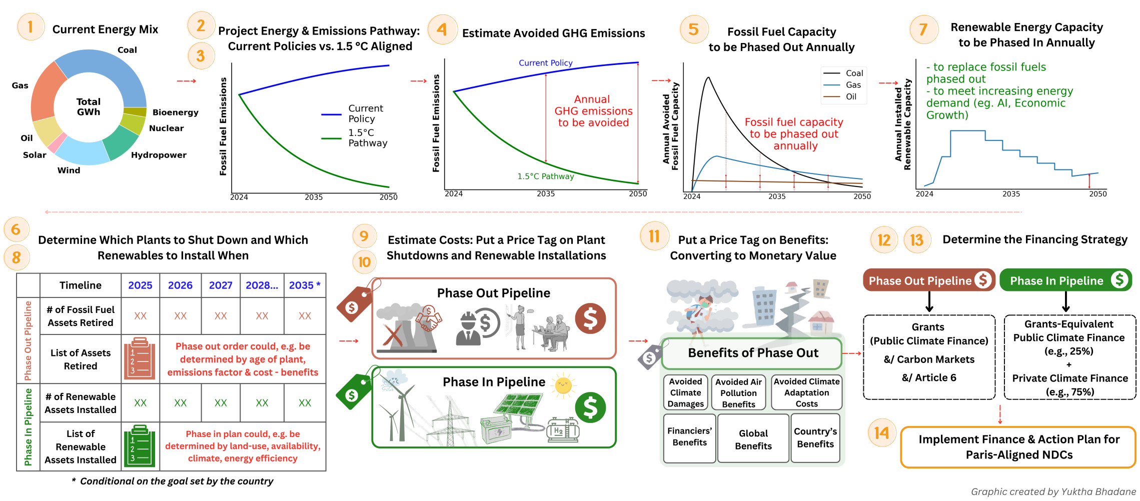

Figure 3.1: Steps for Decarbonizing the Power Sector.

This thesis focuses on the economic evaluation components of power sector decarbonization, specifically addressing the costs and benefits analysis outlined in Bolton and Kleinnijenhuis (2025). The comprehensive methodology developed in the forthcoming paper provides a 13-step process for implementing and financing power sector decarbonization (see Figure 3.1). Within this framework, I concentrate on steps 9, 10, and 11, which involve quantifying the costs of fossil fuel phase-out, renewable energy phase-in, and the climate-related benefits of this transition. As Bolton and Kleinnijenhuis (2025) identify, the current stage of the green transition requires turning net-zero pledges into "financed implementation, at speed and gigaton scale." This thesis contributes by detailing methodological approaches for:

1. Valuing economic benefits from avoided climate damages (step 11, excluding air pollution benefits)
2. Calculating costs for phasing out fossil fuel capacity (step 9)
3. Determining investments required for renewable energy deployment (step 10)

This economic analysis is situated within the broader context of steps 1-8, which establish technical requirements, and informs steps 12-13, which address financing strategies.

3.3 Benefits of Power Sector Decarbonization

This section details the methodology for quantifying the benefits of power sector decarbonization (Step 11 in Figure 3.1). The benefits from avoided emissions are calculated based on the difference between emissions under current policies i.e. the Business as Usual (BAU) scenario i.e. s_1 and emissions under a 1.5 °C carbon budget consistent net-zero 2050 scenario (NZ 1.5°C 50%) i.e. s_2.

Thus, the total benefits are the present value of benefits from avoided climate damages and adaptation costs, over time period $[t, T]$, is given by $B_{t,T}^{s_1,s_2,\theta,D}$ and the present value of the benefits from avoided air pollution $B_{t,T}^{s_1,s_2,\theta,A}$ i.e.

$$
\begin{aligned}
B_{t,T}^{s_1,s_2,\theta} &= B_{t,T}^{s_1,s_2,\theta,D} + B_{t,T,A}^{s_1,s_2} \\
&= \theta \times \sum_{\tau=t}^{T} \Delta E_{\tau}^{s_1,s_2} + B_{t,T,A}^{s_1,s_2,\theta},
\end{aligned}
\tag{3.1}
$$

where,

- θ is the Global Social Cost of Carbon (see 3.3.1)
- $\sum_{\tau=t}^{T} \Delta E_{\tau}^{s_1,s_2}$ is the difference between avoided annual emissions under BAU scenario s_1 and NZ 1.5 50% scenario s_2.
- $B_{t,T,A}^{s_1,s_2,\theta}$ are the avoided air pollution benefits as calculated in Bolton and Kleinnijenhuis (2025)

3.3.1 Social Cost of Carbon

SCC is the present value of future climate damages (in dollars) from emitting one additional ton of CO_2 into the atmosphere today. This Pigouvian approach aims to internalize external costs of carbon emissions, theoretically allowing market mechanisms to achieve efficient outcomes when emissions are priced at their marginal social cost.[9]

The estimation of SCC involves complex scientific modeling and significant normative judgments, leading to a range of values with important policy implications. Three major Integrated Assessment Models (IAMs) dominate the landscape: the DICE model, treating the world as a single unit; the PAGE model, employing Monte Carlo methods for uncertainty; and the FUND model, providing detailed regional assessments.[10]

Recent political and academic developments underscore the evolving nature of SCC estimates. During the Biden Administration, the EPA released an updated estimate of $190 per ton of CO_2 in 2023[11], while research by Bilal and Känzig (2024) found substantially higher values—up to $1,367 per ton—by exploiting global temperature variability to better capture extreme climate events[12].

[9] As mentioned in the Great Carbon Arbitrage, the marginal SCC is relevant to evaluate a marginal change in emissions relative to the BAU scenario.

[10] The DICE (Dynamic Integrated Climate-Economy) model was developed by W. D. Nordhaus (1992), the PAGE (Policy Analysis of the Greenhouse Effect) model by Hope (2008), and the FUND (Climate Framework for Uncertainty, Negotiation and Distribution) model by Anthoff and Tol (2019). Each model yields varying SCC estimates depending on structure, assumptions, and discount rates.

[11] See https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf. The EPA estimate reflects methodological improvements in modeling climate impacts and damages. In contrast, President Trump's administration disbanded the Interagency Working Group on the Social Cost of Greenhouse Gases in 2017 through Executive Order 14154. See https://www.whitehouse.gov/presidential-actions/2025/01/unleashing-american-energy/

[12] Bilal and Känzig (2024)'s August 2024 study initially reported an SCC of $1,065 per ton, which was updated to $1,367 per ton in November 2024.

Following Bolton and Kleinnijenhuis (2025), I consider two SCC cases: \$190/tCO_2 (Rennert et al., 2022) and \$1056/tCO_2 (Bilal & Känzig, 2024). Since I analyze large-scale emission reductions relative to current policies, I apply the average SCC to each ton of CO_2 reduction. While the academic literature has focused primarily on marginal SCC estimation, Pindyck's (2019) survey-quantitative approach suggests the average global SCC is at minimum \$80/tCO_2, with estimates reaching approximately \$1000/tCO_2, supporting the chosen range.

3.3.2 Country Specific Decarbonization Benefits

Building on the methodology in the Great Carbon Arbitrage, I now examine how individual countries benefit from their own decarbonization efforts. For any country y within the global set of countries $\mathcal{Y}$, the benefits from transitioning away from fossil fuels in their power sector (comparing scenario s_2 against s_1) can be expressed as:

$$B^{s_1,s_2,\theta}_{y\leftarrow y,t,T} = \theta_y \times \sum_{\tau=t}^{T} \Delta E^{s_1,s_2}_{y,\tau} + B^{s_1,s_2,A}_{y,t,T} \quad (3.2)$$

In 3.2, θ_y represents the country-specific Social Cost of Carbon (SCC). This is a portion of the global SCC (θ), such that $\theta = \sum_{y\in\mathcal{Y}} \theta_y$. Following Ricke, Drouet, Caldeira, and Tavoni (2018), who developed country-level SCC estimates using climate model projections and empirical economic damage estimations, I calculate each country's SCC as:

$$\theta_y = \theta \times \frac{\hat{\theta}_y}{\hat{\theta}} \tag{3.3}$$

where $\frac{\hat{\theta}_y}{\hat{\theta}}$ is the country y's SCC share relative to the global SCC.

Country-specific SCC: The distribution of climate damages is highly unequal across countries. Ricke et al. (2018)'s paper reveals substantial heterogeneity in country-level contributions to the global SCC, with countries like India, China, Saudi Arabia, and the United States consistently incurring large fractions of the global cost across different model specifications. This heterogeneity stems from varying degrees of climate vulnerability and economic exposure. Countries face different climate damage profiles based on their geographical location, level of economic development, and adaptive capacity. Developing economies in tropical regions often have higher climate vulnerability due to their temperature-sensitive economic activities and limited adaptation resources. Meanwhile, wealthier economies typically show higher absolute SCC values due to their larger economic assets at risk, even if their relative vulnerability might be lower. This regional variation in climate damages underscores the importance of dis-aggregating the SCC to the country level when analyzing decarbonization benefits.

3.3.3 Cross-Border Decarbonization Benefits

To analyze the benefit to a country y to decarbonize the power sector of any country other than their own i.e. country y^*, I express that cross-country benefit of avoided climate damages and adaptation costs[13] as:

$$B^{s_1,s_2,\theta}_{y \leftarrow y^*,t,T} = \theta_y \times \sum_{\tau=t}^{T} \Delta E^{s_1,s_2}_{y^*,\tau}. \tag{3.4}$$

Cross-border benefits can be accrued simply because when one country reduces emissions, others benefit from avoided climate damages because the Earth's climate is an interconnected system. This is an important insight - the benefit to the world of avoiding one ton of CO_2 emissions is the same regardless of where the reduction occurs. This creates an economic basis for climate finance at scale.

Extending the cross-border decarbonization to country groups where group g is the beneficiary and group g^* are the countries who are decarbonizing; I calculate the group benefits as:

$$B^{s_1,s_2,\theta}_{g \leftarrow g^*,t,T} = \theta_g \times \sum_{\tau=t}^{T} \Delta E^{s_1,s_2}_{g^*,\tau}. \tag{3.5}$$

True climate benefits from avoided emissions is only realised when fossil fuel fired power plants are phased out and renewable energy is phased in, simultane-

[13] An important difference to note between equation 3.2 and 3.4 is that avoided air pollution benefits are not considered when estimating cross-country benefits since air pollution co-benefits tend to remain localized. For simplicity, I assume that air pollution benefits do not extend beyond national borders.

ously, while meeting energy demands.

3.4 Costs

This section details the methodology for estimating the costs of power sector decarbonisation (Step 9 and 10 in Figure 3.1). The cost estimation builds on the Great Carbon Arbitrage framework, expanding its application from coal production to the broader power sector. More importantly, it introduces the first-ever comprehensive, comparable country-level estimates for forgone profits upon closure of fossil fuel plants, affected workforce numbers, the wages - a granular analysis previously unavailable in the literature.

Decarbonisation requires the replacing fossil fuel with renewable plants, creating two main cost components. The present value of costs $C_{t,T}^{s_1,s_2,s_r}$ to decarbonise global power sector over period $[t, T]$ from BAU scenario, s_1 to NZ 1.5°C 50% scenario, s_2, with renewable energy mix s_r[14] is,

$$C_{t,T}^{s_1,s_2,s_r} = O_{t,T}^{s_1,s_2} + I_{t,T}^{s_1,s_2,s_r}, \tag{3.6}$$

where,

[14] Renewable Energy mix is different for every country as it is based on their current renewable energy mix and the available land / shoreline. I follow the 'Land Use' methodology as modeled in Bolton and Kleinnijenhuis (2025).

- $O_{t,T}^{s_1,s_2}$ is the Opportunity costs from unused fossil fuels[15]
- $I_{t,T}^{s_1,s_2,s_r}$ is the investments in renewable energy and complementary technologies

Global costs of power sector decarbonisation can be calculated as the sum of costs in each country $y \in \mathcal{Y}$:

$$C_{t,T}^{s_1,s_2,s_r} = \sum_{y \in \mathcal{Y}} C_{y,t,T}^{s_1,s_2,s_r}. \tag{3.7}$$

3.4.1 Opportunity Costs from Unused Fossil Fuels

The opportunity costs of phasing out fossil fuels $O_{t,T}^{s_1,s_2}$ consist of three components: the stranded asset value[16] (missed free cash flows) for owners $O_{t,T}^{s_1,s_2,C}$, wage compensation for displaced workers $O_{t,T}^{s_1,s_2,J}$, and retraining costs $O_{t,T}^{s_1,s_2,R}$:

$$O_{t,T}^{s_1,s_2} = O_{t,T}^{s_1,s_2,C} + O_{t,T}^{s_1,s_2,J} + O_{t,T}^{s_1,s_2,R}. \tag{3.8}$$

[15] Opportunity costs reflect the economic value lost by not using existing fossil fuel infrastructure that would otherwise operate under current policies.

[16] Welsby, Price, Pye, and Ekins (2021) find that majority of fossil fuels need to stay in the ground. 90% of the coal must remain unextracted and 60% of Oil and Gas (fossil methane) must stay in the group to keep within 1.5°C carbon budget. It is important to value, estimate and think about these fossil fuel reserves that must remain in the group as stranded assets. Semieniuk et al. (2022) find that most 'losses' will be borne by individuals in 'rich' countries.

Cost to Owners

The present value of global opportunity costs to owners $O_{t,T}^{s_1,s_2,C}$ is given by the sum of the discounted value of missed free cash flows in each country y over time:

$$O_{t,T}^{s_1,s_2,C} = \sum_{\tau=t}^{T} \sum_{y \in \mathcal{Y}} \frac{O_{y,\tau}^{s_1,s_2,C}}{(1+\rho)^{(\tau-t)}}, \tag{3.9}$$

where ρ is the discount rate[17].

For each country y and year τ, the missed free cash flow $O_{y,\tau}^{s_1,s_2,C}$ is calculated by multiplying the reduction in electricity generation by the profit per unit:

$$O_{y,\tau}^{s_1,s_2,C} = \sum_{f \in \mathcal{F}} \sum_{l \in \mathcal{L}_y^f} \Delta Q_{y,f,l,\tau}^{s_1,s_2} \times \pi_{y,f,l}, \tag{3.10}$$

where

- $\mathcal{F}$ is the set of fossil fuel types (coal, oil, gas)
- $\mathcal{L}_y^f$ is the set of power plants of type f in country y
- $\Delta Q_{y,f,l,\tau}^{s_1,s_2}$ is the reduction in electricity generation
- $\pi_{y,f,l}$ is the profit per unit of electricity generation[18]

[17] I use the same discount rate as Adrian et al. (2022)'s calculated coal company discount rate, $\rho = 2.8\%$

[18] I assume profit margins remain constant over time due to the inherent uncertainty in predicting future unit profits under different climate scenarios.

To estimate the profit values $\pi_{y,f,l}$, I analyze financial data from 421 global firms operating 6,950 power plants.[19] The methodology involves calculating average free cash flows for each firm, allocating these across their generation portfolio, and calculating profit per unit of electricity generation. The detailed step-by-step calculation approach is provided in Appendix A.1.

Compensation for Lost Wages

A just transition requires compensating workers who lose their jobs due to early plant closures. I assume that the compensation period is 5 years[20].The present value of wage compensation $O_{t,T}^{s_1,s_2,J}$ is calculated as:

$$O_{y,f,t,T}^{s_2,J} = \sum_{\tau=t}^{T} \frac{j_{y,f,\tau}^{s_2} \times \bar{w}_{y,f,\tau} \times l}{(1+\rho)^{\tau-t}}, \quad f \in \mathcal{F} \tag{3.11}$$

where

- $j_{y,f,\tau}^{s_2}$ is the number of workers losing jobs in country y for fossil fuel type f at time τ

[19]Data sourced from Forward Analytics (2024) and Bloomberg Finance LP (accessed September 2024).

[20]The 5-year period aligns with proposed transition programs in Australia (The Greens political party's job-for-job guarantee package) called the *Powering past coal and gas: the Greens' climate and energy plan to fight the climate crisis, grow jobs and repower the economy with net-zero emissions by 2035* (2022). It could be thought of as 50% compensation for 10 years. It gives younger workers time to find new employment while allowing older workers to retire early as seen in Spain (Just Transition contracts with miners' unions) in 2018 and Germany (5 Billion Euros compensation in the Coal Phase-out Act)

- $\bar{w}_{y,f,\tau}$ is their average wage
- l is the compensation period (assumed to be 5 years)

The projected job losses are calculated proportionally to capacity reductions:

$$j^{s_2}_{y,f,\tau} = W_{y,f,t_0} \times \left(\frac{\hat{C}^{s_2}_{y,f,\tau-1} - \hat{C}^{s_2}_{y,f,\tau}}{\hat{C}^{t_0}_{y,f}} \right), \quad f \in \mathcal{F} \tag{3.12}$$

where W_{y,f,t_0} is the initial number of workers and $\hat{C}$ represents capacity.[21]

To estimate the number of workers affected, we use global and regional employment figures from the International Energy Agency (IEA) and allocate them to countries based on capacity share. This approach is validated by comparing with available country-specific data: for India, the CEEW reports approximately 400,000 workers in coal-fired plants, which aligns with our estimate of 442,000; for the US, the USEER 2023 reports approximately 200,000 workers in fossil fuel power generation, compared to our estimate of 220,000.

The methodologies for estimating power plant workers and their wages by country and fossil fuel type are detailed in Appendices A.2 and A.3, respectively.

[21] We use capacity rather than electricity generation as the basis for job loss estimation because it better reflects the scale of operations and infrastructure requiring staffing.

Compensation for Retraining Workers

Having calculated the present value of wage compensation for job losses, I now estimate the compensation that could be offered for retraining costs of power plant workers projected to lose their jobs under scenario s_2.

As fossil fuel power plant capacity is phased out and renewable energy is phased in, affected workers could be retrained for employment in the renewable industry. The discounted costs of retraining workers in country y are $O^{s_2,R}_{y,f,t,T}$, calculated by multiplying the number of workers losing their jobs by the average retraining cost per worker:

$$O^{s_2,R}_{y,f,t,T} = \sum_{\tau=t}^{T} \frac{j^{s_2}_{y,f,\tau} \times \bar{i}^{R}_{y,f,\tau}}{(1+\rho)^{\tau-t}}. \tag{3.13}$$

where:

- $j^{s_2}_{y,f,\tau}$ is the number of power plant workers losing their job at time τ (as calculated earlier in equation A.10)
- $\bar{i}^{R}_{y,f,\tau}$ is the estimated retraining cost per worker (see equation 3.14

The retraining cost per worker is estimated by scaling US-based cost estimates according to relative wage levels:

$$\bar{i}^{R}_{y,f,t} = \frac{\bar{w}_{y,f,t}}{\bar{w}_{USA,f,t}} \times \bar{r}^{R}_{USA,t} \tag{3.14}$$

where $\bar{w}_{y,f,t}$ is the average power plant worker wage in country y, $\bar{w}_{USA,f,t}$ is the corresponding average wage for the United States, and $\bar{r}^{R}_{USA,t}$ is the baseline retraining cost estimate for the United States from Louie and Pearce (2016).[22]

The wage ratio serves as a scaling factor to adjust US retraining cost estimates to other countries, accounting for differences in local training costs and wages. This approach allows for a globally applicable estimate of retraining costs while recognizing country-specific economic conditions.

3.4.2 Investment Costs in Renewable Energy

An important component of phasing out fossil fuel is phasing in renewable energy, along with supporting technologies (battery and grid infrastructure) which keep up with increase in energy demand. This section details the methodology used to calculate the present value of the investment costs in renewables, $I^{s_1,s_2,s_r}_{t,T}$, which consists of two main components:

[22]Louie and Pearce (2016) specifically estimated the retraining costs for coal workers in the United States. Following the approach in the Great Carbon Arbitrage (Adrian et al., 2022), I assume that this US-based retraining cost factor can be adapted to other countries by scaling with relative wages and that it applies similarly across different fossil fuel types.

$$I_{t,T}^{s_1,s_2,s_r} = I_{t,T}^{s_1,s_2,s_r,R} + I_{t,T}^{s_1,s_2,s_r,C} \tag{3.15}$$

where:

- $I_{t,T}^{s_1,s_2,s_r,R}$ represents the present value of investments required to build renewable capacity that replaces phased-out fossil fuels (See 3.4.2)
- $I_{t,T}^{s_1,s_2,s_r,C}$ captures the present value of investments in complementary technologies necessary for grid stability (See 3.4.2)

Direct Investment in Renewable Capacity

I determine the required renewable capacity investments on a country-level as opposed to a plant-level approach. This approach is preferred as renewable energy development typically occurs at national or regional scales, and national policies generally govern energy transitions.

Global investment cost for replacing fossil fuels with renewables is calculated as the sum of country-specific investments;

$$I_{t,T}^{s_1,s_2,s_r,R} = \sum_{y \in \mathcal{Y}} I_{y,t,T}^{s_1,s_2,s_r,R} \tag{3.16}$$

For country y, the present value of annual investments to replace the phased-out fossil fuels on the power grid in NZ 1.5 50%scenario s_2 relative to the BAU scenario s_1 is given by:

$$I^{s_1,s_2,s_r,R}_{y,t,T} = \sum_{\tau=t}^{T} \frac{I^{s_1,s_2,s_r,R}_{y,\tau}}{(1+\rho)^{(\tau-t)}} \tag{3.17}$$

where:

- ρ is the discount rate, same as equation 3.10
- T is the time horizon for the analysis
- s_r is the renewable energy mix for country y

Annual investment costs in a given country y and year τ are calculated by:

$$I^{s_1,s_2,s_r,R}_{y,\tau} = \sum_{q\in\mathcal{R}} G^{s_1,s_2,s_r,q}_{y,\tau} \times i^{q,s_1,s_2,s_r}_{\tau} \tag{3.18}$$

Here, $G^{s_1,s_2,s_r,q}_{y,\tau}$ represents the capacity of renewable type q that must be built in year τ, and i^{q,s_1,s_2,s_r}_{τ} is the unit investment cost for that renewable type. I discuss below how to determine both these components below. (See equations 3.19 and 3.22)

Determining Required Renewable Capacity The required renewable capacity depends on several factors. For country y, to move from scenario s_1 to s_2, this required renewable capacity would depend on the electricity shortfall due to the phase-out of fossil fuels , the chosen renewable mix s_r and capacity factors f_y^q specific to each country and technology.

The renewable capacity i.e. $G_{y,\tau}^{s_1,s_2,s_r,q}$ to be built in year τ is given by:

$$G_{y,\tau}^{s_1,s_2,s_r,q} = \omega_{y,\tau}^{q,s_r} \times h^{-1}(D_{y,\tau}^{s_1,s_2,s_r}) \times \frac{1}{f_y^q} \tag{3.19}$$

Each component of equation 3.19 has been explained below,

Renewable Energy Mix s_r

I set the baseline replacement renewable mix for country $y \in \mathcal{Y}$ equal to the country's current energy mix in terms of renewable energy capacity. While this approach reflects each country's revealed renewable energy preferences based on existing deployment patterns, it is not a sophisticated assumption. For this reason, I rely on Bolton and Kleinnijenhuis (2025) methodology on Land Use, where they estimate s_r to be time varying such that the chosen mix adhered to each country's land space constraints, including water bodies[23]. If a renewable type q reaches its land constraint during the phase-in, remaining capacity requirements are then re-distributed among other renewable types with available land capacity. The weight

[23] Bolton and Kleinnijenhuis (2025) provide a comprehensive assessment of land use requirements and constraints for different renewable technologies. Their methodology categorizes land types according to suitability for various renewable technologies and accounts for country-specific land availability.

$\omega^q_{y,\tau}$ of each renewable energy type q in country y at time τ is calculated as:

$$\omega^q_{y,\tau} = \frac{\hat{C}^q_{y,t}}{\sum_{g \in Q} \hat{C}^g_{y,t}}, \quad \forall q \in Q \text{ and } \forall \tau \in [t, T] \tag{3.20}$$

where $\hat{C}^q_{y,t}$ represents the existing capacity of renewable energy type q in country y at time t.

Electricity-Capacity Conversion Function h

The function h in equation 3.19 represents the standard conversion from capacity (MW) to energy (MWh), which typically involves multiplying by the number of hours in a year (8,760). Consequently, h^{-1} is the inverse function that converts the energy shortfall $D^{s_1,s_2,s_r}_{y,\tau}$ (in MWh) back to capacity terms (MW), allowing the calculation of required renewable capacity[24].

Electricity Shortfall $D^{s_1,s_2,s_r}_{y,\tau}$

The electricity shortfall due to the phase out of fossil fuels is calculated as:

$$D^{s_1,s_2,s_r}_{y,\tau} = \max\{\Delta Q^{s_1,s_2}_{y,\tau} - R^{s_1,s_2,s_r}_{y,\tau}, 0\} \tag{3.21}$$

where $\Delta Q^{s_1,s_2}_{y,\tau}$ represents the fossil fuel electricity not produced due to the phase-out, and $R^{s_1,s_2,s_r}_{y,\tau}$ is the electricity produced by the existing stock of renewables built to replace fossil fuels. This shortfall calculation ensures energy security by track-

[24]This conversion is necessary because while fossil fuel phase-out creates an energy generation gap measured in MWh, renewable capacity investments are usually made in terms of MW of installed capacity.

ing the cumulative effect of the transition over time. As more renewable capacity is built in earlier years (increasing $R_{y,\tau}^{s_1,s_2,s_r}$), less new capacity needs to be added in later years to address the same amount of fossil fuel phase-out. The max function ensures that no additional investment is required when existing renewable generation exceeds the phased-out fossil fuel generation.

Capacity Factors f_y^q

The sun, say for instance, only shines 25% of the time at full intensity in country y on average, then the capacity factor for solar in that country is $c_{y,q} = 0.25$. This means that for a given amount of energy shortfall, four times as much capacity of solar will need to be installed than the theoretical capacity had $c_{y,q}$ been equal to one. Bolson, Prieto, and Patzek (2022) highlight these regional variations, noting that solar PV in Latin America achieves capacity factors of around 0.20 (or 20%), while in Europe the average is only 0.10 (10%). Similarly, wind power in the Middle East and North Africa (MENA) reaches capacity factors of 0.33, compared to approximately 0.21 in Europe. These regional differences directly impact the infrastructure requirements and investment needed for renewable energy transitions.

Unit Investment Cost Projections (Learning Effects) Investment costs for renewable technologies is not assumed to remain static but follow Wright's Law, capturing the empirically observed decline in costs as cumulative installed capacity increases Samadi (2018). This "learning-by-doing" effect reflects in the the unit investment cost for renewable technology q at time τ i.e. $i_{\tau}^{s_1,s_2,s_r,q}$ modeled as:

$$i_{\tau}^{s_1,s_2,s_r,q} = \alpha_q \left(\sum_{y \in \mathcal{Y}} \left(\sum_{\tau_d \leq t-1} G_{y,\tau_d}^{q} + \sum_{\tau_b = t+2}^{\tau-1} G_{y,\tau_b}^{s_1,s_2,s_r,q} \right) \right)^{-\gamma_q} \tag{3.22}$$

where,

- α_q is a technology-specific normalization constant[25]
- $\sum_{\tau_d \leq t-1} G_{y,\tau_d}^{q}$ is cumulative installed capacity of technology q up to the start of the phase-out (See Table 3.2[26])
- $\sum_{\tau_b=t+2}^{\tau-1} G_{y,\tau_b}^{s_1,s_2,s_r,q}$ new capacity additions from the phase-out start until time $\tau - 1$
- γ_q is the learning rate parameter for technology q

Learning Rate γ_q The learning rate parameter γ_q determines how quickly costs fall with increased deployment. One could think of it as a percentage reduction Θ_q in investment costs for each doubling of installed capacity :

$$\Theta_q = 1 - 2^{-\gamma_q} \tag{3.23}$$

[25]The normalization constant α_q is calibrated using the initial investment cost i_t^q at time $t = 2022$ and the global cumulative installed capacity as of 2023, derived from IRENA (2024a). See table 3.2

[26]The latest available data on cumulative installed capacity is 2023. For simplicity, I assume that this applicable till the start of the phase-out.

As shown in Table 3.2, learning rates vary significantly across technologies, with Solar PV exhibiting the highest rate[27]. (γ = 0.32, yielding a 20% cost reduction per doubling) compared to offshore wind (γ = 0.04, yielding only a 3% reduction). These differences reflect varying technological maturity and innovation potential, with emerging technologies like batteries showing particularly strong learning potential (25% cost reduction per doubling).

This approach provides a conservative estimate of future cost declines, as it only accounts for capacity built specifically to replace phased-out fossil fuels, not renewable capacity deployed for other purposes that would also contribute to global learning effects.

Complementary Investments

High renewable energy reliance requires investments in expanding transmission grids and scaling up storage technologies to ensure power supply (Creutzig, Agoston, Goldschmidt, et al., 2017). Following Adrian et al. (2022), complementary investments in energy storage and grid flexibility systems are included to ensure grid stability with high renewable penetration.

[27]Solar PV costs have demonstrated the power of Wright's Law in action. With a learning rate of $\gamma_q = 0.32$, each doubling of global cumulative capacity has historically reduced costs by approximately 20%. This explains why solar module prices fell from over $75/watt in 1976 to less than $0.30/watt by 2020 – a more than 99% reduction as global capacity increased by several orders of magnitude (Roser, 2020).

Table 3.2: Renewable Energy and Storage System Parameters

Technology	Capacity Factor	Installation Cost (2022)	Learning Rate (γ)	Doubling Invest. Cost Reduction (Θ %)	Lifetime (years)	Degradation Rate (%)	Cumulative Installed Capacity (2022)
Solar PV	0.1380	876 USD/kW	0.32	20%	30	0.50	1412093 MW
Wind Onshore	0.2148	1274 USD/kW	0.07	5%	30	0.48	944205 MW
Wind Offshore	0.2181	3461 USD/kW	0.04	3%	30	0.48	73185 MW
Hydropower	0.4200	2881 USD/kW	-	-	100	0.50	1406863 MW
Geothermal	0.7400	3478 USD/kW	-	-	25	0.50	14846 MW
Storage Systems							
Short-term Batteries	-	315 USD/kWh	0.421	25%	12	2.00	2,400 GWh
Electrolyzers	-	1355 USD/kW	0.129	9%	10	0.50	217 MW

Sources: Capacity factors calculated using Forward Analytics Data 2024; Installation costs from IRENA (2024b) (renewables) and Way, Ives, Mealy, and Farmer (2022) (storage); Learning rates and associated investment costs reduction upon doubling of globally installed capacity from Samadi (2018) (solar and wind) and Way et al. (2022) (storage); Lifetime and degradation rates from Way et al. (2022) and IRENA (2024a); Global cumulative installed capacity data for renewable energy from IRENA (2024a), for batteries from IEA (2024), and for electrolyzers from IEA (2023).

The complementary investments $I_{t,T}^{s_1,s_2,s_r,C}$ has four critical components:

$$I_{t,T}^{s_1,s_2,s_r,C} = I_{t,T}^{s_1,s_2,s_r,B} + I_{t,T}^{s_1,s_2,s_r,E} + I_{t,T}^{s_1,s_2,s_r,G} + I_{t,T}^{s_1,s_2,s_r,R_E} \tag{3.24}$$

These components represent investments in short-term energy storage (B), long-term energy storage (E), grid extensions (G), and additional renewable capacity needed to power electrolyzers (R_E).

This approach adopts the conservative assumptions from Way et al. (2022) that a stable electricity grid with high renewable penetration requires:

- Short-term battery storage capacity sufficient to store 20% of daily generated renewable electricity

- Long-term storage using green hydrogen capable of storing one month's worth of annual electricity generation
- Grid extensions proportional to the additional renewable capacity
- Additional renewable capacity to account for conversion losses in electrolyzers (with a conversion efficiency of $\psi = 0.7$)

These assumptions likely create an upper bound on complementary investment costs, as the renewable penetration from just replacing fossil fuels often remains below the 85% threshold where extensive long-term storage becomes necessary according to Way et al. (2022). Additionally, as with direct renewable investments, learning effects are applied to storage technologies according to Wright's Law, with the parameters shown in Table 3.2.

3.5 Net Benefits

This section details the methodology for estimating the net benefits of the power sector decarbonisation. Following the approach of Bolton and Kleinnijenhuis (2025), I consider cases of global, country specific and cross-country financing arrangements across both public and private sectors.

The net present value of decarbonizing the global power sector over time period $[t, T]$ according to the NZ 1.5 scenario s_2 relative to the BAU scenario s_1, replacing fossil fuels with renewable energy mix s_r for a social cost of carbon of θ, is calculated as:

$$A_{t,T}^{s_1,s_2,s_r,\theta} = B_{t,T}^{s_1,s_2,\theta} - C_{t,T}^{s_1,s_2,s_r} \tag{3.25}$$

Where:

- $A_{t,T}^{s_1,s_2,s_r,\theta}$ represents the net present value
- $B_{t,T}^{s_1,s_2,\theta}$ represents the benefits as defined in equation 3.1
- $C_{t,T}^{s_1,s_2,s_r}$ represents the costs as defined in equation 3.6

3.5.1 Country-Level Net Benefits

Similar to the Global Net Benefits, country-level net benefits can be calculated as the difference between benefits and costs. However, on a country-level there are two scenarios to consider,(1) Benefits a country receives when the entire world decarbonizes (global action) and (2) Benefits a country receives solely from self decarbonization (unilateral action).

Country Net Benefits from Global Decarbonisation: For a country y, the net benefits derived from global decarbonisation, assuming it pays its own decarbonisation costs, are expressed as:

$$A^{s_1,s_2,\theta}_{y\leftarrow w,t,T} = B^{s_1,s_2,\theta}_{y\leftarrow w,t,T} - C^{s_1,s_2,s_r}_{y,t,T} \tag{3.26}$$

Here, the notation $y \leftarrow w$ indicates that country y receives benefits from worldwide (w) decarbonization. The benefits term $B^{s_1,s_2,\theta}_{y\leftarrow w,t,T}$ represents the country's share of global climate benefits, proportional to its country-specific social cost of carbon share θ_y. (See equation 3.2)

Country Net Benefits from Self Decarbonisation: The net benefits to country y from its own unilateral decarbonization, assuming it pays all associated costs is:

$$A^{s_1,s_2,\theta}_{y\leftarrow y,t,T} = B^{s_1,s_2,\theta}_{y\leftarrow y,t,T} - C^{s_1,s_2,s_r}_{y,t,T} \tag{3.27}$$

In this case, $y \leftarrow y$ indicates that country y receives benefits from its own decarbonization efforts.

It follows that $A^{s_1,s_2,\theta}_{y\leftarrow y,t,T} < A^{s_1,s_2,\theta}_{y\leftarrow w,t,T}$, indicating that a country receives greater benefits from global collective action than from unilateral efforts. This inequality arises because global decarbonization leads to greater total avoided emissions than a single country's actions, thereby providing greater overall climate benefits to each participating country.

Blended Finance Approach

In practice, countries typically seek to distribute decarbonization costs between public and private sectors through blended finance mechanisms. This approach, similar to Adrian et al. (2022), leverages public funds to catalyze investments from capital markets.

For a catalytic ratio of $1 : \varphi$ (indicating that \$1 of public funds attracts \$ φ of private capital), with the public sector covering a proportion $\lambda \in [0, 1]$ of renewable investment costs, the country's net benefits become:

$$A^{s_1,s_2,\theta,\lambda}_{y\leftarrow y,t,T} = B^{s_1,s_2,\theta}_{y\leftarrow y,t,T} - C^{s_1,s_2,s_r,\lambda}_{y,t,T} \tag{3.28}$$

Where the adjusted costs are:

$$C^{s_1,s_2,s_r,\lambda}_{y,t,T} = \lambda \times I^{s_1,s_2,s_r}_{y,t,T} + O^{s_1,s_2,s_r}_{y,t,T} \tag{3.29}$$

Here:

- λ is the proportion of renewable investment costs paid by the public sector
- $I^{s_1,s_2,s_r}_{y,t,T}$ represents the investment costs for renewable energy
- $O^{s_1,s_2}_{y,t,T}$ represents the opportunity costs due the phase out of fossil fuel power plants (Recall equation 3.8)

For instance, with $\lambda = 0.25$, the public sector would bear 25% of renewable investment costs plus all early retirement costs for fossil fuel plants, while private capital would fund the remaining 75% of renewable investments.

Notably, equation 3.29 reflects that private capital typically funds only renewable energy development, as these generate revenue streams, while the public sector must cover 100% of early fossil fuel closure costs through grants. While Adrian et al. (2022) use a public-private ratio of 1:9 (approximately 10% public funding), I use a more conservative ratio of 1:3 (25% public funding) in line with the Bolton and Kleinnijenhuis (2025) paper.

3.5.2 Cross-Border Financing and Net Benefits

Cross-border financing arrangements are particularly relevant for climate finance from developed to developing countries. With COP26 and COP27 reaffirming the need for developed nations to provide substantial financial support to developing countries for climate mitigation and adaptation, understanding the economic logic of such transfers.

When one group of countries provides climate finance to another group, we can analyze the net benefits for both the financier and recipient countries:

Net Benefits for Financier Countries For a coalition of willing countries, denoted as $g_f \in \mathcal{Y}_f$ financing decarbonization in a group recipient countries denoted as $g_r \in \mathcal{Y}_r$, the net benefits to the financier coalition are:

$$A^{s_1,s_2,\theta,\lambda}_{g_f \leftarrow g_r,t,T} = B^{s_1,s_2,\theta}_{g_f \leftarrow g_r,t,T} - C^{s_1,s_2,s_r,\lambda}_{g_r,t,T} \tag{3.30}$$

Where:

- $B^{s_1,s_2,\theta}_{g_f \leftarrow g_r,t,T}$ represents climate benefits received by financier coalition from emissions reductions in recipient countries (Recall equation 3.5)
- $C^{s_1,s_2,s_r,\lambda}_{g_r,t,T}$ represents the costs of decarbonization in recipient countries that financier coalition pays

Net Benefits for Recipient Countries For the recipient developing countries g_r, the net benefits when financier countries g_d cover a proportion λ of the public costs equal their gross benefits:

$$A^{s_1,s_2,\theta,\lambda}_{g_r \leftarrow g_r,g_f,t,T} = B^{s_1,s_2,\theta}_{g_r \leftarrow g_r,t,T} > 0 \tag{3.31}$$

Thus, receiving climate finance for decarbonization in the economic interest of the recipient countries, as they gain substantial benefits including reduced air pollution.

Economic Returns Calculation

To assess the efficiency of decarbonization investments, I calculate economic returns as the ratio of net benefits to costs. Simply, the economic return R is defined as:

$$R = \frac{\text{Benefits} - \text{Costs}}{\text{Costs}} \tag{3.32}$$

For public financing with blended finance approaches, the relevant costs are the public investment costs plus early retirement costs. Thus, the public economic return R_p is calculated as:

$$R_p = \frac{B_{t,T}^{s_1,s_2,\theta} - (\lambda \times I_{t,T}^{s_1,s_2,s_r} + O_{t,T}^{s_1,s_2})}{\lambda \times I_{t,T}^{s_1,s_2,s_r} + O_{t,T}^{s_1,s_2}} \tag{3.33}$$

This provides a straightforward measure of the economic efficiency of public funds deployed for decarbonization, expressed as a percentage return on investment. The Results section will present calculations using this framework across different countries and financier scenarios.

CHAPTER 4

RESULTS

In this chapter, I present the costs, benefits, net benefits and the economic returns of decarbonizing the global power sector.

4.1 Current Energy & Emissions Mix

Referring to the Table 3.1, the global power sector accounts for 14.16 Gt CO_2e annually (as per the Forward Analytics dataset). Coal fired power plants are the highest emitting source in the energy mix at 71.2% followed by Gas (24.1%)[1] and Oil (4.5%).

[1]Note, this figure reflects only direct combustion emissions and does not account for methane leakages throughout the natural gas supply chain (extraction, processing, transmission). Research by Howarth (2024) demonstrates that when these upstream emissions are included, the total climate impact of natural gas may be significantly higher.

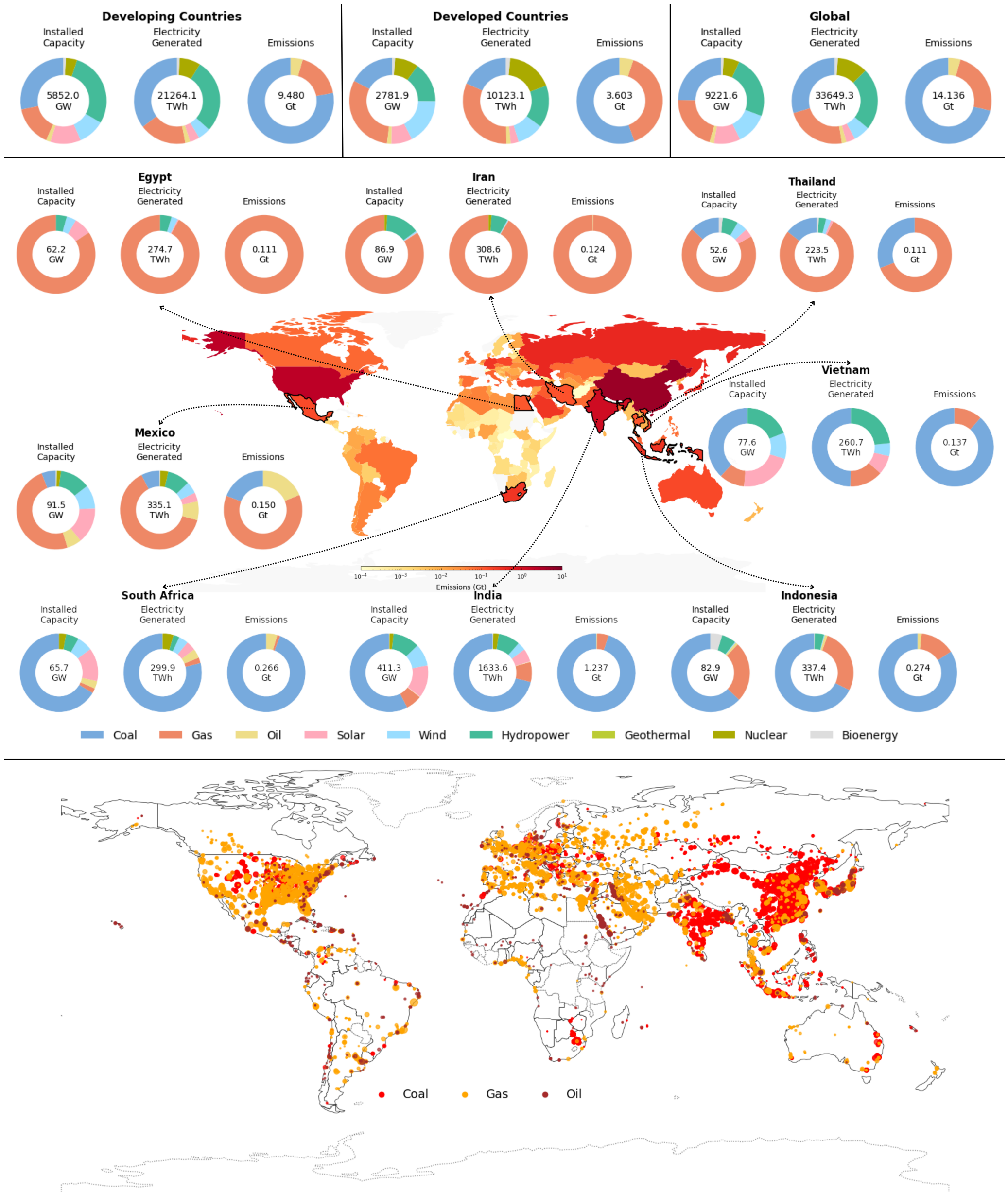

Figure 4.1: Energy Mix of Power Sector, Emissions Heatmap and Plant Locations (2024)

As per Figure 4.1, we see the current energy mix for the world, developing countries and developed countries[2]. We observe that Developing countries contribute to 9.4 Gt CO_2e (66%) of the emissions out of the world's energy emissions, a majority of which are coal related. The figure also illustrates a set of eight countries (India, Indonesia, South Africa, Mexico, Viet Nam, Iran, Thailand, and Egypt) who have the highest emissions among developing countries. In the emissions heat map in the center of the figure, we can observe that China and United States of America are the world's largest emitters (See Figure 4.2). In the bottom map of Figure 4.1, we observe that majority of coal fired power plants are concentrated in Asia whereas Gas plants are concentrated in Europe and North America. Oil plants are very few, scattered all across the globe.

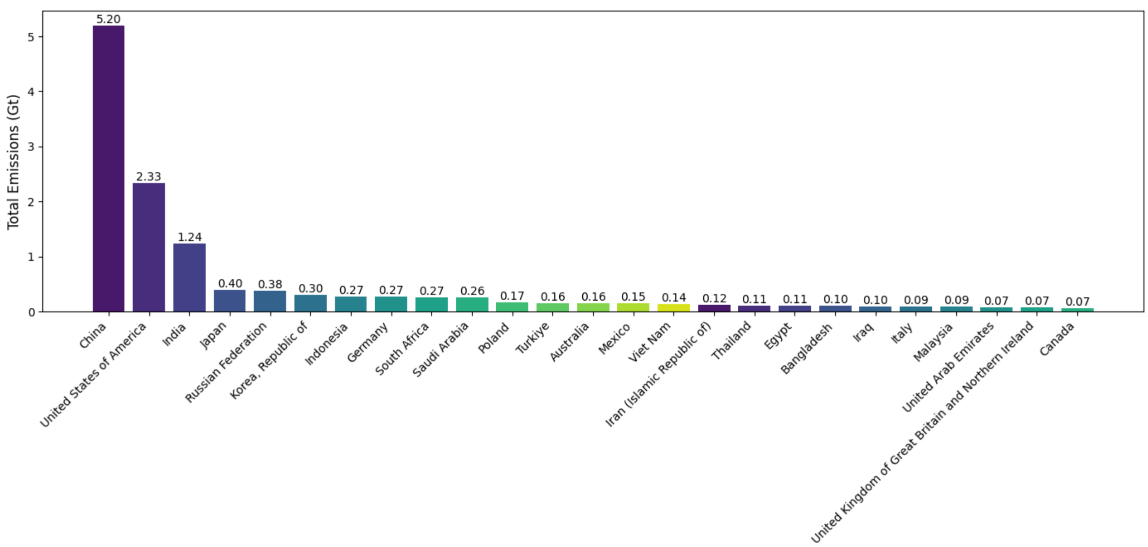

Figure 4.2: Top 25 power sector emitting countries (2024)

[2]Developed and developing countries are classified as per the 1992 UNFCCC. In this framework, the established Annex I (developed countries and economies in transition) and non-Annex I (developing countries) classification is based on historical emissions, economic capabilities, and the principle of 'Common but Differentiated Responsibilities and Respective Capabilities' (CBDR-RC).

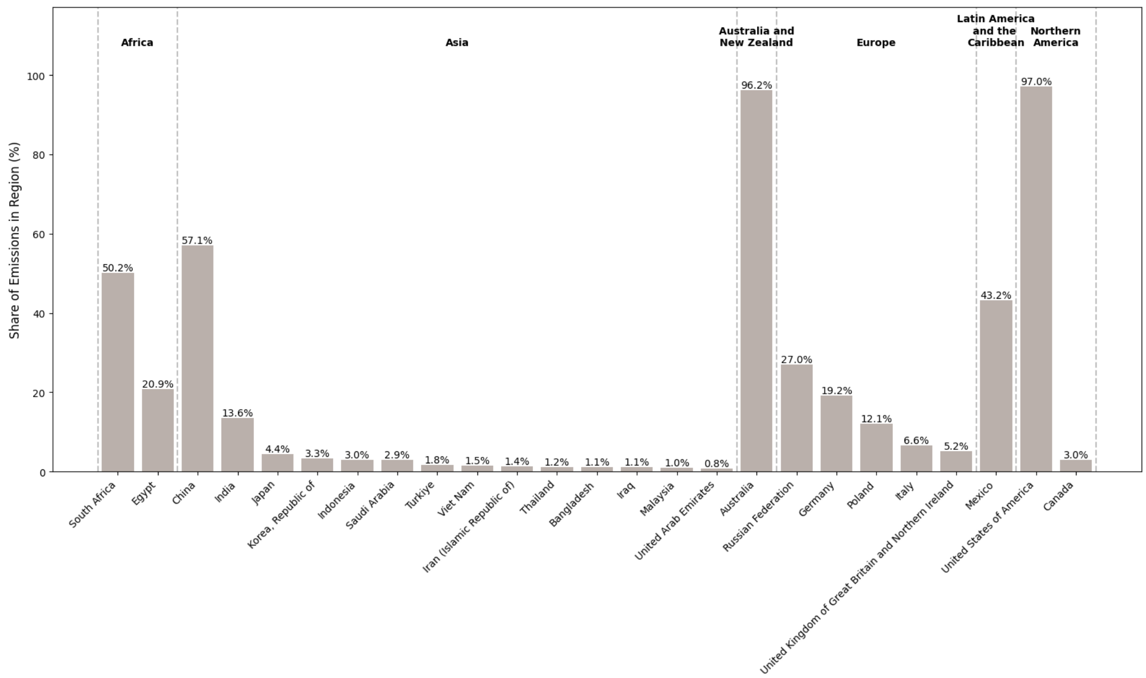

Figure 4.3: Share of emissions by country within each region (2024)

4.2 Net Benefits of Global Power Sector Decarbonization

The economic analysis of decarbonizing the global power sector reveals substantial net benefits over both medium-term (2025-2035) and long-term (2025-2050) time horizons. Table 4.1 presents a comprehensive breakdown of the costs, benefits, and net benefits of this transition.

With a conservative social cost of carbon (SCC) of \$190/tCO_2, the present value of benefits reaches \$74.6 trillion by 2050, primarily from avoided climate damages (\$67.9 trillion) and reduced air pollution (\$6.6 trillion). Using a higher SCC of

$1056/tCO_2$, which better accounts for climate tipping points, total benefits increase to $384.2 trillion.

The costs of this transition amount to $24.2 trillion through 2050, dominated by renewable investments ($23.4 trillion) with minimal opportunity costs from stranded fossil assets ($0.8 trillion). These costs remain constant regardless of the SCC valuation used. This breakdown of costs presents an important point. It is not expensive to phase out fossil fuels i.e. paying the polluter to not pollute is only 2.5% (2025-2035) and 3.3% (2025-2050) of the total costs of decarbonization.

Net benefits are positive across all scenarios, ranging from $50.4 trillion (with $190/tCO_2$) to $360.0 trillion (with $1056/tCO_2$) by 2050. On a per-tonne basis, each tonne of CO_2 avoided generates $140.9 to $1006.7 in net benefits, with costs of only $67.7 per tonne. By not decarbonising, these findings demonstrate that the world is forgoing a highly favourable investment, with benefit-cost ratios between 3:1 and 16:1 depending on the SCC valuation.

Table 4.1: Global costs, benefits and net benefits (in PV) of phasing out fossil fuels in the power sector and phasing in replacement renewables while keeping up with any growth in energy demand.

		2025-2035		2025-2050	
		$190/tCO_2$	$1056/tCO_2$	$190/tCO_2$	$1056/tCO_2$
Benefits (tn $)		26.9	138.8	74.6	384.2
	Of which:				
	Benefits from avoided climate damages and adaptation costs	24.6	136.5	67.9	377.6
	Benefits from lower air pollution	2.4	2.4	6.6	6.6
Costs (tn $)		15.9		24.2	
	Of which:				
	Investment costs in renewables	15.5		23.4	
	Opportunity costs of fossil fuels	0.4		0.8	
Net benefits (tn $)		11.0	122.9	50.4	360.0
Avoided emissions ($GtCO_2$)		129.2		357.6	
Benefits per tonne of avoided emissions ($/tCO_2$)		208.2	1075.1	208.6	1074.4
Costs per tonne of avoided emissions ($/tCO_2$)		123.1		67.7	
Net benefits per tonne of avoided emissions ($/tCO_2$)		85.1	952.0	140.9	1006.7

4.3 Net Benefits of Country Decarbonization

Tables B.1 and B.2 present the economic benefits of power sector decarbonization over 2025-2035 and 2025-2050 respectively, for individual countries[3]. The tables show both climate benefits and air pollution benefits, ranked from highest to lowest total benefits.

Tables B.3 and B.4 show the present value costs of decarbonization for the same periods. These tables break down the opportunity costs of fossil fuel phase-out (compensation to owners, workers' wages, and retraining costs) and renewable energy investments (including grid extensions and storage).

[3]The Forward Analytics data only has asset-level data from 156 countries.

4.3.1 Country- Level Benefits:

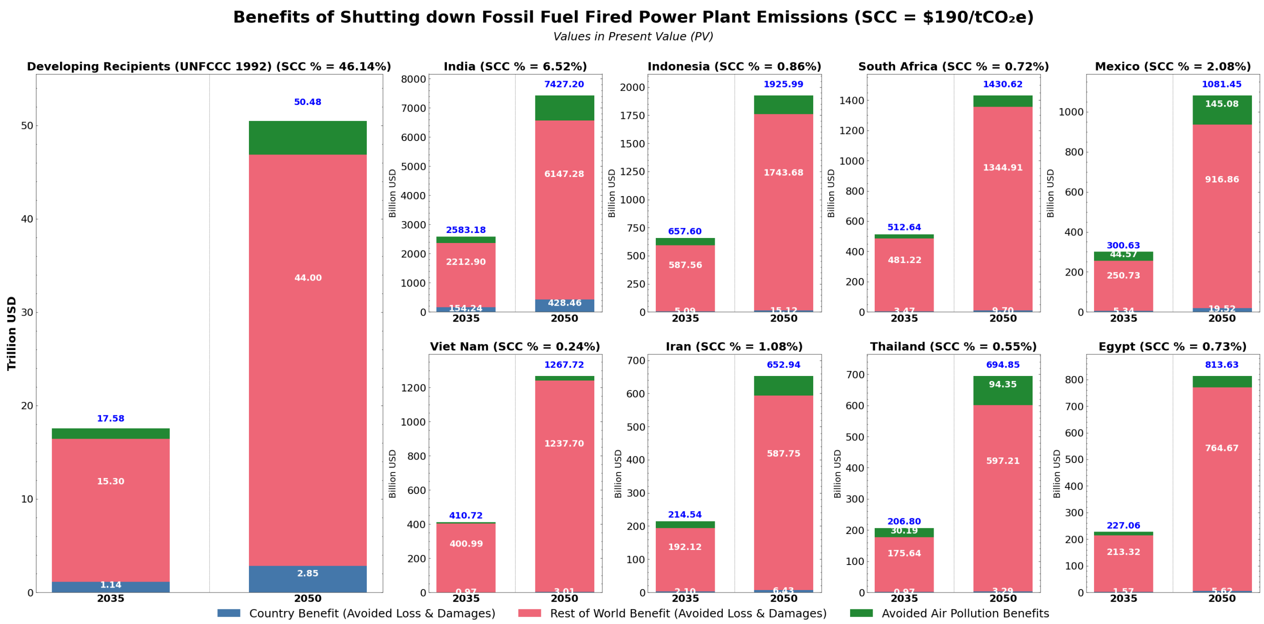

Figure 4.4: Total Benefits of Power sector Decarbonization for 2025-2035 and 2025-2050

Figure 4.4 shows the benefits breakdown for the select 8 developing countries (using $190/$tCO_2$ SCC) and country SCC shares from Ricke et al. (2018).

Developing Recipients would gain $17.58 trillion by 2035 and $50.48 trillion by 2050. Looking at specific countries, India would receive $2.58 trillion by 2035 and $7.4 trillion by 2050. For all countries analyzed, benefits in 2050 are typically 2-3 times higher than in 2035, reflecting accumulating avoided emissions over time.

The avoided air pollution co-benefits represent a significant portion of total benefits. The benefits reveals a critical challenge in climate action: individual countries receive only a small portion of the total climate benefits from their decarbonization efforts (as we saw in section 3.5.1). For Developing Recipients, only \$1.14 trillion (7%) of climate benefits in 2035 accrue to the emitting countries themselves, with \$15.30 trillion (93%) benefiting other countries. This distribution pattern highlights the collective action problem inherent in climate mitigation.

4.3.2 Country-Level Costs

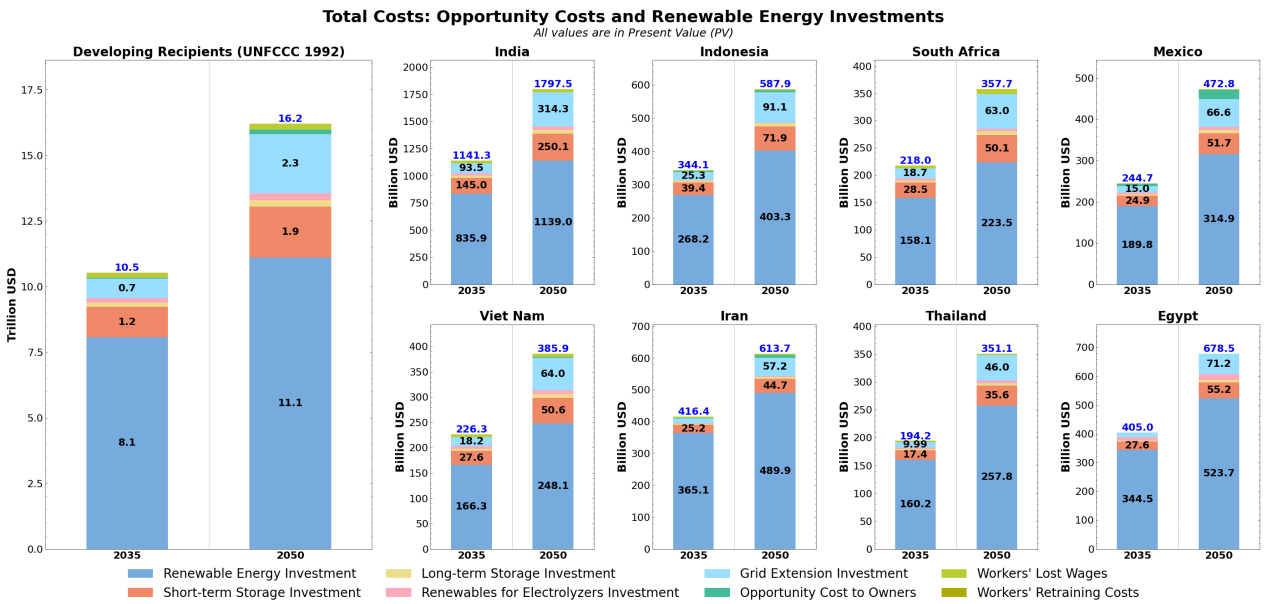

Figure 4.5: Total Costs of Power sector Decarbonization for 2025-2035 and 2025-2050.

Figure 4.5 shows the cost breakdown for the select 8 developing countries over the 2025-2035 and 2025-2050 time horizons.

Renewable energy investments constitute the vast majority of costs across all countries - approximately 70%. For Developing Recipients, renewable investments total $8.1 trillion in 2035 and $11.72 trillion in 2050, compared to fossil fuel opportunity costs of just $0.4 trillion (3.6%) and $0.8 trillion (3.3%) respectively.

For India, renewable investments account for $0.84 trillion (73.7%) in 2035 and $1.14 trillion (63.3%) in 2050. Storage investments (both short and long-term) represent $0.14 trillion (12.3%) in 2035 and $0.25 trillion (13.9%) in 2050. Grid extension costs are $0.09 trillion (7.9%) and $0.31 trillion (17.2%) respectively.

Viet Nam's total costs are $0.23 trillion in 2035 and $0.39 trillion in 2050, with opportunity costs to fossil fuel owners being nearly negligible at 0.01-0.02 trillion (4.3-5.1%).

This cost breakdown contradicts the common perception that compensating fossil fuel interests is the primary financial barrier to decarbonization. In reality, investment in clean energy infrastructure represents the overwhelming majority of transition costs. As discussed in section 3.5.1, renewable energy investments generate revenues and thus are typically funded by private capital.

4.3.3 Economic Returns of Self Decarbonisation

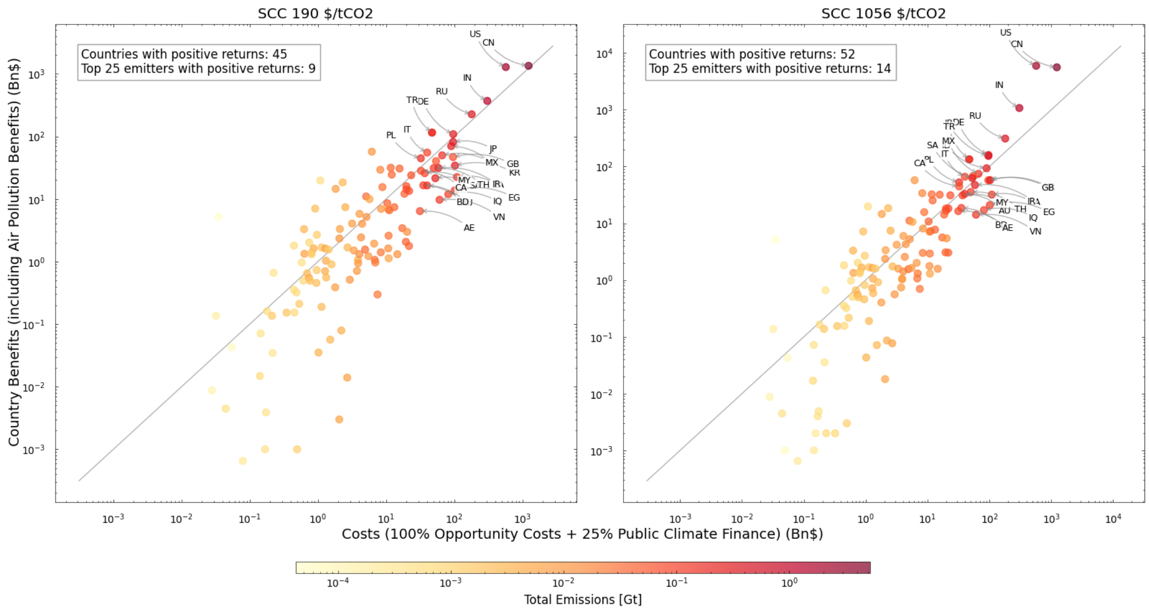

Figure 4.6: Costs and benefits of self-financed decarbonization (2025-2035).

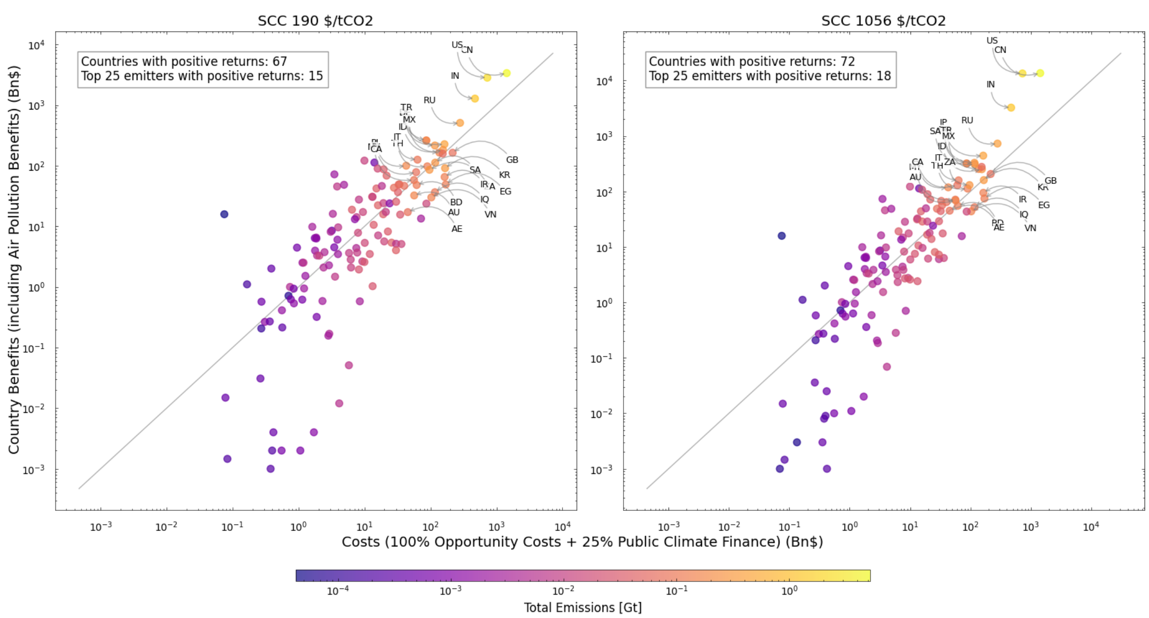

Figure 4.7: Costs and benefits of self-financed decarbonization (2025-2050).

Figures 4.6 and 4.7 map the cost-benefit positions of all countries when financing their own decarbonization. For the time horizon 2025-2050 with SCC=\$190/tCO_2, 67 countries show positive net benefits from self-financing, including 15 of the top 25 emitters. With SCC=\$1056/tCO_2, this increases to 72 countries and 18 top emitters. For the shorter 2025-2035 timeframe, countries with positive returns drop to 45 and 52 respectively, with only 9 and 14 of the top 25 emitters[4] showing positive returns. These results demonstrate that for many countries, particularly major emitters, decarbonization represents not just an environmental imperative but an economically rational choice even when self-financed.

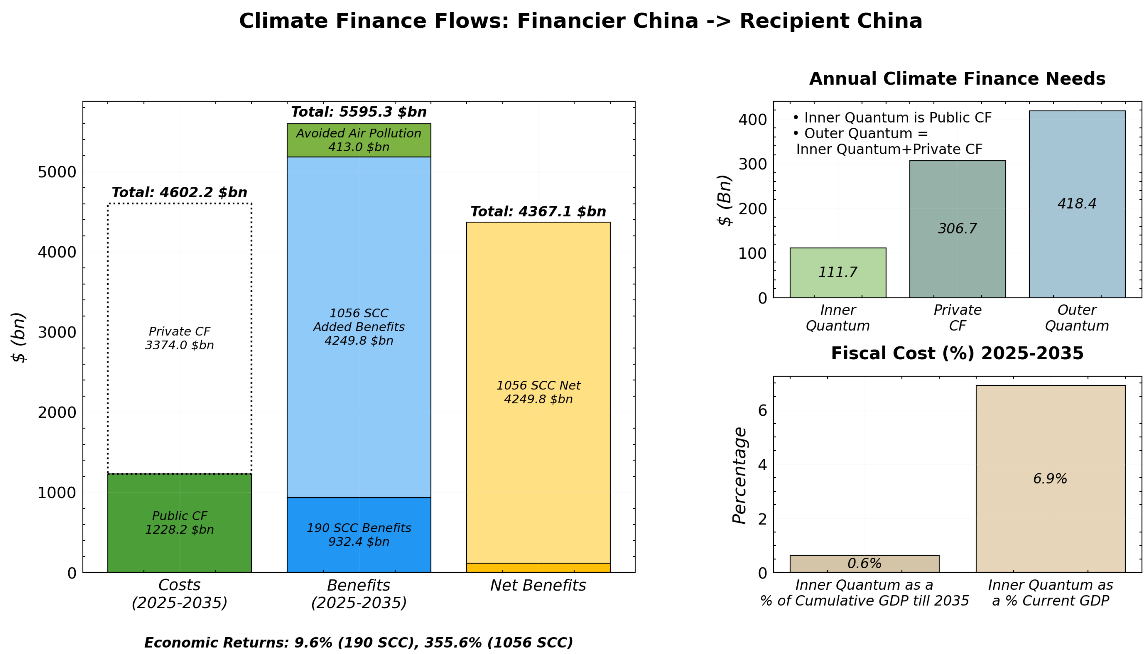

Figure 4.8: China: Self-financed power sector decarbonization

Figure 4.8 presents ***China***'s self-financing scenario for 2025-2035. China would

[4]The top 25 emitting countries constitute 90.7% of total emissions.

need to invest \$4602.2 billion, with 26.7% (\$1228.2 billion) from public finance and 73.3% (\$3374.0 billion) from private capital. The benefits total \$5595.3 billion, including \$413.0 billion from avoided air pollution and \$5182.3 billion from climate benefits. This generates economic returns of 9.6% under SCC=\$190/tCO_2 and 355.6% under SCC=\$1056/tCO_2. The public finance requirement represents 0.6% of China's cumulative GDP through 2035, or 6.9% of current GDP, with annual needs of \$111.7 billion in public finance leveraging \$306.7 billion in private capital.

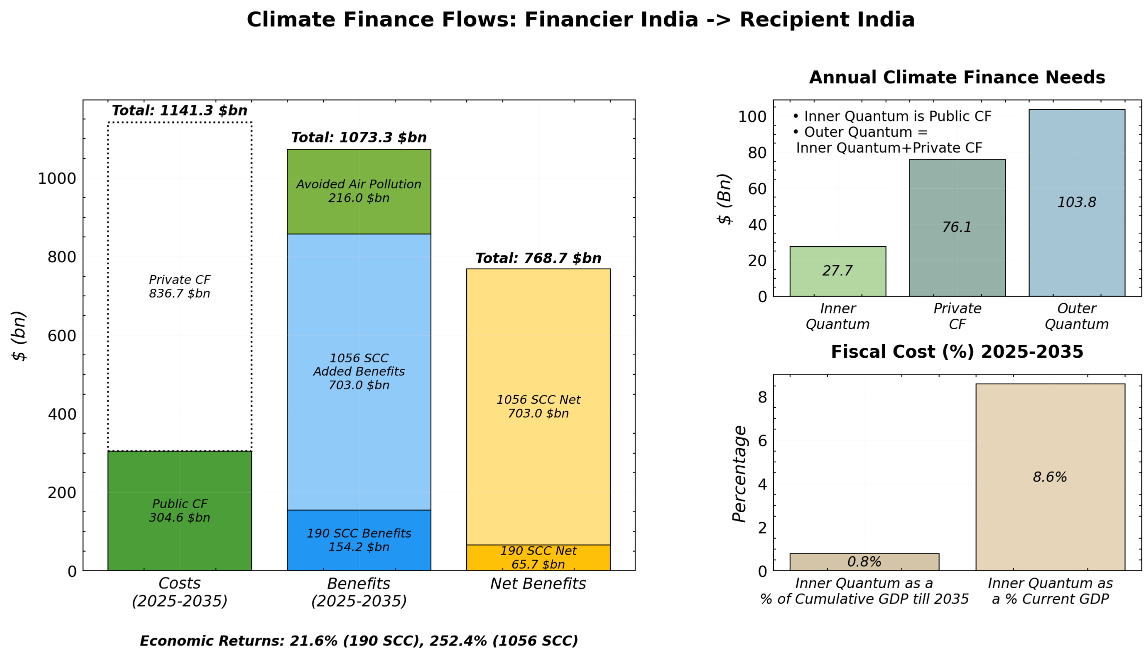

Figure 4.9: India: Self-financed power sector decarbonization

Similarly, Figure 4.9 shows ***India*** would need to invest \$1141.3 billion during 2025-2035, with \$304.6 billion from public finance and \$836.7 billion from private capital. The benefits amount to \$1073.3 billion, including \$216.0 billion from avoided air pollution. This delivers economic returns of 21.6% under SCC=\$190/tCO_2 and 252.4% under SCC=\$1056/tCO_2. The public finance requirement constitutes 0.8% of India's cumulative GDP through 2035, with annual needs of \$27.7 billion in public finance catalyzing \$76.1 billion in private capital.

Thus even for the world's largest emitters, self-financing decarbonization represents an economically sound investment with substantial returns. However, with the climate clock ticking and limited carbon budget, it is important that economically sound cross-border climate financing arrangements are explored.

4.4 Net Benefits of Cross-Border Decarbonization

In this section I examine the economic returns from various cross-border climate finance arrangements. This analysis is informed by Bolton and Kleinnijenhuis (2024) COP29 policy brief and the Nature commentary by Bolton, Edenhofer, Kleinnijenhuis, Rockström, and Zettelmeyer (2025).

4.4.1 Climate Finance Flows Between Country Groups

The UNFCCC's list of developed and developing countries the groundwork for cross-border climate financing mechanisms, however these countries, their emissions and exploitation of fossil fuels have evolved over time. In this subsection, I begin with the baseline scenario, just as the UNFCCC (1992) classification imagines it. Later, I explore alternative financier-recipient arrangements that reflect current economic and political realities.

Scenario 0: The UNFCCC Baseline

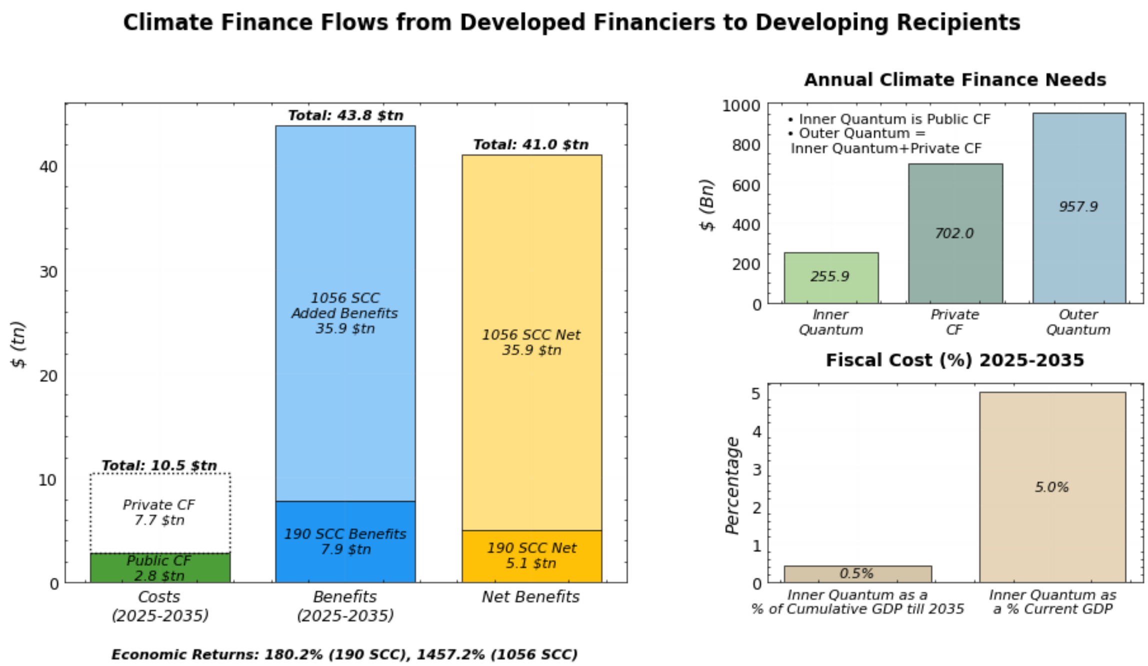

Figure 4.10: UNFCCC baseline Climate Finance Flows (Scenario 0)

Under Scenario 0, when all developed countries finance all developing countries' power sector decarbonization (2025-2035), the total cost reaches $10.5 trillion with 26.7% ($2.8 trillion) as public finance. This investment delivers economic returns of 180.2% under a social cost of carbon (SCC) of $190/t$CO_2$ and 1457.2% under $1056/t$CO_2$, while requiring annual public finance of $255.9 billion or 0.5% of developed countries' cumulative GDP.

This baseline follows the original UNFCCC configuration but requires significant coordination among all developed countries, which has proven challenging as evidenced by the limited outcomes at COP29.[5]

Scenario 1: Coalition of Wealthy Nations Financing a Targeted Recipient Group

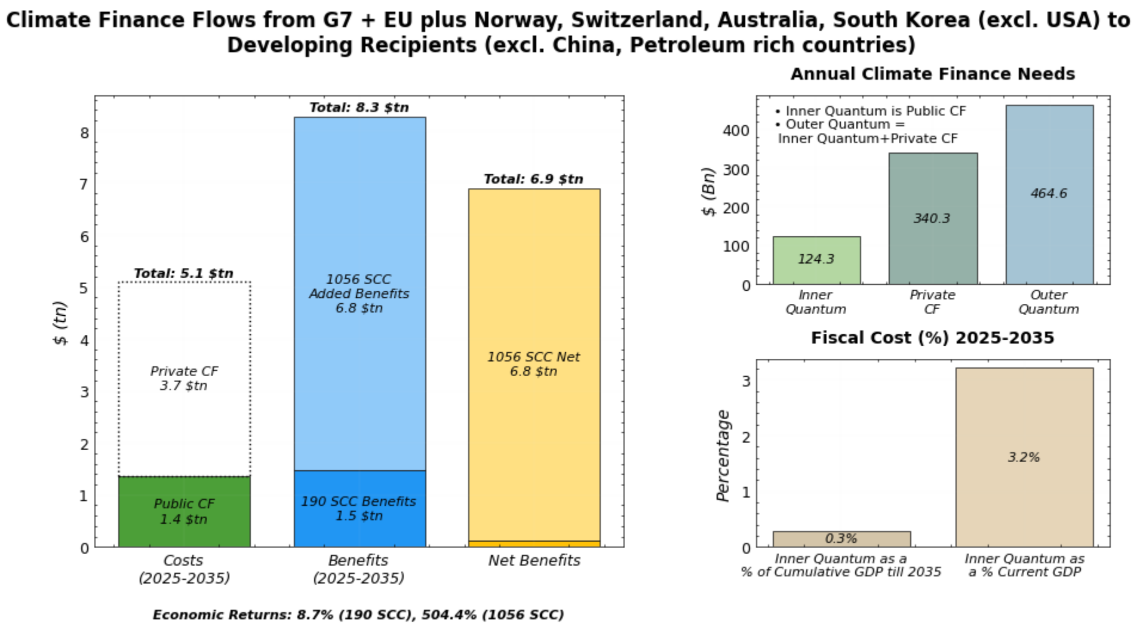

Figure 4.11: Coalition of Wealthy Nations Financing Flows (Scenario 1)

This scenario examines a coalition of G7+EU (excluding USA), plus Norway, Switzerland, Australia, and South Korea financing developing countries exclud-

[5]The recent Joint Statement on the New Common Quantified Goal (NCQG) signed by leading academics and climate scientists highlight the insufficient NCQG set in Baku i.e. climate finance commitments of 300 Bn USD annually, including public and private sources.

ing China and petroleum-rich nations. This approach reduces costs to $5.1 trillion while still delivering positive economic returns of 8.7-504.4% depending on the SCC value. The fiscal impact decreases to 0.3% of the financiers' cumulative GDP, requiring $124.3 billion annually.

The coalition configuration is based on countries that already provide public climate finance as documented in the Oxfam Climate Finance Shadow Report 2023, which details reported public climate finance and grant-equivalent estimates for 2019-2020 (Zagema et al., 2023). Excluding the United States reflects its withdrawal from the Paris Agreement, while the recipient group excludes China and petroleum-rich states based on their financial capacity to self-finance their energy transitions. This targeted approach allows for more efficient allocation of resources to countries with greater need and less financial capacity.

Scenario 2: Adding China as a Financier

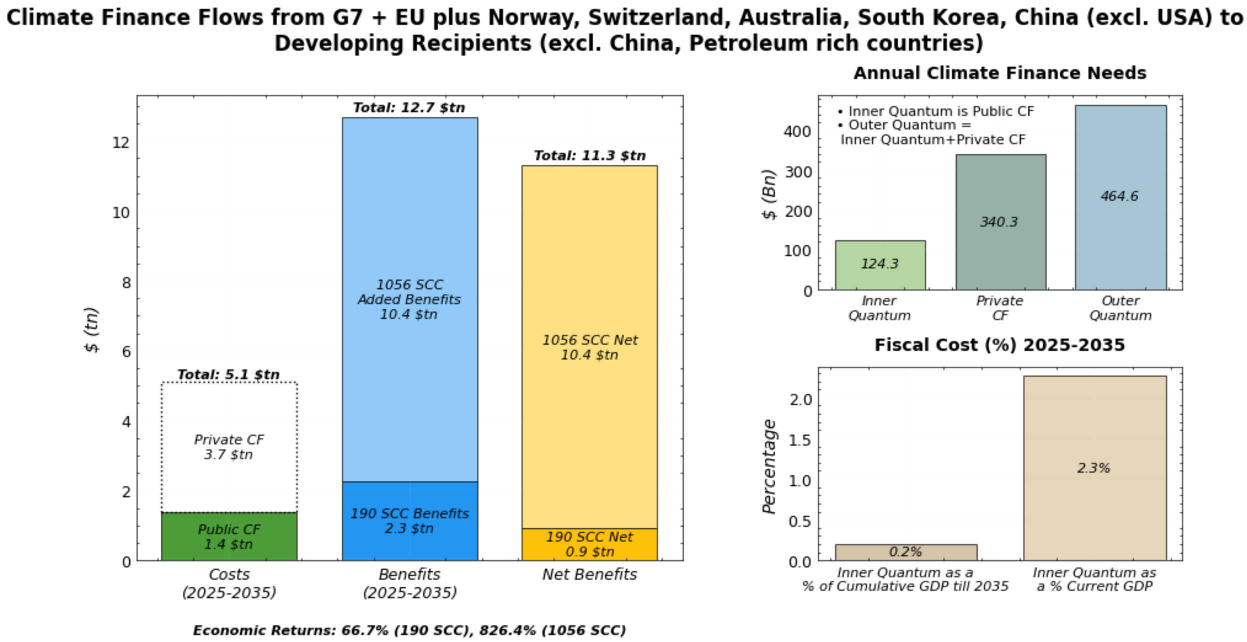

Figure 4.12: Adding China to the Financing Coalition (Scenario 2)

When China joins as a financier alongside the coalition above, economic returns increase to 66.7-828.4% with fiscal impact further reduced to 0.2% of GDP. This scenario demonstrates how broadening the financier coalition improves outcomes while maintaining feasible coordination.

China's inclusion as a financier rather than recipient acknowledges its dual status as both the world's largest emitter and a major economic power with growing international influence. With approximately 11% of the global social cost of carbon impact (Ricke et al., 2018), China has strong economic incentives to support global decarbonization with its increasing climate adaptation costs.

These scenarios recognize that effective climate finance coalitions may need to evolve beyond traditional developed/developing country classifications to reflect current geopolitical and economic realities. Additionally, the returns on climate finance vary by recipient country. Coal-reliant economies like India, Indonesia, South Africa, and Vietnam offer higher returns (273-1973%) compared to primarily gas-reliant economies like Egypt, Thailand, and Iran. This difference stems from the higher emission intensity of coal plants, which creates larger emission reductions per dollar invested.

Lastly, there is a need to move away from the narrow focus on ”moral obligation” and towards an approach that emphasises the ”economic” interest of developed countries in order to scale climate finance from billions to trillions (Cite E axes policy brief).

CHAPTER 5

DISCUSSION

The economic returns of global power sector decarbonization revealed in the results section are substantial, but significant bottlenecks prevent this potential from being realized. This chapter examines key barriers to scaling climate finance and proposes practical solutions to overcome them.

5.1 Reframing Climate Finance: From Moral Obligation to Economic Interest

Perhaps the most fundamental obstacle to mobilizing climate finance at scale has been the persistent framing of such funding as charity rather than investment. This mischaracterization has dominated international climate negotiations since the establishment of the UNFCCC in 1992.[1] Bolton and Kleinnijenhuis (2024) in their COP29 focused policy brief note, “a highly plausible explanation for why developed countries found it hard to garner the $100 billion a year for developing countries is that they considered it as an act of charity, or moral obligation, rather than an act of economic self-interest.” This framing explicitly contradicts the empirical findings presented in Chapter 4, where I demonstrated that financ-

[1]The UNFCCC established the principle of ”Common but Differentiated Responsibilities and Respective Capabilities” (CBDR-RC) based on historical emissions, economic capabilities, and different development priorities.

ing developing countries' power sector decarbonization generates economic returns ranging from 180.2% to 1457.2%, depending on the social cost of carbon valuation.

The principle of Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC), while well-intentioned, has inadvertently reinforced this charity framework. Even at recent climate negotiations, this mindset persists. At COP29, Prime Minister Gaston Browne of Antigua and Barbuda criticized wealthy nations, stating that "many rich countries see climate finance as a random act of charity, not recognizing that they have a moral obligation to provide funding."[2] While the ethical dimension has merit, the economic interests revealed in this thesis suggest a more compelling narrative.

Economists have long understood that substantial financial flows are driven by economic incentives, not charitable impulses. Nobel Laureate W. Nordhaus succinctly captured this reality when he observed that "Global warming is a trillion-dollar solution requiring a trillion-dollar solution, and that demands a robust incentive structure." My findings on the economic returns of financing power sector decarbonization across borders provide precisely this incentive structure.

This narrative shift—from charity to investment—is essential for scaling climate finance from billions to trillions. Both science and economics agree: Climate finance at scale from developed to developing countries is not only equitable but

[2]Prime Minister Browne made this statement during a high-level segment at COP29 as noted in a New York Times Article. See https://www.nytimes.com/2024/11/13/climate/cop24-climate-finance.html

also economically beneficial to developed nations and fiscally affordable.[3]

5.2 Industry Resistance: Fossil Fuel Lobbying Against Economic Self-Interest

The second major bottleneck is the powerful fossil fuel lobby that has consistently impeded international climate commitments. At COP29, opposition to targeting fossil fuels became explicit, with Saudi Arabia's delegate stating[4] that "the Arab group will not accept any text that targets any specific sectors, including fossil fuels." This resistance persists despite the precedent set at COP28[5], which established the first agreement to transition away from fossil fuels.

The scale and sophistication of fossil fuel industry influence is well-documented. US oil companies alone spent $72 million on federal lobbying in just the first six months of 2024 (Carter, 2025). The results of this thesis show that only 3.3% of the total costs of decarbonization relate to paying fossil fuel owners for stranded assets. Yet, this small minority exerts disproportionate influence over global climate policy.

[3] Both Adrian et al. (2022) and Bolton, Kleinnijenhuis, and Zettelmeyer (2024)) demonstrate the economic returns of climate finance, particularly for coal phaseouts.

[4] See This statement was reported by Mark Carrington from The Guardian covering COP29 negotiations. See https://www.theguardian.com/environment/live/2024/nov/21/cop29-live-draft-texts-negotiations-climate-crisis

[5] The COP28 agreement called upon parties to accelerate the transition towards low-emission energy systems, including by phasing down unabated coal power and phasing out inefficient fossil fuel subsidies as noted in Bolton et al. (2024)

This opposition appears increasingly counterproductive given that approximately 33% of fossil fuel owners also own renewable energy plants (as per the Forward Analytics Data.) Research by Lantushenko and Schellhorn revealed that fossil fuel firms increase lobbying activities and expenditures when they become more vulnerable to climate change news risk. This creates a dangerous feedback loop where the companies most resistant to clean energy transition are also most actively working to delay climate policy.

Fossil fuel lobbying employs multi-faceted strategies: direct political donations, trade associations, "astroturf" campaigns [6], and extensive lobbying through think tanks and academia. A 2021 undercover investigation exposed how ExxonMobil lobbied "under the guise" of the American Petroleum Institute on controversial issues that it did not want to be publicly associated with (Carter, 2025).This coordinated opposition hinders the realization of the economic benefits identified in my analysis.

5.3 Solutions: Climate Clubs and Blended Finance

5.3.1 Building Effective Climate Clubs

To overcome these bottlenecks, I argue for developing effective climate clubs or coalitions. The concept offers a promising approach to international climate coop-

[6] Astroturf lobbying is a manufactured effort to appear like a genuine grassroots movement.

eration by providing both incentives for participation and mechanisms to address free-rider problems. As noted in The Great Carbon Arbitrage, "The obstacles to bargaining and transaction costs will be lower when regional deals are struck as fewer parties have to come together. Tangible benefits from reduced emissions can be reaped even if only a climate club (e.g., one region or country) strikes a deal."[7]

My cross-border financing scenarios in Chapter 4 provide empirical support for this approach. I demonstrated that smaller coalitions of wealthy nations (Scenario 1) or coalitions that include major developing economies like China (Scenario 2) can achieve positive economic returns while reducing the coordination challenges inherent in global agreements. By creating exclusive benefits for members who commit to ambitious climate action while imposing costs on non-participants, climate clubs can accelerate the transition away from fossil fuels.

5.3.2 Harnessing Blended Finance

To address the climate finance gap, my analysis in section 3.5.1 demonstrates that blended finance offers a strategic mechanism to mobilize private investment. This approach strategically uses concessional public and philanthropic capital to attract private investment. According to Igbokwe, blended finance transactions have leveraged an average of $4.1 of commercial capital for every dollar of con-

[7] This observation from Adrian et al. (2022) highlights the practical advantages of climate clubs compared to universal agreements.

cessional capital, with $1.8 coming from private sector investors. Surprisingly, this 4:1 leverage ratio has remained static since 2018 despite a substantially larger sample size, suggesting that donors must become more strategic in prioritizing private sector mobilization.

The potential for blended finance is enormous, considering that global private investors hold over $410 trillion in financial assets, with $20.5 trillion in low- and middle-income countries alone (Igbokwe, 2025). Mobilizing just 1.4% of these private assets would dramatically advance climate finance. However, several barriers must be overcome to scale up blended finance effectively.

The Network for Greening the Financial System (NGFS) identifies seven key barriers hindering the expansion of blended finance:[8] structural issues specific to emerging markets and developing economies (EMDEs); limited investment opportunities and lack of viable climate projects; data gaps and fragmented disclosure standards; knowledge gaps across the blended finance ecosystem; the bespoke nature and complexity of blended finance instruments; lack of climate policies and regulatory clarity; and broader enabling environment challenges. The IMF estimates that private finance will need to account for 90% of mitigation finance going to EMDEs excluding China, yet of the $115.9 billion provided for climate action in developing countries in 2022, only $21.9 billion (19%) came from the private sector (Butler, 2024).

[8] The NGFS (2023) identified these barriers in its analysis of scaling up blended finance for climate action. See https://www.ngfs.net/system/files/import/ngfs/medias/documents/scaling-up-blended-finance-for-climate-mitigation-and-adaptation-in-emdes.pdf

Structuring climate financing as blended finance offers several advantages: it reduces reliance on public funds that have higher marginal costs due to taxation distortions; it limits increases in public debt-to-GDP ratios, particularly important for countries with sovereign debt vulnerabilities; and it frees up public funds for other essential purposes like education. Real-world examples demonstrate this approach's viability. The IFC-Amundi emerging market green bond fund achieved a remarkable 1:9 ratio of public to private capital by having a development institution take the first-loss tranche while successfully placing investment-grade senior tranches in the marketplace[9].

The Salkhit Wind Farm in Mongolia provides another compelling example, achieving approximately a 1:3 ratio between public and private capital. As Mongolia's first wind farm and first private power generator, this USD 120 million project demonstrates how public, private, and development finance can be strategically combined[10].

For blended finance to work at scale, we need more strategic allocation of concessional capital. This requires more flexibility with catalytic capital, adjusting business models to better integrate private investors, and encouraging multilateral development banks to take more junior positions in blended finance struc-

[9] This successful example of blended finance was highlighted in Adrian et al. (2022)

[10] The European Bank for Reconstruction and Development (EBRD) and the Netherlands Development Finance Company (FMO) each provided US$ 47 million in debt financing alongside equity investments. See https://sdg.iisd.org/news/ebrd-funds-first-wind-energy-farm-in-mongolia/ and Appendix (A2) of https://cdm.unfccc.int/UserManagement/FileStorage/ODLH1U20SCPTE4BN5JQA6G7FIXW3KZ#page=22.16. The FMO is 51% owned by the Dutch government

tures (Igbokwe, 2025). Importantly, the optimal blending ratio will likely vary by project, sector, and country context. More research is needed on optimal blended finance structures across different contexts, sectoral estimates beyond power generation to include other high-emitting sectors such as mining, extraction of fossil fuels, transportation, and heavy industry, and the development of standardized frameworks that can reduce transaction costs while maintaining effectiveness.

5.4 Methodological Considerations and Limitations

Several methodological considerations and potential pitfalls warrant acknowledgment when interpreting these results. First, the SCC values that underpin the benefit calculations remain subject to significant uncertainty. While the analysis addresses this by using a range of values (\$190-\$1056/tCO_2), both values could be contested. Lower SCC estimates would reduce the calculated benefits, while some recent research suggests even higher values might be appropriate.[11] Additionally, the country-specific SCC distribution from Ricke et al. (2018) affects which countries are calculated to receive the greatest benefits, which in turn influences the optimal allocation of climate finance.

Second, the analysis assumes perfect implementation of least-cost transition pathways, which may be unrealistic given political and institutional constraints.

[11] Updated versions of Bilal and Känzig (2024) estimate SCC values potentially higher than even the upper range used in this analysis.

Suboptimal implementation could increase costs relative to the estimates presented, potentially reducing net benefits. These implementation inefficiencies are particularly likely in contexts with limited institutional capacity or significant vested interests opposing transition.

Third, the opportunity costs of fossil fuel phase-out may be underestimated for some contexts. While the analysis incorporates direct economic impacts on plant owners and workers, broader economic effects on communities and supply chains are not fully captured. These effects could be particularly significant in regions with high economic dependence on fossil fuel activities.

Finally, the temporal distribution of costs and benefits creates potential pitfalls for implementation. The analysis shows that costs are front-loaded while benefits accrue over longer timeframes. This temporal mismatch creates political challenges, as current decision-makers bear the costs while future constituencies receive many of the benefits. This dynamic helps explain the gap between economic opportunity and implementation progress to date.

CHAPTER 6

CONCLUSION

This thesis asks three main questions, (1) What are the costs and benefits of global power sector decarbonization? (2) how do these costs and benefits vary on the country level and (3) what is the economic potential of cross-border finance? To answer these questions, 79,797 operational power plants across 156 countries are analyzed. Both costs and benefits of transitioning from fossil fuels to renewable energy through 2035 and 2050 are quantified.

Substantial positive economic returns are found across various scenarios. Globally, net benefits reach $11.0 trillion by 2035 and $50.4 trillion by 2050 (SCC $190/tCO_2$). For a higher estimate of SCC ($1056/tCO_2$), the net benefits increase to $122.9 trillion by 2035 and $360.0 trillion by 2050.

Only 3.3% of the total costs is attributable to compensating fossil fuel owners. Thus, paying the polluter is not the significant financier barrier as commonly perceived. Instead, the principal challenge is mobilizing capital at scale for renewable energy infrastructure.

The analysis of cross-border climate finance demonstrates economic returns of 180-1457% for developed countries financing energy transitions in developing nations. This transforms the framing of climate finance from a perceived moral obligation to an economically rational investment opportunity.

Several limitations of this study should be noted. The temporal distribution of costs and benefits creates implementation challenges, as current decision-makers bear immediate expenses while future constituencies receive many of the benefits. Additionally, SCC values remain subject to ongoing scientific debate, and optimal blended finance ratios are likely vary across different contexts. Future research should explore these variations in greater depth, extending this methodological approach to sectors beyond electricity generation and developing standardized frameworks for structuring international climate finance agreements.

This thesis contributes to the literature by providing the first comprehensive, comparable country-level estimates of both costs and benefits of power sector decarbonization, quantifying the economic returns of cross-border climate finance arrangements, and reframes the understanding of financial barriers. The findings demonstrate that power sector decarbonization represents not merely an environmental imperative but a compelling economic opportunity.

APPENDIX A

ESTIMATION METHODOLOGY: COUNTRY SPECIFIC DATASETS

A.1 Power Plant Profits

The following steps detail the methodology used to estimate profit per unit of electricity generation ($\pi_{y,f,l}$) for fossil fuel power plants:

1. Calculate average free cash flows for global firms:

   (a) Obtain 5-year free cash flow data for 421 firms owning 6950 power plants from Bloomberg Finance LP:

   $$F_i = \frac{1}{5} \sum_{\tau=2019}^{2023} F_{i,\tau} \tag{A.1}$$

   where F_i is the mean free cash flow for firm i and $F_{i,\tau}$ is the free cash flow for firm i in year τ.

   (b) Extract electricity generation data from Forward Analytics 2024.

2. Allocate firm profits across fuel types and countries:

   $$\Pi_{i,y,f} = F_i \times \frac{Q_{i,y,f}}{\sum_{f' \in \mathcal{F}_{all}} Q_{i,f'}}, \quad f \in \mathcal{F}_{all} \tag{A.2}$$

where $\Pi_{i,y,f}$ is firm i's profit for fuel f in country y, and $Q_{i,y,f}$ is the electricity generation.[1]

3. Calculate profit per unit of electricity generation:

$$\pi_{i,y,f} = \frac{\Pi_{i,y,f}}{Q_{i,y,f}}, \quad f \in \mathcal{F} \tag{A.3}$$

4. Estimate country-level average profitability:

   (a) Identify each firm's primary country for each fuel type:

$$Primary_{i,f} = y \text{ such that } Q_{i,y,f} > Q_{i,y',f} \text{ for all } y' \in Y, y' \neq y \tag{A.4}$$

   For example, consider a firm i with the following electricity generation: Oil: 1000 MWh in Indonesia, 500 MWh in Malaysia; Gas: 2000 MWh in India, 1500 MWh in Thailand; Solar: 3000 MWh in UK, 2500 MWh in Germany. The primary countries for each fuel type would be: $Primary_{i,\text{Oil}}$ = Indonesia, $Primary_{i,\text{Gas}}$ = India, $Primary_{i,\text{Solar}}$ = UK.[2]

   (b) Define the set of countries for profit estimation:

$$Y_{fossil} = \{y \mid y = Primary_{i,f} \text{ for some firm } i \text{ and fuel } f \in \mathcal{F}\} \tag{A.5}$$

[1] This assumes homogeneous free cash flow generation across all electricity production. This assumption is reasonable as 66.7% of firms in our sample operate only fossil fuel plants, with 85% of these focusing on a single fuel type.

[2] This approach focuses on locations where firms have their most significant operations, which likely provides more reliable profit estimates.

This means I calculate country-level profit estimates for any country that serves as a primary location for at least one firm's fossil fuel type. This approach is logical because if a power generating firm has its largest operations of a particular fuel type in a country, it signals that this country represents a significant market for that type of power generation.

(c) Calculate weighted average profits for these primary countries:

$$\pi_{y,f} = \sum_{i \in I_y} \pi_{i,y,f} \times \left(\frac{Q_{i,y,f}}{\sum_{i \in I_y} Q_{i,y,f}} \right), \quad f \in \mathcal{F} \tag{A.6}$$

where I_y is the set of firms with country y as primary location for fuel f. For example, if three firms have Indonesia as their primary country for coal, with profits of \$20/MWh, \$25/MWh, and \$22/MWh, and electricity generation of 1000 MWh, 1500 MWh, and 500 MWh respectively, the weighted average profit would be:

$$\begin{aligned} \pi_{\text{Indonesia,coal}} &= 20 \times \frac{1000}{3000} + 25 \times \frac{1500}{3000} + 22 \times \frac{500}{3000} \\ &= 20 \times 0.33 + 25 \times 0.5 + 22 \times 0.17 \\ &= 6.6 + 12.5 + 3.74 = 22.84 \text{ \$/MWh} \end{aligned}$$

This weighted average ensures that firms with larger generation have greater influence on the country's average profit estimate.[3]

[3]The weights for all firms in I_y sum to 1, which is a property of weighted averages.

5. Develop regional estimates for countries with incomplete data:

$$\pi_{r,f} = \sum_{i \in I_r} \sum_{y \in Y_r} \pi_{i,y,f} \times \left(\frac{Q_{i,y,f}}{\sum_{i \in I_r} \sum_{y \in Y_r} Q_{i,y,f}} \right), \quad f \in \mathcal{F} \tag{A.7}$$

   where I_r is all firms in region r and Y_r is all countries in region r.

   For example, for Southeast Asia, if firm-level profit data exists across Indonesia, Malaysia, Thailand, and Vietnam, I calculate the weighted average using all firms operating in these countries, regardless of whether any country is their primary location.

6. Apply hierarchical approach for complete coverage:

$$\pi_{y,f} = \begin{cases} \pi_{y,f} & \text{if } y \in Y_{fossil} \text{ and estimate exists for fuel } f \\ \pi_{r(y),f} & \text{otherwise} \end{cases}, \quad f \in \mathcal{F} \tag{A.8}$$

   For example, if Indonesia has a country-specific average profit estimate for coal but not for oil, I use Indonesia's own estimate for coal and the Southeast Asia regional estimate for oil. Smaller countries may not have any country-specific estimates due to data constraints. In such a case, I use Southeast Asia regional estimates for all fuel types.[4]

For each power plant l of type f in country y, we assume $\pi_{y,f,l} = \pi_{y,f}$ if the plant-specific profit data is unavailable. This allows us to calculate the opportunity costs

[4]Regional estimates serve as reasonable proxies because countries within the same region often face similar input costs, regulatory environments, and market conditions.

in equation 3.10 for all fossil fuel plants globally.

A.2 Power Plant Workers

Due to the absence of comprehensive country-level employment data for power plants, I develop a systematic approach to estimate workforce distribution. This methodology uses global and regional employment figures from IEA (2023) to derive country-level employment data using the total capacity by country from Forward Analytics 2024 data.

1. I use the total number of workers in fossil fuel-fired power plants f given in the World Energy Employment Report IEA (2023)[5].
   (a) Global number of workers across power plants in 2022 is $W_g = 3{,}000{,}000$ where $W_{g,coal} = 1{,}700{,}000$, $W_{g,gas} = 1{,}000{,}000$ and $W_{g,oil} = 300{,}000$.
   (b) To estimate the number of workers in fossil fuel f fired power plants across regions & countries defined by the IEA:

$$W_{r,f} = W_{g,f} \times p_{r,f}, \quad f \in \mathcal{F} \tag{A.9}$$

where

[5]The IEA's latest report has global and regional number of power plant workers from 2022, I assume these figures remain applicable for 2024 due to the limited availability of more recent data.

- $W_{r,f}$ is the number of workers in region[6] r for fuel f
- $W_{g,f}$ is the global number of workers for fuel f
- $p_{r,f}$ is the regional percentage of workers for fuel f reported in the World Energy Employment Report IEA (2023)[7]

2. Since country-wise employment data in fossil fuel fired power plants is not publicly available, I estimate the number of workers in country y and fossil fuel f i.e. $W_{y,f}$ based on the share of their region's total capacity:

$$W_{y,f} = \left(\frac{\hat{C}_{y,f}}{\hat{C}_{r,f}} \right) \times W_{r,f}, \quad f \in \mathcal{F} \tag{A.10}$$

where $\hat{C}_{y,f}$ is the total capacity of fuel type f in country y, and $\hat{C}_{r,f}$ is the total capacity of fuel f in region r.

3. To validate this estimation methodology, I compare the results with available country-specific data:

- For India, Jhujhunwala, Mehta, Dileep, and Malhotra (2024) report that $\approx$ 400,000 workers are employed in coal-fired power plants as of 2022, which is close to our estimate of $\approx$ 442,000 workers.
- For the US, $\approx$ 200,000 total workers were employed in coal, oil, gas power plants in 2022, which is close to our estimate of $\approx$ 220,000 workers (U.S. Department of Energy, 2023).

[6] The Report by IEA defines its regions as North America, Europe, Central & South America, Africa, Middle East, Other Asia Pacific, Rest of the World) and specifies countries China and India.

[7] Page 69 presents a combined pie chart titled 'Employment in fossil fuel power generation by region, 2022'. The angles in this pie chart are used to calculate $p_{r,f}$.

A.3 Power Plant Worker Wages

Estimating average wages for power plant workers at the country level presents several challenges: (1) power plants employ workers across diverse job categories, from operators and engineers to maintenance staff and managers, (2) most countries do not publicly report such specific sectoral wage data, and (3) available wage data often does not distinguish between different types of fossil fuel power plants. To overcome these data limitations, I develop a systematic methodology using the Economic Research Institute (ERI) Salary Assessor[8].

This approach addresses these challenges by combining three key elements: (a) detailed job function-specific salary data from ERI, (b) industry-level employment distribution patterns, and (c) representative job function categories for different types of fossil fuel power plants. For simplicity, wage estimates are assumed constant over time in this analysis. The approach consists of five main steps:

1. **Define Industry Categories and Employment Distribution:**
   Various industries comprise the mix of jobs at a fossil fuel fired power plant. Based on the U.S. Department of Energy (2023), power plant employment is categorized into six industries: Utilities, Construction, Manufacturing, Wholesale Trade, Professional Services, and Other Services. Table A.1 shows

[8] World Energy Employment Report (IEA, 2023) cites the ERI Salary Assessor while developing their figures on Annual Salaries & Annual average earnings on Pages 43 and 44. ERI is a leader in the collection, and analysis of compensation, occupation, and cost-of-living data. Their data is employer-provided and come from a variety of sources. They report a detailed methodology for the Salary Assessor at https://cdn.erieri.com/help/SA/SAMethodUS.pdf

the employment distribution.

Fuel Type	Utilities	Construction	Manufacturing	Wholesale Trade	Professional Services	Other Services
Coal	41%	11%	2%	9%	36%	1%
Natural Gas	40%	23%	8%	7%	19%	2%
Oil	3%	0%	44%	17%	35%	1%

Table A.1: Employment Distribution $E_{f,n}\%$ by Fossil Fuel Type f and Industry n
Source: US Energy Employment Report, 2023

While this distribution is based on US data, I apply it globally. This may not be entirely accurate since the employment distribution by fossil fuel type and industry will depend on how widely said fossil fuel is used in the country[9]. However, due to the absence of comparable detailed employment data for other countries, this distribution is applied to all countries.

2. **Select Representative Jobs:**

   A set of representative job titles, *job*, is selected for each fossil fuel sector from the ERI Salary Assessor. Each job title is linked to one or more industries as presented in Table A.2.

   In Table A.2, it becomes clear that certain job functions are common across all fossil fuel power plants, while others are fuel-specific[10]. This categorisation of jobs helps identify transferable skills across different types of power plants[11].

[9]If a country is in the phase of installing a certain fossil fuel fired power plant capacity then the 'Construction' industry might have more % of workers than others.

[10]While the ERI Salary Assessor provides detailed salary data for each job function (e.g., "power plant installer", "boiler operator"), it does not distinguish these salaries based on the type of fossil fuel power plant (coal, oil, or gas).

[11]This method of categorising a set of jobs to determine what jobs come with transferable skills was also employed in the Louie and Pearce (2016).

Table A.2: Representative Jobs by Fossil Fuel Sector with Industry Classifications

Job Title/Function (*job*)	**Gas**	**Coal**	**Oil**	**Industry Classifications** (*n*)
Sales Manager	✓	✓	✓	Wholesale Trade, Professional Services
Safety Inspector	✓	✓	✓	Professional Services
Power Plant Installer	✓	✓	✓	Construction
Gas Leak Inspector	✓			Professional Services
Natural Gas Compressor Operator	✓			Utilities
Boiler Operator	✓	✓	✓	Utilities
Turbine Operator	✓	✓	✓	Utilities
Furnace Operator		✓		Utilities
Coal Equipment Operator		✓		Utilities, Wholesale Trade
Oil Burner			✓	Utilities
Oil Analyst			✓	Professional Services
Power Plant Manager	✓	✓	✓	Utilities
Power Generating Plant Operator	✓	✓	✓	Utilities
Power Distributor & Dispatcher	✓	✓	✓	Utilities, Wholesale Trade
Power Electrician	✓	✓	✓	Utilities, Other Services
Power Plant Engineer	✓	✓	✓	Utilities, Professional Services, Manufacturing
Power Plant Worker	✓	✓	✓	Utilities, Other Services

When a job is associated with multiple industries[12], it means that workers in this role typically perform functions that span these industries. This approach reflects the reality that some power plant job functions are more cross-functional than others, and their wages may be influenced by practices across multiple industry sectors.

3. **Calculate Normalized Weights:**

   For each job power plant with fossil fuel type f, a normalized weight v is calculated. This process involves two steps:

   (a) Calculate the initial weight $v'_{job,f}$:

$$v'_{job,f} = \frac{\sum_n E_{f,n} \times \mathbb{1}_{job,n}}{\sum_n \mathbb{1}_{job,n}} \tag{A.11}$$

[12] Example: "Power Plant Engineer" may be involved in utilities operations, professional engineering services, and manufacturing processes.

where

- $E_{f,n}$ is the employment % for fuel f in industry n (from Table A.1)
- $\mathbb{1}_{job,n} = 1$ if job title job is associated with industry n, and 0 otherwise (from Table A.2)
- $\mathcal{J}_f$ is the set of all representative jobs for fuel type f

(b) Normalize the weight:

$$v_{job,f} = \frac{v'_{job,f}}{\sum_{j \in \mathcal{J}_f} v'_{j,f}} \tag{A.12}$$

For instance, consider the job title ”Sales Manager” for a Coal fired power plant (CFPP). We know that,

- $E_{\text{Coal, Wholesale Trade}} = 9\%$, $E_{\text{Coal, Professional Services}} = 36\%$
- $\mathbb{1}_{\text{Sales Manager, Wholesale Trade}} = 1$, $\mathbb{1}_{\text{Sales Manager, Professional Services}} = 1$

To calculate the initial weight for ”Sales Manager” in a coal-fired power plant (CFPP),

$$\begin{aligned} v'_{\text{Sales Manager, CFPP}} &= \frac{E_{\text{Coal, Wholesale Trade}} + E_{\text{Coal, Professional Services}}}{2} \\ &= \frac{9\% + 36\%}{2} \\ &= 22.5\% \end{aligned}$$

After calculating the initial weights for all jobs, they are normalized to ensure that they sum up to 1 for each type of power plant.

4. **Calculate Country-Specific Weighted Average Salaries:**

   The weighted average salary for each country y and power plant type f is calculated:

$$\bar{w}_{y,f} = \sum_{job \in \mathcal{J}_f} S_{y,job} \times v_{job,f} \tag{A.13}$$

   Where:

   - $S_{y,job}$ is the mean salary[13] for job title *job* in country y (from ERI Salary Assessor)
   - $v_{job,f}$ is the normalized weight for job *job* in power plant type f from equation A.12

   In the ERI Salary Assessor data, wage information is available for 71 countries, which covers the majority of global power generation capacity. For the rest of the countries in the Forward Analytics dataset, I use regional averages.

5. **Regional Averages for Missing Data:**

   For countries where the mean salary $S_{y_x,job}$ for job *job* is not available, the capacity-weighted regional average for that country is used:

[13] All salaries are converted to United States dollar (USD) using current exchange rates from the U.S. Treasury Reporting Data *(accessed on 6/30/2024)*. The ERI Salary Assessor provides job-specific salaries (e.g., for ”power plant installer”) but does not differentiate these salaries by fossil fuel type (coal, oil, or gas). The differentiation in average wages between fossil fuel types comes from the weighting scheme, which applies different weights to each job based on the employment distribution patterns specific to each fossil fuel type.

$$\bar{w}_{y_x,f} = \bar{w}_{r,f} \tag{A.14}$$

where the mean wage for region r is calculated as:

$$\bar{w}_{r,f} = \frac{\sum_{y \in \mathcal{Y}_r \setminus y_x} \bar{w}_{y,f} \times \hat{C}_{y,f}}{\sum_{y \in \mathcal{Y}_r \setminus y_x} \hat{C}_{y,f}} \tag{A.15}$$

Where:

- $\mathcal{Y}_r \setminus y_x$ represents all countries in region r except country y_x
- $\hat{C}_{y,f}$ is the total capacity of power plant type f in country y

For example, if salary data for Indonesia is not available, the regional average for Southeast Asia would be calculated using data from countries like Malaysia, Thailand, and Vietnam (excluding Indonesia itself), weighted by each country's power plant capacity. This approach ensures that the regional proxy reflects similar economic and labor market conditions while avoiding circular references.

This hierarchical approach—using country-specific estimates where available and regional estimates otherwise—balances the need for geographic specificity with comprehensive global coverage. The methodology captures wage variations across different job functions and fossil fuel types while accounting for regional labor market differences.

APPENDIX B

COUNTRY SPECIFIC COSTS & BENEFITS

Table B.1: Present value of economic benefits of phasing out fossil fuels according to 50% 1.5°C carbon budget consistent net zero scenario s_2 over 2025-2035, by country and by region

#	Region/Country	UNFCCC Development Status	Benefits 2024 - 2035 (Bn $)								
			Total				Of which benefits from: avoided climate damages and adaptation costs				Of which benefits from: avoided air pollution
			Country	Global	Country	Global	Country	Global	Country	Global	
			SCC $ 190/tCO2		SCC $ 1056/tCO2		SCC $ 190/tCO2		SCC $ 1056/tCO2		
	Global		26939.0		138849.1		24553.0		136463.1		2385.9
	All Developed Countries		2237.3	8946.1	7219.0	44506.3	1093.0	7801.9	6074.8	43362.1	1144.2
	All Developing Countries		2376.0	17674.7	7558.6	92586.7	1137.0	16435.7	6319.6	91347.8	1239.0
1	China	Developing	1345.4	8752.7	5595.3	46764.3	932.4	8339.7	5182.3	46351.2	413.0
2	Unites States of America	All Developed	1284.5	3744.0	5942.1	19611.6	1021.9	3481.3	5679.4	19349.0	262.6
3	India	Developing	370.3	2583.2	1073.3	13372.3	154.2	2367.1	857.2	13156.3	216.0
4	Russian Federation	All Developed	226.2	1048.0	310.9	4878.0	18.6	840.3	103.2	4670.4	207.6
5	Turkey	All Developed	115.2	405.2	134.0	1745.5	4.1	294.1	22.8	1634.4	111.1
6	Germany	All Developed	108.7	627.7	159.7	3044.3	11.2	530.2	62.2	2946.8	97.5
7	Japan	All Developed	81.6	624.3	153.3	3169.5	15.7	558.4	87.5	3103.7	65.8
8	Indonesia	Developing	70.0	657.6	93.3	3358.9	5.1	592.7	28.3	3293.9	64.9
9	Romania	All Developed	57.1	93.7	57.3	260.9	0.06	36.7	0.31	203.9	57.0
10	Italy	All Developed	55.3	207.1	66.1	909.8	2.4	154.2	13.2	856.8	52.9
11	Mexico	Developing	49.9	300.6	74.2	1467.7	5.3	256.1	29.7	1423.2	44.6
12	United Kingdom of Great Britain and Northern Ireland	All Developed	46.7	181.3	57.2	804.9	2.289	136.8	12.72	760.4	44.4
13	Poland	All Developed	44.8	369.1	52.6	1855.1	1.7	326.0	9.5	1812.0	43.1
14	Brazil	Developing	40.3	254.1	67.5	1255.5	6.0	219.7	33.1	1221.1	34.4
15	Republic of Korea	Developing	34.3	516.3	57.6	2736.8	5.1	487.2	28.5	2707.6	29.2
16	Ukraine	All Developed	31.7	112.6	32.4	481.9	0.2	81.0	0.9	450.4	31.5
17	South Africa	Developing	31.4	512.6	47.2	2721.8	3.5	484.7	19.3	2693.8	27.9
18	Thailand	Developing	31.2	206.8	35.6	1011.8	1.0	176.6	5.4	981.6	30.2
19	Czech Republic	All Developed	30.7	149.1	31.9	689.9	0.3	118.7	1.5	659.5	30.4
20	France	All Developed	29.3	74.6	33.9	285.5	1.01	46.3	5.62	257.1	28.3
21	Canada	All Developed	28.3	186.0	44.6	920.9	3.6	161.2	19.9	896.1	24.7
22	Malaysia	Developing	25.9	202.5	31.0	1012.7	1.1	177.8	6.3	988.0	24.7
23	Greece	All Developed	24.5	90.0	25.2	389.3	0.2	65.6	0.9	364.9	24.4
24	Spain	All Developed	24.0	132.1	31.1	632.1	1.57	109.7	8.7	609.7	22.4
25	Iran	Developing	22.4	214.5	32.0	1099.8	2.1	194.2	11.7	1079.4	20.3
26	Saudi Arabia	Developing	21.5	275.1	62.6	1472.3	9.0	262.6	50.2	1459.8	12.5
27	Lithuania	All Developed	19.8	23.6	19.8	40.7	0.002	3.8	0.009	20.9	19.8
28	Slovakia	All Developed	18.4	28.4	18.5	73.7	0.010	9.9	0.054	55.2	18.4
29	Bangladesh	Developing	16.5	235.8	18.6	1237.4	0.5	219.7	2.5	1221.3	16.1
30	Australia	All Developed	16.5	266.6	33.0	1423.1	3.6	253.7	20.1	1410.3	12.8
31	Philippines	Developing	16.0	143.7	18.2	727.5	0.5	128.1	2.6	712.0	15.6
32	Bulgaria	All Developed	15.5	80.2	15.7	375.1	0.05	64.7	0.3	359.6	15.5
33	Hungary	All Developed	14.5	25.5	14.6	75.5	0.013	11.0	0.08	61.0	14.5
34	Kazakhstan	Developing	14.2	163.4	16.5	845.4	0.5	149.6	2.8	831.7	13.7
35	Egypt	Developing	13.7	227.1	20.9	1206.5	1.6	214.9	8.7	1194.3	12.2
36	Pakistan	Developing	13.5	136.7	18.3	703.1	1.1	124.3	5.9	690.7	12.4
37	Argentina	Developing	12.1	90.8	14.2	451.3	0.5	79.1	2.6	439.6	11.7
38	Iraq	Developing	11.9	154.4	17.1	808.9	1.1	143.6	6.3	798.1	10.8
39	Serbia	Developing	11.0	61.8	11.1	293.5	0.0	50.8	0.2	282.6	11.0
40	Venezuela, Bolivarian Republic of	Developing	10.0	30.9	10.6	126.9	0.129	21.1	0.71	117.1	9.8
41	Viet Nam	Developing	9.7	410.7	14.2	2242.8	1.0	402.0	5.4	2234.1	8.8
42	Israel	Developing	8.6	76.5	10.8	388.3	0.5	68.4	2.7	380.2	8.1
43	Uzbekistan	Developing	7.4	72.3	7.7	368.2	0.1	64.9	0.4	360.9	7.3
44	Myanmar	Developing	7.4	13.5	7.4	41.4	0.005	6.1	0.02	34.0	7.4
45	Sweden	All Developed	7.0	13.0	7.2	40.2	0.026	6.0	0.146	33.2	7.0
46	Colombia	Developing	7.0	48.6	8.1	239.3	0.2	41.8	1.4	232.6	6.7
47	Belgium	All Developed	6.875	21.1	7.084	86.1	0.046	14.3	0.255	79.3	6.8
48	Chile	Developing	6.6	97.4	7.3	512.1	0.15	91.0	0.82	505.7	6.5
49	United Arab Emirates	Developing	6.4	135.0	16.4	731.2	2.19	130.8	12.14	727.0	4.2
50	Austria	All Developed	5.8	19.3	6.0	81.0	0.04	13.5	0.22	75.2	5.8
51	Cuba	Developing	5.2	19.5	5.2	84.6	0.00	14.3	0.03	79.4	5.2
52	Belarus	All Developed	5.2	22.5	5.2	101.6	0.017	17.4	0.10	96.5	5.2
53	Switzerland	All Developed	5.150	5.3	5.152	5.7	0.000	0.1	0.002	0.6	5.2
54	Denmark	All Developed	4.1	21.5	4.2	101.0	0.03	17.4	0.16	97.0	4.0
55	Finland	All Developed	4.0	32.8	4.3	164.1	0.1	28.8	0.3	160.2	4.0
56	Kuwait	Developing	3.4	61.3	5.6	327.2	0.5	58.3	2.7	324.3	2.9
57	Sri Lanka	Developing	3.3	12.5	3.4	54.2	0.0	9.2	0.05	50.9	3.3
58	Croatia	All Developed	3.3	5.9	3.3	18.0	0.002	2.6	0.01	14.7	3.3
59	Nigeria	Developing	3.0	60.1	5.4	322.8	0.5	57.6	3.0	320.4	2.5
60	Latvia	All Developed	2.7	4.6	2.7	13.6	0.000	2.0	0.003	10.9	2.7
61	Morocco	Developing	2.6	63.1	2.9	339.5	0.1	60.6	0.41	337.0	2.5
62	Dominican Republic	Developing	2.4	27.6	2.6	142.3	0.029	25.2	0.158	139.9	2.4
63	Bosnia and Herzegovina	Developing	2.3	18.1	2.4	89.9	0.00	15.7	0.02	87.5	2.3
64	Algeria	Developing	2.1	54.5	3.1	294.4	0.221	52.6	1.23	292.6	1.8
65	Estonia	All Developed	2.0	5.6	2.0	21.8	0.001	3.6	0.00	19.8	2.0
66	Azerbaijan	Developing	1.9	16.7	2.0	84.1	0.015	14.8	0.08	82.2	1.9
67	Norway	All Developed	1.802	2.9	1.818	7.8	0.003	1.1	0.019	6.0	1.8
68	Netherlands	All Developed	1.8	60.4	3.0	328.8	0.3	58.9	1.5	327.3	1.5
69	Montenegro	Developing	1.7	10.7	1.7	51.6	0.00	9.0	0.0	49.9	1.7
70	Yemen	Developing	1.7	12.7	1.7	63.0	0.01	11.0	0.07	61.4	1.7
71	Ecuador	Developing	1.6	8.2	1.7	38.1	0.01	6.6	0.04	36.5	1.6
72	Turkmenistan	Developing	1.6	37.2	1.8	199.3	0.031	35.6	0.174	197.7	1.6
73	Slovenia	All Developed	1.6	10.5	1.6	51.1	0.005	8.9	0.026	49.5	1.6
74	Singapore	Developing	1.6	24.2	1.6	127.2	0.00	22.6	0.00	125.6	1.6
75	United Republic of Tanzania	Developing	1.554	10.5	1.595	51.5	0.009	9.0	0.050	50.0	1.5
76	Hong Kong	N/A	1.5	33.1	1.5	177.2	0.0	31.6	0.00	175.7	1.5
77	Portugal	All Developed	1.5	12.3	1.6	61.7	0.02	10.8	0.10	60.2	1.5
78	Qatar	Developing	1.4	37.1	3.0	201.1	0.35	36.0	1.95	200.1	1.1
79	Guatemala	Developing	1.386	8.6	1.42	41.6	0.006	7.2	0.04	40.2	1.4
80	North Macedonia	Developing	1.3	7.1	1.3	33.6	0.001	5.8	0.01	32.2	1.3
81	Ireland	All Developed	1.3	24.3	1.4	128.9	0.0	23.0	0.1	127.6	1.3
82	Syrian Arab Republic	Developing	1.3	36.8	1.6	198.8	0.06	35.5	0.33	197.6	1.3

#	Region/Country	UNFCCC Development Status	Benefits 2024 - 2035 (Bn $)								
			Total				Of which benefits from: avoided climate damages and adaptation costs				Of which benefits from: avoided air pollution
			Country	Global	Country	Global	Country	Global	Country	Global	
			SCC $ 190/tCO2		SCC $ 1056/tCO2		SCC $ 190/tCO2		SCC $ 1056/tCO2		
83	Uruguay	Developing	1.31	5.1	1.3	22.1	0.00	3.7	0.00	20.8	1.3
84	Democratic People's Republic of Korea	Developing	1.2	18.7	1.2	98.5	0.000	17.5	0.000	97.3	1.2
85	Peru	Developing	1.2	32.6	1.6	175.8	0.1	31.4	0.5	174.7	1.1
86	Afghanistan	Developing	1.221	1.3	1.222	1.8	0.000	0.1	0.001	0.6	1.2
87	Ghana	Developing	1.1	53.4	1.3	291.6	0.04	52.3	0.21	290.5	1.1
88	Bahrain	Developing	1.1	37.3	1.1	202.4	0.000	36.2	0.00	201.3	1.1
89	Zimbabwe	Developing	1.1	30.8	1.1	166.1	0.00	29.7	0.00	165.0	1.1
90	Botswana	Developing	1.0	8.1	1.1	40.3	0.00	7.1	0.03	39.3	1.0
91	Oman	Developing	1.0	30.0	1.3	162.6	0.074	29.1	0.41	161.7	0.9
92	Zambia	Developing	1.0	5.3	1.0	25.2	0.002	4.4	0.010	24.2	1.0
93	Lao People's Democratic Republic	Developing	0.9	16.2	1.0	85.5	0.00	15.2	0.02	84.6	0.9
94	Tunisia	Developing	0.9	20.3	1.0	108.8	0.0	19.4	0.1	107.9	0.9
95	El Salvador	Developing	0.9	9.2	0.9	47.1	0.002	8.3	0.01	46.2	0.9
96	Angola	Developing	0.7	5.5	0.8	27.4	0.019	4.8	0.11	26.7	0.7
97	Lebanon	Developing	0.7	13.0	0.7	69.0	0.0	12.3	0.04	68.3	0.7
98	Honduras	Developing	0.7	11.4	0.7	60.1	0.0	10.7	0.02	59.4	0.7
99	Tajikistan	Developing	0.661	1.6	0.662	6.1	0.000	1.0	0.001	5.4	0.7
100	Kenya	Developing	0.7	3.9	0.7	18.6	0.002	3.2	0.013	18.0	0.6
101	Panama	Developing	0.6	8.7	0.6	45.8	0.0	8.1	0.04	45.2	0.5
102	Mongolia	Developing	0.6	5.9	0.6	30.1	0.00	5.3	0.00	29.5	0.6
103	Jordan	Developing	0.5	17.1	0.6	92.6	0.0	16.6	0.1	92.1	0.5
104	Cameroon	Developing	0.5	5.0	0.5	25.3	0.002	4.5	0.013	24.8	0.5
105	Kyrgyzstan	Developing	0.5	7.8	0.5	41.2	0.001	7.3	0.00	40.7	0.5
106	Jamaica	Developing	0.456	4.3	0.458	21.9	0.000	3.9	0.002	21.4	0.5
107	Macau	N/A	0.4	2.9	0.4	14.4	0.000	2.5	0.000	13.9	0.4
108	Namibia	Developing	0.410	0.5	0.410	1.2	0.000	0.1	0.000	0.7	0.4
109	New Zealand	All Developed	0.4	16.1	0.5	88.0	0.01	15.8	0.08	87.6	0.4
110	Cambodia	Developing	0.388	10.3	0.403	55.5	0.003	9.9	0.018	55.2	0.4
111	Georgia	Developing	0.355	1.4	0.356	6.2	0.000	1.1	0.001	5.9	0.4
112	Armenia	Developing	0.3	1.2	0.3	5.5	0.000	0.9	0.00	5.1	0.3
113	Libya	Developing	0.3	41.2	0.7	228.2	0.1	41.0	0.5	228.0	0.2
114	Bahamas	Developing	0.224	2.4	0.226	12.2	0.000	2.1	0.002	11.9	0.2
115	Brunei Darussalam	Developing	0.2	3.7	0.2	19.6	0.001	3.5	0.007	19.4	0.2
116	Cyprus	N/A	0.2	9.1	0.2	49.6	0.002	8.9	0.013	49.5	0.2
117	Republic of Moldova	Developing	0.2	5.7	0.2	31.1	0.00	5.6	0.00	30.9	0.2
118	Equatorial Guinea	Developing	0.16	0.7	0.17	3.0	0.000	0.5	0.00	2.9	0.2
119	Uganda	Developing	0.2	0.9	0.2	4.3	0.001	0.7	0.00	4.2	0.2
120	Madagascar	Developing	0.2	2.1	0.2	11.0	0.000	2.0	0.002	10.9	0.2
121	Gabon	Developing	0.154	2.0	0.157	10.6	0.001	1.9	0.004	10.4	0.2
122	Nicaragua	Developing	0.2	3.1	0.2	16.7	0.0	3.0	0.0	16.5	0.2
123	Papua New Guinea	Developing	0.15	0.4	0.15	1.5	0.000	0.2	0.000	1.3	0.1
124	Taiwan	N/A	0.1	250.9	0.1	1393.6	0.0	250.7	0.0	1393.5	0.1
125	Costa Rica	Developing	0.136	0.3	0.137	1.3	0.000	0.2	0.001	1.2	0.1
126	Mauritius	Developing	0.136	2.7	0.14	14.2	0.000	2.5	0.00	14.0	0.1
127	Kosovo	N/A	0.1	15.9	0.1	87.8	0.000	15.8	0.000	87.7	0.1
128	Maldives	Developing	0.084	0.2	0.084	0.8	0.000	0.1	0.000	0.7	0.1
129	Chad	Developing	0.080	0.8	0.081	4.1	0.000	0.7	0.001	4.0	0.1
130	Trinidad and Tobago	Developing	0.1	6.9	0.1	38.1	0.001	6.8	0.01	38.1	0.1
131	Rwanda	Developing	0.08	0.2	0.08	0.9	0.000	0.1	0.000	0.8	0.1
132	Malta	N/A	0.1	2.3	0.1	12.5	0.000	2.2	0.000	12.4	0.1
133	Congo	Developing	0.071	0.6	0.072	3.2	0.000	0.6	0.001	3.1	0.1
134	Somalia	Developing	0.068	0.9	0.068	4.8	0.000	0.8	0.000	4.7	0.1
135	South Sudan	Developing	0.1	14.6	0.1	80.7	0.000	14.5	0.000	80.6	0.1
136	Bolivia (Plurinational State of)	Developing	0.1	5.6	0.1	30.9	0.003	5.5	0.018	30.8	0.1
137	Djibouti	Developing	0.1	0.9	0.1	4.6	0.000	0.8	0.000	4.5	0.1
138	Benin	Developing	0.043	0.2	0.043	0.9	0.000	0.1	0.000	0.8	0.0
139	Burkina Faso	Developing	0.035	1.3	0.038	7.0	0.001	1.2	0.004	6.9	0.0
140	Senegal	Developing	0.0	6.6	0.0	36.7	0.00	6.6	0.010	36.7	0.0
141	Mozambique	Developing	0.035	0.8	0.036	4.4	0.000	0.8	0.001	4.3	0.0
142	Seychelles	Developing	0.03	0.6	0.03	3.3	0.000	0.6	0.000	3.3	0.0
143	Antigua and Barbuda	Developing	0.024	0.2	0.024	1.0	0.000	0.2	0.000	1.0	0.0
144	Mali	Developing	0.0	1.2	0.0	6.8	0.000	1.2	0.002	6.8	0.0
145	Sierra Leone	Developing	0.0	1.1	0.0	6.3	0.000	1.1	0.000	6.3	0.0
146	Aruba	N/A	0.012	2.5	0.012	13.8	0.000	2.5	0.000	13.8	0.0
147	Barbados	Developing	0.012	0.8	0.012	4.5	0.000	0.8	0.000	4.4	0.0
148	Central African Republic	Developing	0.010	0.1	0.010	0.8	0.000	0.1	0.000	0.8	0.0
149	Togo	Developing	0.009	0.1	0.009	0.7	0.000	0.1	0.000	0.7	0.0
150	Mauritania	Developing	0.007	3.0	0.009	16.4	0.001	3.0	0.003	16.4	0.0
151	Suriname	Developing	0.004	0.3	0.004	1.6	0.000	0.3	0.000	1.6	0.0
152	Niger	Developing	0.00	0.4	0.00	2.1	0.000	0.4	0.001	2.1	0.0
153	Eritrea	Developing	0.001	0.2	0.001	1.1	0.000	0.2	0.000	1.1	0.0
154	French Guiana	N/A	0.000	0.9	0.000	4.9	0.000	0.9	0.000	4.9	0.0
155	Western Sahara	N/A	0.000	0.3	0.000	1.9	0.000	0.3	0.000	1.9	0.0

Table B.2: Present value of economic benefits of phasing out fossil fuels according to 50% 1.5°C carbon budget consistent net zero scenario s_2 over 2025-2050, by country and by region

#	Region/Country	UNFCCC Development Status	Benefits 2024 - 2050 (Bn $)								
			Total				Of which benefits from: avoided climate damages and adaptation costs				Of which benefits from: avoided air pollution
			Country	Global	Country	Global	Country	Global	Country	Global	
			SCC $ 190/tCO2		SCC $ 1056/tCO2		SCC $ 190/tCO2		SCC $ 1056/tCO2		
	Global		74559.9		384230.7		67941.6		377612.5		6618.2
	All Developed Countries		6137.2	23678.7	17569.7	115064.0	2508.3	20049.9	13940.9	111435.1	3628.9
	All Developing Countries		5827.4	49831.1	18795.4	263363.3	2845.2	46848.9	15813.2	260381.1	2982.2
1	China	Developing	3368.1	21110.8	13547.7	112159.6	2233.4	19976.1	12413.0	111024.9	1134.7
2	Unites States of America	All Developed	2831.6	8395.2	13367.5	44289.7	2311.6	7875.2	12847.6	43769.8	520.0
3	India	Developing	1279.9	7427.2	3232.8	37398.7	428.5	6575.7	2381.3	36547.2	851.5
4	Russian Federation	All Developed	509.0	2632.7	727.8	12531.0	48.0	2171.7	266.8	12070.0	461.0
5	Turkey	All Developed	260.9	1157.5	318.8	5301.9	12.7	909.3	70.5	5053.7	248.3
6	Japan	All Developed	226.4	1849.9	441.1	9464.4	47.1	1670.6	261.8	9285.1	179.3
7	Germany	All Developed	215.5	1362.7	328.2	6704.3	24.7	1171.9	137.4	6513.5	190.8
8	Indonesia	Developing	182.3	1926.0	251.2	9942.4	15.1	1758.8	84.0	9775.2	167.2
9	Mexico	Developing	164.6	1081.4	253.5	5349.3	19.5	936.4	108.5	5204.3	145.1
10	United Kingdom of Great Britain and Northern Ireland	All Developed	163.6	709.0	205.9	3237.1	9.3	554.7	51.6	3082.8	154.3
11	Brazil	Developing	158.1	1093.1	277.0	5473.7	26.1	961.1	145.0	5341.7	132.0
12	Italy	All Developed	125.8	579.2	158.1	2678.4	7.1	460.6	39.4	2559.7	118.7
13	Romania	All Developed	121.4	225.8	122.2	702.4	0.2	104.6	0.9	581.1	121.3
14	Lithuania	All Developed	112.8	196.7	113.0	578.9	0.04	83.9	0.2	466.1	112.8
15	Saudi Arabia	Developing	112.4	1318.5	308.0	7011.6	42.9	1249.1	238.5	6942.1	69.5
16	Poland	All Developed	99.9	864.8	118.3	4369.6	4.0	768.9	22.4	4273.7	95.9
17	Thailand	Developing	97.6	694.9	112.6	3431.9	3.3	600.5	18.3	3337.5	94.4
18	Republic of Korea	Developing	91.1	1508.3	159.7	8036.9	15.1	1432.4	83.7	7960.9	76.0
19	France	All Developed	89.6	262.9	107.3	1070.1	3.9	177.1	21.5	984.3	85.8
20	Ukraine	All Developed	87.2	308.5	89.1	1319.3	0.4	221.8	2.4	1232.6	86.7
21	South Africa	Developing	85.7	1430.6	129.9	7604.8	9.7	1354.6	53.9	7528.8	76.0
22	Canada	All Developed	78.3	569.6	129.2	2859.8	11.2	502.5	62.0	2792.6	67.1
23	Sweden	All Developed	72.0	129.1	73.2	390.5	0.3	57.3	1.4	318.7	71.8
24	Czech Republic	All Developed	68.6	355.3	71.5	1665.2	0.6	287.4	3.6	1597.2	67.9
25	Iran	Developing	65.2	652.9	94.5	3361.2	6.4	594.2	35.8	3302.4	58.8
26	Malaysia	Developing	58.0	503.0	71.1	2544.3	2.9	447.9	15.9	2489.1	55.1
27	Philippines	Developing	49.3	456.2	56.2	2317.9	1.5	408.5	8.4	2270.1	47.8
28	Egypt	Developing	49.0	813.6	74.6	4324.5	5.6	770.3	31.2	4281.2	43.3
29	Spain	All Developed	48.9	329.3	67.4	1626.1	4.1	284.5	22.6	1581.3	44.8
30	Slovakia	All Developed	48.5	82.5	48.6	237.5	0.03	34.0	0.2	189.1	48.4
31	Bangladesh	Developing	48.0	787.0	55.0	4162.1	1.5	740.5	8.6	4115.6	46.5
32	Pakistan	Developing	46.5	493.7	64.0	2549.2	3.8	451.0	21.3	2506.5	42.7
33	Venezuela, Bolivarian Republic of	Developing	46.3	161.5	49.5	689.8	0.7	115.9	3.9	644.2	45.6
34	Hungary	All Developed	45.4	91.3	45.6	301.1	0.1	46.0	0.3	255.7	45.3
35	Kazakhstan	Developing	43.4	394.8	48.7	2001.8	1.2	352.6	6.5	1959.6	42.2
36	Greece	All Developed	42.1	194.9	43.8	893.0	0.4	153.2	2.0	851.2	41.8
37	Argentina	Developing	36.6	319.3	44.2	1615.3	1.7	284.3	9.3	1580.3	34.9
38	Iraq	Developing	36.5	455.9	51.8	2382.7	3.3	422.7	18.6	2349.5	33.2
39	Australia	All Developed	32.3	586.3	68.9	3147.7	8.0	562.0	44.6	3123.4	24.3
40	Bulgaria	All Developed	30.8	200.2	31.3	972.8	0.1	169.5	0.7	942.2	30.7
41	Finland	All Developed	30.6	231.3	32.5	1148.0	0.4	201.1	2.4	1117.9	30.1
42	Viet Nam	Developing	30.0	1267.7	43.7	6922.7	3.0	1240.7	16.7	6895.7	27.0
43	Denmark	All Developed	27.6	122.4	28.3	555.1	0.2	94.9	0.9	527.7	27.5
44	Chile	Developing	25.4	511.4	29.0	2729.9	0.8	486.8	4.4	2705.3	24.6
45	Colombia	Developing	24.1	189.0	28.6	944.9	1.0	165.8	5.5	921.8	23.2
46	Uruguay	Developing	23.9	183.7	24.1	912.3	0.04	159.8	0.2	888.4	23.9
47	Nigeria	Developing	23.7	480.4	43.3	2582.0	4.3	461.1	23.9	2562.6	19.4
48	Israel	Developing	22.2	218.6	28.6	1120.2	1.4	197.8	7.8	1099.4	20.8
49	Serbia	Developing	18.8	126.3	19.1	616.8	0.1	107.6	0.3	598.0	18.7
50	Belgium	All Developed	17.2	59.7	17.9	254.1	0.1	42.6	0.8	236.9	17.1
51	Belarus	All Developed	17.2	79.1	17.5	361.2	0.1	61.9	0.3	344.0	17.2
52	United Arab Emirates	Developing	17.2	375.6	44.9	2036.9	6.1	364.5	33.8	2025.9	11.1
53	Myanmar	Developing	16.1	33.7	16.1	114.1	0.01	17.6	0.1	98.1	16.1
54	Switzerland	All Developed	15.8	16.2	15.8	18.0	0.001	0.4	0.01	2.1	15.8
55	Uzbekistan	Developing	15.8	181.2	16.6	935.7	0.2	165.5	1.0	920.1	15.6
56	Morocco	Developing	15.6	351.2	17.5	1882.6	0.4	336.0	2.3	1867.4	15.2
57	Austria	All Developed	14.2	54.9	14.7	240.8	0.1	40.8	0.7	226.7	14.1
58	Yemen	Developing	13.4	457.0	15.6	2480.8	0.5	444.0	2.7	2467.9	12.9
59	United Republic of Tanzania	Developing	13.1	97.2	13.5	481.1	0.1	84.2	0.5	468.1	13.0
60	Singapore	Developing	10.6	190.5	10.6	1010.5	0.000	179.9	0.000	999.9	10.6
61	Cuba	Developing	10.3	42.8	10.4	191.1	0.01	32.5	0.1	180.7	10.3
62	Croatia	All Developed	9.8	30.2	9.9	122.9	0.01	20.3	0.1	113.1	9.8
63	Sri Lanka	Developing	9.6	40.8	9.8	183.3	0.03	31.2	0.2	173.7	9.6
64	Zambia	Developing	8.5	66.2	8.6	329.3	0.02	57.7	0.1	320.8	8.5
65	Kuwait	Developing	8.2	156.3	13.9	836.9	1.2	149.3	6.9	829.9	7.0
66	Ecuador	Developing	8.1	46.0	8.3	218.9	0.04	37.9	0.2	210.8	8.1
67	Dominican Republic	Developing	7.8	84.5	8.2	434.4	0.1	76.8	0.5	426.7	7.7
68	Peru	Developing	7.1	198.0	9.6	1070.7	0.5	191.5	3.1	1064.1	6.5
69	Guatemala	Developing	6.5	37.6	6.6	179.3	0.03	31.1	0.2	172.8	6.5
70	Estonia	All Developed	6.4	21.8	6.4	92.1	0.003	15.4	0.02	85.7	6.4
71	Latvia	All Developed	6.3	12.8	6.3	42.6	0.002	6.5	0.01	36.4	6.3
72	Angola	Developing	6.0	42.2	6.7	207.7	0.1	36.3	0.8	201.9	5.9
73	Turkmenistan	Developing	5.6	131.2	6.1	704.2	0.1	125.7	0.6	698.7	5.5
74	Algeria	Developing	5.4	145.3	8.1	785.9	0.6	140.5	3.3	781.1	4.8
75	Ireland	All Developed	5.3	130.3	5.9	700.4	0.1	125.1	0.7	695.2	5.2
76	Ghana	Developing	5.2	275.1	6.0	1506.5	0.2	270.2	1.1	1501.6	5.0
77	Syrian Arab Republic	Developing	5.1	162.8	6.3	882.6	0.3	157.9	1.4	877.7	4.8
78	Afghanistan	Developing	5.056	5.6	5.059	8.0	0.000	0.5	0.003	3.0	5.1
79	Cameroon	Developing	4.5	51.6	4.6	266.4	0.02	47.1	0.1	261.9	4.5
80	Democratic People's Republic of Korea	Developing	4.493	71.9	4.493	379.1	0.000	67.4	0.000	374.6	4.5
81	Norway	All Developed	4.5	7.6	4.5	22.2	0.01	3.2	0.1	17.8	4.4
82	Zimbabwe	Developing	4.4	149.9	4.4	813.2	0.004	145.5	0.02	808.8	4.4
83	Lao People's Democratic Republic	Developing	4.03	62.6	4.1	329.6	0.01	58.6	0.1	325.5	4.0
84	Netherlands	All Developed	4.0	152.6	7.2	832.8	0.7	149.2	3.9	829.5	3.3
85	Montenegro	Developing	4.0	31.1	4.0	154.7	0.002	27.1	0.01	150.7	4.0

#	Region/Country	UNFCCC Development Status	Benefits 2024 - 2050 (Bn $)								
			Total				Of which benefits from: avoided climate damages and adaptation costs				Of which benefits from: avoided air pollution
			Country	Global	Country	Global	Country	Global	Country	Global	
			SCC $ 190/tCO2		SCC $ 1056/tCO2		SCC $ 190/tCO2		SCC $ 1056/tCO2		
86	Botswana	Developing	3.7	34.7	3.9	175.8	0.02	31.0	0.1	172.1	3.7
87	Azerbaijan	Developing	3.7	36.6	3.8	186.6	0.03	32.9	0.2	183.0	3.7
88	Portugal	All Developed	3.6	37.2	3.9	190.3	0.1	33.6	0.3	186.7	3.6
89	Namibia	Developing	3.6	6.0	3.6	17.2	0.001	2.4	0.004	13.6	3.6
90	Qatar	Developing	3.5	92.7	7.5	503.3	0.9	90.1	4.9	500.6	2.6
91	El Salvador	Developing	3.5	39.8	3.5	205.1	0.01	36.3	0.1	201.7	3.5
92	Slovenia	All Developed	3.3	24.1	3.4	118.9	0.01	20.8	0.1	115.6	3.3
93	Bosnia and Herzegovina	Developing	3.3	31.4	3.3	159.3	0.005	28.1	0.03	156.0	3.3
94	Hong Kong	N/A	3.228	95.3	3.228	515.0	0.000	92.1	0.000	511.7	3.2
95	Tunisia	Developing	2.8	59.7	3.1	319.1	0.1	56.9	0.3	316.3	2.8
96	Lebanon	Developing	2.6	54.5	2.8	291.0	0.03	51.9	0.2	288.4	2.6
97	Bahrain	Developing	2.6	97.3	2.6	529.0	0.000	94.7	0.000	526.4	2.6
98	Kenya	Developing	2.5	17.1	2.6	83.4	0.01	14.6	0.1	80.9	2.5
99	North Macedonia	Developing	2.5	18.8	2.5	92.9	0.003	16.3	0.02	90.4	2.5
100	Panama	Developing	2.3	35.3	2.4	185.8	0.03	33.0	0.2	183.6	2.2
101	Jordan	Developing	2.1	82.9	2.3	451.3	0.05	80.8	0.3	449.2	2.0
102	Honduras	Developing	2.1	35.4	2.1	187.4	0.01	33.3	0.1	185.3	2.1
103	Tajikistan	Developing	2.0	4.8	2.0	17.6	0.000	2.8	0.002	15.6	2.0
104	Oman	Developing	1.9	66.3	2.7	360.6	0.2	64.6	0.9	358.8	1.8
105	Macau	N/A	1.732	18.1	1.732	92.8	0.000	16.4	0.000	91.1	1.7
106	Kyrgyzstan	Developing	1.5	25.2	1.5	133.0	0.002	23.6	0.01	131.4	1.5
107	Cambodia	Developing	1.5	39.2	1.5	211.0	0.01	37.7	0.1	209.5	1.5
108	Costa Rica	Developing	1.1	3.5	1.1	14.4	0.002	2.4	0.01	13.3	1.1
109	New Zealand	All Developed	1.1	59.0	1.3	323.3	0.1	58.0	0.3	322.3	1.0
110	Libya	Developing	1.0	141.2	2.4	781.5	0.3	140.5	1.7	780.8	0.7
111	Mongolia	Developing	1.0	11.7	1.0	60.3	0.001	10.7	0.01	59.3	1.0
112	Bahamas	Developing	0.951	15.5	0.96	81.6	0.002	14.5	0.01	80.6	0.9
113	Jamaica	Developing	0.9	10.4	0.9	53.5	0.001	9.5	0.005	52.6	0.9
114	Georgia	Developing	0.9	4.6	0.9	21.4	0.000	3.7	0.003	20.5	0.9
115	Equatorial Guinea	Developing	0.930	4.0	0.94	17.8	0.002	3.0	0.01	16.9	0.9
116	Madagascar	Developing	0.811	11.7	0.82	61.2	0.002	10.9	0.01	60.4	0.8
117	Papua New Guinea	Developing	0.773	1.9	0.774	7.1	0.000	1.1	0.001	6.4	0.8
118	Benin	Developing	0.7	4.8	0.7	23.2	0.001	4.0	0.004	22.5	0.7
119	Armenia	Developing	0.6	3.1	0.6	14.5	0.000	2.5	0.001	13.8	0.6
120	Gabon	Developing	0.6	8.9	0.6	46.7	0.003	8.3	0.02	46.1	0.6
121	Republic of Moldova	Developing	0.6	20.2	0.6	109.6	0.001	19.6	0.004	109.0	0.6
122	Senegal	Developing	0.6	99.0	0.7	547.6	0.03	98.4	0.2	547.1	0.6
123	Uganda	Developing	0.6	3.4	0.6	16.4	0.002	2.8	0.01	15.8	0.6
124	Brunei Darussalam	Developing	0.5	11.5	0.6	61.3	0.004	10.9	0.02	60.8	0.5
125	Chad	Developing	0.469	5.3	0.48	27.4	0.001	4.8	0.01	26.9	0.5
126	Rwanda	Developing	0.452	1.2	0.453	4.4	0.000	0.7	0.001	4.0	0.5
127	Taiwan	N/A	0.435	811.5	0.435	4508.5	0.000	811.1	0.000	4508.1	0.4
128	Cyprus	N/A	0.42	24.4	0.45	133.6	0.01	24.0	0.04	133.2	0.4
129	Nicaragua	Developing	0.4	9.1	0.4	48.9	0.001	8.7	0.01	48.5	0.4
130	Somalia	Developing	0.387	6.1	0.387	32.3	0.000	5.7	0.000	31.9	0.4
131	South Sudan	Developing	0.363	94.5	0.363	523.5	0.000	94.1	0.000	523.1	0.4
132	Maldives	Developing	0.346	1.0	0.346	3.8	0.000	0.6	0.000	3.5	0.3
133	Mali	Developing	0.3	26.2	0.4	144.2	0.01	25.9	0.05	143.8	0.3
134	Kosovo	N/A	0.319	61.1	0.319	338.0	0.000	60.8	0.000	337.7	0.3
135	Congo	Developing	0.3	2.7	0.3	13.7	0.001	2.4	0.005	13.4	0.3
136	Mauritius	Developing	0.3	6.8	0.3	36.7	0.001	6.6	0.005	36.5	0.3
137	Djibouti	Developing	0.222	5.7	0.223	30.7	0.000	5.5	0.001	30.4	0.2
138	Mozambique	Developing	0.2	4.6	0.2	24.5	0.001	4.4	0.01	24.2	0.2
139	Togo	Developing	0.2	2.8	0.2	14.4	0.000	2.6	0.001	14.2	0.2
140	Burkina Faso	Developing	0.202	8.6	0.22	47.0	0.004	8.4	0.02	46.8	0.2
141	Trinidad and Tobago	Developing	0.2	16.4	0.2	90.5	0.004	16.3	0.02	90.3	0.2
142	Bolivia (Plurinational State of)	Developing	0.2	17.5	0.2	96.5	0.01	17.3	0.1	96.4	0.1
143	Malta	N/A	0.120	13.7	0.120	75.7	0.000	13.6	0.000	75.6	0.1
144	Seychelles	Developing	0.120	4.1	0.120	22.5	0.000	4.0	0.000	22.4	0.1
145	Antigua and Barbuda	Developing	0.108	1.0	0.108	5.1	0.000	0.9	0.000	5.0	0.1
146	Sierra Leone	Developing	0.081	7.7	0.084	42.3	0.000	7.6	0.003	42.3	0.1
147	Central African Republic	Developing	0.063	1.0	0.063	5.3	0.000	0.9	0.000	5.2	0.1
148	Aruba	N/A	0.056	16.8	0.056	93.2	0.000	16.8	0.000	93.2	0.1
149	Barbados	Developing	0.055	5.5	0.055	30.1	0.000	5.4	0.000	30.1	0.1
150	Mauritania	Developing	0.040	19.1	0.06	106.0	0.004	19.1	0.02	106.0	0.0
151	Niger	Developing	0.03	2.6	0.04	14.3	0.001	2.6	0.01	14.2	0.0
152	Suriname	Developing	0.01	1.1	0.01	5.9	0.000	1.1	0.000	5.9	0.0
153	French Guiana	N/A	0.002	5.9	0.002	33.0	0.000	5.9	0.000	33.0	0.0
154	Eritrea	Developing	0.001	0.4	0.001	2.4	0.000	0.4	0.000	2.4	0.0
155	Western Sahara	N/A	0.000	2.3	0.000	12.8	0.000	2.3	0.000	12.8	0.0

Table B.3: Present value of the costs over 2025-2035 of phasing out fossil fuels on the power grid and phasing in replacement renewables (while keeping up with any growth in energy demand).

#	Country Name	UNFCCC Development Status	Total CF Need ($ Bn) (2025-2035)	Renewables Investment Costs ($ Bn) (2025-2035)						Opportunity Costs ($ Mn) (2025-2035)			
				Total RE Investment	Renewable energy	Short-term storage	Long-term storage	Renewables to power electrolyzers	Grid extension	Total OC	Owners	Workers 5 yr wages	Workers retraining
	Global		15,915.4	15,465.4	11,958.9	1,816.4	242.5	278.6	1,169.0	449,984.0	129,545.0	314,271.0	6,165.0
	All Developing Countries		10,537.4	10,296.5	8,065.5	1,159.1	152.7	181.4	737.9	240,886.0	40,445.0	196,582.0	3,849.0
	All Developed Countries		5,118.0	4,913.7	3,681.7	635.9	86.9	91.2	417.9	204,305.0	87,620.0	114,438.0	2,253.0
1	China	Developing	4,602.2	4,498.7	3,490.4	515.7	67.4	92.6	332.6	103,469.0	0.0	101,475.0	1,993.0
2	Unites States of America	All Developed	2,061.0	1,988.6	1,417.3	297.0	40.5	37.6	196.3	72,355.0	7,667.0	63,438.0	1,250.0
3	India	Developing	1,141.3	1,115.6	835.9	145.0	19.2	22.0	93.5	25,700.0	1,060.0	24,165.0	475.0
4	Russian Federation	All Developed	673.3	657.8	519.3	73.5	9.6	8.4	47.0	15,470.0	8,750.0	6,591.0	130.0
5	Iran	Developing	416.4	409.7	365.1	25.2	3.4	0.9	15.1	6,748.0	2,617.0	4,050.0	80.0
6	Egypt	Developing	405.0	404.6	344.5	27.6	3.6	12.2	16.7	393.0	155.0	233.0	5.0
7	Republic of Korea	Developing	401.5	398.9	330.2	35.8	4.6	5.7	22.7	2,627.0	200.0	2,381.0	47.0
8	Japan	All Developed	367.4	361.5	279.6	41.6	5.7	7.9	26.7	5,900.0	0.0	5,786.0	114.0
9	Indonesia	Developing	344.1	338.7	268.2	39.4	5.2	0.7	25.3	5,349.0	2,255.0	3,034.0	60.0
10	Germany	All Developed	341.1	326.1	248.7	37.8	5.1	8.5	26.0	14,941.0	7,198.0	7,595.0	149.0
11	Iraq	Developing	305.3	298.3	268.3	16.6	2.1	0.0	11.2	7,051.0	1,767.0	5,184.0	100.0
12	Mexico	Developing	244.7	237.8	189.8	24.9	3.3	4.7	15.0	6,888.0	5,549.0	1,312.0	26.0
13	United Kingdom of Great Britain and Northern Ireland	All Developed	233.0	182.8	150.4	15.5	2.1	4.9	9.9	50,122.0	46,570.0	3,483.0	68.0
14	Viet Nam	Developing	226.3	220.8	166.3	27.6	3.6	5.2	18.2	5,530.0	451.0	4,981.0	98.0
15	Taiwan	N/A	225.2	222.2	186.9	17.3	2.3	5.2	10.5	3,058.0	1,318.0	1,707.0	34.0
16	South Africa	Developing	218.0	212.7	158.1	28.5	3.8	3.6	18.7	5,256.0	16.0	5,138.0	101.0
17	Thailand	Developing	194.2	192.4	160.2	17.4	2.3	2.6	10.0	1,723.0	26.0	1,664.0	33.0
18	Saudi Arabia	Developing	184.9	176.1	130.4	24.9	3.3	3.9	13.5	8,719.0	4,435.0	4,201.0	82.0
19	Turkey	All Developed	180.6	177.9	140.9	19.7	2.6	2.1	12.6	2,679.0	120.0	2,510.0	50.0
20	Turkey	All Developed	180.6	177.9	140.9	19.7	2.6	2.1	12.6	2,679.0	120.0	2,510.0	50.0
21	Brazil	Developing	169.0	153.4	115.5	20.4	2.7	2.2	12.6	15,613.0	12,474.0	3,078.0	61.0
22	Italy	All Developed	144.1	138.8	105.7	16.9	2.5	2.7	11.0	5,353.0	1,446.0	3,831.0	75.0
23	Malaysia	Developing	140.6	138.3	108.7	15.6	2.0	1.7	10.2	2,307.0	953.0	1,328.0	26.0
24	Australia	All Developed	129.5	119.5	86.3	17.1	2.3	2.2	11.6	9,989.0	4,254.0	5,625.0	111.0
25	Poland	All Developed	123.7	121.8	86.5	17.9	2.5	2.8	12.2	1,855.0	62.0	1,759.0	35.0
26	Bangladesh	Developing	122.6	116.6	82.7	17.6	2.3	2.4	11.5	5,990.0	902.0	4,991.0	97.0
27	United Arab Emirates	Developing	118.6	116.3	83.2	17.2	2.3	2.6	11.0	2,279.0	10.0	2,225.0	44.0
28	Canada	All Developed	112.3	106.5	76.6	15.8	2.1	1.7	10.3	5,835.0	3,143.0	2,640.0	52.0
29	Spain	All Developed	86.3	84.0	60.0	12.2	1.8	1.6	8.4	2,349.0	149.0	2,160.0	43.0
30	Netherlands	All Developed	80.5	78.4	64.3	6.6	0.9	2.1	4.4	2,058.0	1,270.0	774.0	15.0
31	Nigeria	Developing	79.4	78.8	67.1	6.9	0.9	0.1	3.8	633.0	36.0	585.0	12.0
32	Pakistan	Developing	78.5	75.7	54.8	11.1	1.5	0.7	7.5	2,802.0	270.0	2,483.0	48.0
33	Algeria	Developing	76.7	76.2	62.8	6.9	0.9	1.3	4.4	443.0	40.0	396.0	8.0
34	Kazakhstan	Developing	76.0	74.8	57.3	8.8	1.2	1.6	5.9	1,119.0	194.0	908.0	18.0
35	Argentina	Developing	72.7	72.2	54.9	9.2	1.2	1.0	5.8	517.0	30.0	477.0	9.0
36	Philippines	Developing	71.1	68.4	51.2	8.7	1.4	1.2	5.8	2,730.0	252.0	2,430.0	47.0
37	Kuwait	Developing	62.4	60.2	45.0	7.7	1.0	1.4	5.1	2,216.0	81.0	2,093.0	41.0
38	Czech Republic	All Developed	61.3	60.8	48.2	6.5	0.9	0.7	4.5	545.0	196.0	342.0	6.0
39	Syrian Arab Republic	Developing	54.2	52.8	45.1	4.3	0.5	0.1	2.8	1,422.0	455.0	949.0	18.0
40	Uzbekistan	Developing	49.4	48.3	36.3	6.4	0.9	0.4	4.3	1,144.0	526.0	607.0	12.0
41	Greece	All Developed	46.0	45.2	34.3	5.6	0.9	0.7	3.7	780.0	2.0	762.0	15.0
42	Ukraine	All Developed	45.3	44.8	36.0	4.5	0.6	0.7	3.0	497.0	182.0	310.0	6.0
43	Ghana	Developing	43.2	43.1	32.6	5.7	0.7	0.6	3.5	140.0	38.0	100.0	2.0
44	Morocco	Developing	42.6	42.2	34.8	3.9	0.5	0.5	2.6	319.0	35.0	279.0	6.0
45	Chile	Developing	41.5	40.4	28.9	6.2	0.8	0.7	3.7	1,081.0	176.0	888.0	17.0
46	Turkmenistan	Developing	41.1	40.4	31.8	4.6	0.6	0.8	2.7	639.0	474.0	162.0	3.0
47	Israel	Developing	38.9	38.0	26.5	6.0	0.8	0.8	4.0	886.0	17.0	852.0	17.0
48	Bulgaria	All Developed	34.8	34.6	27.7	3.5	0.5	0.5	2.4	187.0	0.0	184.0	3.0
49	France	All Developed	31.0	30.3	23.4	3.6	0.5	0.6	2.3	634.0	0.0	622.0	12.0
50	Colombia	Developing	30.6	29.6	22.4	3.7	0.5	0.6	2.3	1,039.0	751.0	281.0	6.0
51	Belgium	All Developed	30.1	25.8	21.6	1.9	0.3	0.7	1.3	4,289.0	3,869.0	411.0	8.0
52	Qatar	Developing	29.3	27.9	18.7	4.8	0.6	0.6	3.1	1,402.0	526.0	859.0	17.0
53	Libya	Developing	27.8	27.1	18.5	4.7	0.6	0.6	2.8	709.0	29.0	668.0	13.0
54	Bahrain	Developing	25.7	25.2	15.9	4.9	0.6	0.5	3.3	516.0	29.0	477.0	9.0
55	Azerbaijan	Developing	25.3	24.8	20.8	2.1	0.3	0.2	1.4	466.0	231.0	231.0	5.0
56	Oman	Developing	25.1	24.3	17.8	3.9	0.5	0.6	1.5	875.0	42.0	817.0	16.0
57	Romania	All Developed	22.0	21.1	16.0	2.6	0.4	0.3	1.7	906.0	198.0	695.0	13.0
58	Peru	Developing	21.3	21.0	15.7	2.9	0.4	0.4	1.6	242.0	155.0	85.0	2.0
59	Serbia	Developing	19.5	19.2	13.7	2.7	0.4	0.5	1.9	305.0	40.0	260.0	5.0
60	Venezuela, Bolivarian Republic of	Developing	19.5	18.4	13.8	2.6	0.3	0.0	1.6	1,118.0	726.0	384.0	8.0
61	Belarus	All Developed	18.9	18.3	14.1	2.2	0.3	0.4	1.2	597.0	342.0	250.0	5.0
62	Hong Kong	N/A	18.7	17.3	12.7	2.3	0.4	0.4	1.5	1,360.0	105.0	1,231.0	23.0
63	Singapore	Developing	17.5	16.7	11.1	2.9	0.4	0.3	1.9	741.0	328.0	405.0	8.0
64	Finland	All Developed	16.8	16.5	12.9	2.0	0.3	0.4	1.0	329.0	131.0	193.0	4.0
65	Dominican Republic	Developing	15.3	14.7	10.9	2.0	0.3	0.3	1.2	620.0	347.0	267.0	5.0
66	Tunisia	Developing	15.2	15.0	10.3	2.5	0.3	0.3	1.6	129.0	15.0	113.0	2.0
67	Ireland	All Developed	14.3	13.6	9.3	2.2	0.3	0.3	1.5	659.0	277.0	376.0	7.0
68	Austria	All Developed	13.1	12.0	8.5	1.8	0.3	0.2	1.2	1,074.0	864.0	205.0	4.0
69	Lebanon	Developing	13.1	12.4	10.8	1.0	0.1	0.0	0.5	633.0	67.0	555.0	11.0
70	Denmark	All Developed	12.0	11.8	9.8	1.0	0.2	0.3	0.6	212.0	43.0	167.0	4.0
71	Portugal	All Developed	11.9	11.3	8.6	1.4	0.2	0.2	0.9	545.0	357.0	184.0	4.0
72	Zimbabwe	Developing	11.2	9.8	7.1	1.4	0.2	0.2	0.9	1,413.0	0.0	1,386.0	27.0
73	Jordan	Developing	10.3	9.8	6.3	1.8	0.2	0.2	1.2	490.0	181.0	303.0	6.0
74	Yemen	Developing	10.1	9.8	7.8	1.1	0.1	0.2	0.6	259.0	94.0	161.0	3.0
75	New Zealand	All Developed	10.0	9.7	6.6	1.6	0.3	0.1	1.1	258.0	10.0	244.0	5.0
76	South Sudan	Developing	9.4	8.7	7.0	1.0	0.1	0.0	0.6	696.0	11.0	673.0	12.0
77	Democratic People's Republic of Korea	Developing	8.9	8.8	7.4	0.8	0.1	0.0	0.5	115.0	6.0	108.0	2.0
78	Slovakia	All Developed	8.7	8.5	7.0	0.8	0.1	0.0	0.5	185.0	92.0	92.0	2.0
79	Trinidad and Tobago	Developing	7.9	7.6	5.8	0.9	0.1	0.2	0.6	311.0	257.0	54.0	1.0
80	Bosnia and Herzegovina	Developing	7.6	7.4	6.2	0.8	0.1	0.0	0.2	219.0	0.0	214.0	4.0
81	Sri Lanka	Developing	7.3	6.9	5.6	0.7	0.1	0.1	0.4	374.0	41.0	327.0	6.0
82	Lao People's Democratic Republic	Developing	7.2	6.9	5.2	1.0	0.1	0.0	0.6	342.0	7.0	329.0	6.0
83	Myanmar	Developing	6.7	5.6	4.3	0.7	0.1	0.0	0.4	1,126.0	1.0	1,104.0	21.0
84	Hungary	All Developed	6.3	6.0	4.3	0.9	0.1	0.1	0.6	324.0	34.0	284.0	5.0
85	Cambodia	Developing	6.2	5.9	4.6	0.7	0.1	0.1	0.4	315.0	8.0	302.0	6.0
86	El Salvador	Developing	6.1	6.1	4.7	0.7	0.1	0.1	0.4	62.0	15.0	46.0	1.0
87	Cuba	Developing	5.9	5.8	4.1	0.9	0.1	0.1	0.6	133.0	133.0	0.0	0.0
88	Kosovo	N/A	5.8	5.8	4.5	0.7	0.1	0.1	0.5	0.0	0.0	0.0	0.0
89	United Republic of Tanzania	Developing	5.7	5.7	4.8	0.6	0.1	0.0	0.3	8.0	6.0	2.0	0.0
90	Bolivia (Plurinational State of)	Developing	5.2	5.0	3.5	0.8	0.1	0.1	0.5	278.0	219.0	58.0	1.0
91	Cyprus	N/A	4.9	4.8	3.7	0.5	0.1	0.1	0.4	115.0	16.0	98.0	2.0
92	Slovenia	All Developed	4.8	4.7	3.3	0.7	0.1	0.0	0.5	110.0	45.0	62.0	1.0
93	Panama	Developing	4.8	4.6	3.5	0.6	0.1	0.1	0.4	174.0	95.0	78.0	1.0
94	Honduras	Developing	4.6	4.4	3.3	0.6	0.1	0.1	0.4	163.0	77.0	85.0	1.0
95	Montenegro	Developing	4.3	4.2	3.5	0.39	0.05	0.07	0.25	70.0	0.0	69.0	1.0
96	Lithuania	All Developed	4.2	4.1	3.2	0.48	0.06	0.08	0.27	60.0	0.0	59.0	1.0
97	Republic of Moldova	Developing	4.0	3.9	2.6	0.72	0.10	0.08	0.42	158.0	117.0	40.0	1.0
98	Senegal	Developing	3.9	3.9	2.8	0.59	0.08	0.08	0.32	45.0	3.0	41.0	1.0
99	Angola	Developing	3.8	3.8	3.1	0.41	0.06	0.02	0.21	11.0	3.0	8.0	0.0
100	Jamaica	Developing	3.6	3.6	2.8	0.39	0.05	0.09	0.26	49.0	10.0	39.0	0.0
101	Latvia	All Developed	3.6	3.5	3.0	0.28	0.04	0.02	0.19	90.0	49.0	40.0	1.0
102	Botswana	Developing	3.5	2.9	2.2	0.38	0.05	0.06	0.23	578.0	0.0	566.0	11.0
103	Sweden	All Developed	3.4	3.3	2.7	0.34	0.05	0.06	0.14	84.0	0.0	82.0	1.0
104	Ecuador	Developing	3.3	3.2	2.6	0.38	0.05	0.00	0.22	58.0	54.0	4.0	0.0
105	Macau	N/A	3.2	3.1	2.7	0.16	0.02	0.09	0.10	134.0	8.0	124.0	2.0
106	Guatemala	Developing	3.0	3.0	2.3	0.38	0.05	0.04	0.22	70.0	19.0	50.0	1.0
107	Uruguay	Developing	3.0	2.9	2.3	0.34	0.05	0.06	0.16	82.0	68.0	14.0	0.0

#	Country Name	UNFCCC Development Status	Total CF Need ($ Bn) (2025-2035)	Renewables Investment Costs ($ Bn) (2025-2035)						Opportunity Costs ($ Mn) (2025-2035)			
				Total RE Investment	Renewable energy	Short-term storage	Long-term storage	Renewables to power electrolyzers	Grid extension	Total OC	Owners	Workers 5 yr wages	Workers retraining
108	Estonia	All Developed	2.9	2.9	2.0	0.46	0.06	0.07	0.30	14.0	0.0	14.0	0.0
109	Kyrgyzstan	Developing	2.9	2.8	2.2	0.36	0.05	0.00	0.22	60.0	2.0	56.0	1.0
110	Cameroon	Developing	2.4	2.4	1.8	0.34	0.05	0.00	0.19	11.0	3.0	8.0	0.0
111	North Macedonia	Developing	2.3	2.2	2.0	0.15	0.02	0.01	0.05	87.0	12.0	73.0	1.0
112	Croatia	All Developed	2.1	2.0	1.7	0.17	0.02	0.03	0.06	136.0	4.0	129.0	3.0
113	Brunei Darussalam	Developing	2.0	2.0	1.5	0.25	0.03	0.04	0.16	41.0	8.0	32.0	1.0
114	Mongolia	Developing	1.8	1.5	1.5	0.00	0.00	0.00	0.00	370.0	2.0	361.0	7.0
115	Zambia	Developing	1.8	1.7	1.3	0.22	0.03	0.01	0.12	162.0	1.0	158.0	3.0
116	Gabon	Developing	1.8	1.8	1.3	0.25	0.03	0.00	0.17	13.0	1.0	11.0	0.0
117	Armenia	Developing	1.7	1.6	1.6	0.00	0.00	0.00	0.00	90.0	16.0	73.0	1.0
118	Georgia	Developing	1.6	1.5	1.2	0.15	0.02	0.00	0.10	75.0	17.0	57.0	1.0
119	Kenya	Developing	1.4	1.0	0.7	0.18	0.03	0.02	0.12	444.0	1.0	434.0	8.0
120	Mauritania	Developing	1.3	1.1	0.7	0.21	0.03	0.02	0.13	218.0	112.0	104.0	2.0
121	Nicaragua	Developing	1.2	1.1	0.8	0.16	0.02	0.01	0.10	66.0	19.0	47.0	1.0
122	Norway	All Developed	1.2	1.0	0.7	0.15	0.02	0.01	0.10	201.0	174.0	27.0	1.0
123	Bahamas	Developing	1.1	1.0	0.8	0.11	0.01	0.02	0.07	74.0	13.0	60.0	1.0
124	Malta	N/A	0.9	0.9	0.6	0.17	0.02	0.02	0.11	34.0	13.0	20.0	0.0
125	Mauritius	Developing	0.7	0.7	0.5	0.14	0.02	0.01	0.05	35.0	0.0	34.0	1.0
126	Mozambique	Developing	0.7	0.7	0.5	0.10	0.01	0.01	0.05	50.0	1.0	48.0	1.0
127	Tajikistan	Developing	0.7	0.6	0.5	0.08	0.01	0.00	0.05	69.0	5.0	63.0	1.0
128	Madagascar	Developing	0.7	0.6	0.4	0.10	0.01	0.01	0.06	82.0	1.0	79.0	1.0
129	Aruba	N/A	0.6	0.6	0.4	0.13	0.02	0.01	0.08	56.0	15.0	41.0	1.0
130	Mali	Developing	0.6	0.6	0.4	0.06	0.01	0.01	0.04	1.0	1.0	0.0	0.0
131	Congo	Developing	0.5	0.5	0.4	0.08	0.01	0.00	0.02	22.0	0.0	21.0	0.0
132	Equatorial Guinea	Developing	0.5	0.4	0.3	0.05	0.01	0.00	0.03	46.0	0.0	45.0	1.0
133	Burkina Faso	Developing	0.5	0.4	0.3	0.07	0.01	0.01	0.04	71.0	1.0	69.0	1.0
134	Djibouti	Developing	0.4	0.4	0.3	0.04	0.01	0.01	0.03	68.0	1.0	66.0	1.0
135	Chad	Developing	0.4	0.3	0.3	0.038	0.005	0.006	0.023	64.0	1.0	62.0	1.0
136	Sierra Leone	Developing	0.4	0.3	0.2	0.059	0.008	0.006	0.036	70.0	1.0	67.0	1.0
137	Uganda	Developing	0.4	0.3	0.2	0.042	0.006	0.001	0.028	112.0	1.0	110.0	2.0
138	French Guiana	N/A	0.3	0.3	0.2	0.046	0.006	0.002	0.028	5.0	5.00	0.00	0.00
139	Somalia	Developing	0.3	0.2	0.2	0.045	0.006	0.005	0.027	28.0	1.00	27.00	1.00
140	Niger	Developing	0.3	0.1	0.1	0.000	0.000	0.000	0.000	145.0	0.00	142.00	3.00
141	Barbados	Developing	0.2	0.2	0.1	0.042	0.006	0.005	0.026	18.0	5.00	13.00	0.00
142	Papua New Guinea	Developing	0.2	0.2	0.2	0.033	0.005	0.000	0.022	0.0	0.00	0.00	0.00
143	Antigua and Barbuda	Developing	0.2	0.2	0.1	0.025	0.004	0.004	0.017	8.0	7.00	1.00	0.00
144	Benin	Developing	0.2	0.2	0.2	0.020	0.003	0.005	0.011	6.0	0.00	5.00	0.00
145	Seychelles	Developing	0.2	0.2	0.1	0.031	0.004	0.003	0.019	25.0	0.00	24.00	0.00
146	Afghanistan	Developing	0.2	0.2	0.1	0.015	0.002	0.001	0.010	6.0	2.00	4.00	0.00
147	Western Sahara	N/A	0.2	0.1	0.1	0.018	0.002	0.003	0.011	31.0	0.00	30.00	1.00
148	Maldives	Developing	0.1	0.1	0.1	0.018	0.002	0.003	0.012	3.0	2.00	1.00	0.00
149	Switzerland	All Developed	0.1	0.1	0.1	0.014	0.002	0.000	0.009	4.0	2.00	2.00	0.00
150	Suriname	Developing	0.1	0.1	0.1	0.023	0.005	0.000	0.002	17.0	2.00	15.00	0.00
151	Eritrea	Developing	0.1	0.0	0.0	0.000	0.000	0.000	0.000	67.0	0.00	66.00	1.00
152	Togo	Developing	0.1	0.1	0.1	0.015	0.002	0.002	0.006	0.0	0.00	0.00	0.00
153	Rwanda	Developing	0.1	0.1	0.1	0.020	0.003	0.002	0.014	2.0	0.00	2.00	0.00
154	Costa Rica	Developing	0.1	0.1	0.1	0.011	0.002	0.001	0.007	12.0	1.00	11.00	0.00
155	Central African Republic	Developing	0.1	0.0	0.0	0.007	0.001	0.001	0.004	21.0	0.00	21.00	0.00
156	Namibia	Developing	0.1	0.1	0.0	0.006	0.001	0.001	0.004	0.00	0.00	0.00	0.00

Table B.4: Present value of the costs over 2025-2050 of phasing out fossil fuels on the power grid and phasing in replacement renewables (while keeping up with any growth in energy demand).

#	Country Name	UNFCCC Development Status	Total CF Need ($ Bn) (2025-2050)	Renewables Investment Costs ($ Bn) (2025-2050)						Opportunity Costs ($ Mn) (2025-2050)			
				Total RE Investment	Renewable energy	Short-term storage	Long-term storage	Renewables to power electrolyzers	Grid extension	Total OC	Owners	Workers 5 yr wages	Workers retraining
	Global		24,189.1	23,391.9	16,157.3	2,992.0	382.2	402.4	3,458.3	797,205.0	425,341.0	364,713.0	7,151.0
	All Developing Countries		16,206.9	15,805.7	11,108.0	1,932.6	240.9	262.3	2,261.9	401,177.0	165,847.0	230,801.0	4,520.0
	All Developed Countries		7,524.0	7,136.7	4,712.4	1,017.1	135.5	129.6	1,142.0	387,331.0	255,089.0	129,703.0	2,549.0
1	China	Developing	5,378.4	5,264.1	3,674.6	686.1	74.1	108.4	720.9	114,234.0	0.0	11,203.3	2,201.0
2	Unites States of America	All Developed	2,624.4	2,531.6	1,552.8	440.2	58.6	43.3	436.5	92,797.0	2,123.2	7,018.1	1,383.0
3	India	Developing	1,797.5	1,767.7	1,139.0	250.1	33.1	31.1	314.3	29,769.0	295.1	2,630.2	517.0
4	Russian Federation	All Developed	1,012.6	976.2	661.6	123.4	15.9	18.6	156.8	36,370.0	2,937.6	686.0	135.0
5	Egypt	Developing	678.5	677.6	523.7	55.2	7.2	20.3	71.2	854.0	58.7	26.3	5.0
6	Republic of Korea	Developing	652.3	648.1	476.1	66.9	8.4	9.4	87.3	4,177.0	48.2	362.3	72.0
7	Japan	All Developed	615.8	604.2	406.3	76.6	10.2	13.0	98.2	11,675.0	0.0	1,145.3	223.0
8	Iran	Developing	613.7	600.1	489.9	44.7	5.8	2.5	57.2	13,649.0	871.7	483.6	95.0
9	Indonesia	Developing	587.9	578.0	403.3	71.9	9.4	2.2	91.1	9,931.0	655.4	331.3	66.0
10	Mexico	Developing	472.8	448.5	314.9	51.7	6.8	8.5	66.6	24,348.0	2,266.3	165.2	33.0
11	United Kingdom of Great Britain and Northern Ireland	All Developed	454.8	318.0	239.7	29.4	4.0	8.1	36.8	136,809.0	13,305.1	368.5	73.0
12	Iraq	Developing	433.2	422.1	357.5	27.3	3.5	0.0	33.7	11,134.0	454.8	646.1	124.0
13	Brazil	Developing	432.8	372.8	252.1	48.0	6.5	6.0	60.2	59,940.0	5,634.3	352.7	70.0
14	Taiwan	N/A	393.6	386.9	293.3	34.7	4.5	9.1	45.3	6,638.0	394.6	263.9	52.0
15	Germany	All Developed	386.4	360.0	259.2	44.9	5.4	9.1	41.4	26,453.0	1,855.7	774.4	151.0
16	Viet Nam	Developing	385.9	377.3	248.1	50.6	6.6	8.1	64.0	8,605.0	233.8	614.6	121.0
17	Saudi Arabia	Developing	378.9	348.1	224.6	51.3	6.6	7.6	58.0	30,794.0	1,984.6	1,074.0	208.0
18	South Africa	Developing	357.7	348.5	223.5	50.1	6.7	5.2	63.0	9,223.0	11.6	893.3	174.0
19	Thailand	Developing	351.1	348.8	257.8	35.6	4.6	4.8	46.0	2,255.0	6.2	215.1	42.0
20	Nigeria	Developing	343.6	342.7	278.4	27.2	4.0	0.6	32.5	875.0	27.8	58.5	12.0
21	Turkey	All Developed	341.9	338.5	239.7	39.2	5.2	4.1	50.3	3,471.0	41.5	299.7	59.0
22	Turkey	All Developed	341.9	338.5	239.7	39.2	5.2	4.1	50.3	3,471.0	41.5	299.7	59.0
23	Yemen	Developing	278.2	275.2	231.6	19.9	3.5	4.6	15.6	3,004.0	283.1	16.9	4.0
24	Italy	All Developed	227.7	218.9	145.9	29.0	4.1	4.0	35.9	8,797.0	452.0	419.5	83.0
25	Bangladesh	Developing	221.9	213.6	130.2	33.6	4.5	3.9	41.4	8,264.0	298.7	517.6	101.0
26	Malaysia	Developing	210.3	205.4	141.6	25.8	3.4	2.5	32.1	4,835.0	333.8	146.9	29.0
27	Canada	All Developed	203.4	190.4	118.8	28.8	3.8	3.1	35.8	13,019.0	1,019.3	277.1	54.0
28	United Arab Emirates	Developing	173.5	171.1	99.1	28.6	3.7	3.3	36.5	2,467.0	3.1	238.8	47.0
29	Australia	All Developed	171.9	153.7	92.7	25.0	3.4	2.4	30.3	18,114.0	1,234.1	566.3	111.0
30	Poland	All Developed	165.3	163.3	97.8	26.7	3.7	3.2	32.0	2,005.0	15.0	182.0	36.0
31	Pakistan	Developing	149.1	145.6	94.7	20.8	2.9	1.6	25.6	3,564.0	84.9	266.3	51.0
32	Morocco	Developing	137.5	137.0	112.2	10.4	1.5	1.4	11.5	473.0	18.0	28.8	6.0
33	Syrian Arab Republic	Developing	136.4	133.5	109.6	10.1	1.4	0.3	12.2	2,837.0	184.3	97.5	19.0
34	Argentina	Developing	126.5	125.8	82.9	17.1	2.2	1.8	21.8	681.0	10.2	56.7	11.0
35	Philippines	Developing	124.8	121.2	82.4	15.7	2.3	1.9	18.8	3,585.0	89.2	264.2	52.0
36	Spain	All Developed	123.6	121.0	75.1	18.9	2.7	2.0	22.4	2,591.0	36.3	218.6	43.0
37	Ghana	Developing	118.2	117.5	80.7	14.7	2.0	1.8	18.3	701.0	18.7	50.4	10.0
38	Chile	Developing	111.9	109.0	68.5	16.1	2.2	1.8	20.5	2,883.0	157.7	128.1	24.0
39	Netherlands	All Developed	107.3	103.1	76.5	10.2	1.4	2.6	12.5	4,208.0	337.2	82.0	16.0
40	Kazakhstan	Developing	105.9	104.0	68.6	14.1	1.8	2.1	17.5	1,910.0	90.2	98.7	19.0
41	Algeria	Developing	101.0	100.4	72.1	11.1	1.4	1.5	14.2	589.0	11.6	46.4	9.0
42	Uruguay	Developing	87.5	84.6	68.2	7.2	1.3	1.9	6.0	2,865.0	281.8	4.5	1.0
43	Czech Republic	All Developed	83.4	82.4	58.1	10.0	1.4	0.8	12.1	997.0	60.6	38.4	8.0
44	Kuwait	Developing	83.3	81.0	50.3	12.1	1.5	1.7	15.4	2,360.0	22.2	209.6	41.0
45	Ukraine	All Developed	74.0	72.8	52.4	8.1	1.1	1.1	10.1	1,283.0	96.0	31.7	6.0
46	Turkmenistan	Developing	73.5	71.5	47.9	9.1	1.2	1.4	11.9	2,018.0	182.1	19.3	4.0
47	Uzbekistan	Developing	70.7	68.6	44.6	9.9	1.4	0.7	12.0	2,044.0	140.3	62.8	13.0
48	Colombia	Developing	67.1	63.7	43.1	8.1	1.1	1.3	10.1	3,402.0	310.9	28.7	6.0
49	Peru	Developing	61.3	60.2	39.3	8.1	1.1	1.3	10.4	1,028.0	75.5	26.8	5.0
50	France	All Developed	61.2	60.5	41.8	7.3	1.0	1.2	9.1	688.0	0.0	67.5	13.0
51	Israel	Developing	61.1	60.1	35.1	10.1	1.3	1.0	12.5	938.0	4.5	87.5	17.0
52	Venezuela, Bolivarian Republic of	Developing	60.6	56.4	39.1	7.3	1.0	0.0	9.0	4,203.0	371.4	48.0	10.0
53	Greece	All Developed	58.2	57.4	37.8	8.1	1.2	0.8	9.5	793.0	0.6	77.3	15.0
54	Lithuania	All Developed	56.3	56.2	45.5	4.6	0.8	1.0	4.3	60.0	0.0	5.9	1.0
55	Bulgaria	All Developed	51.6	51.4	37.8	5.5	0.8	0.6	6.7	207.0	0.0	20.3	4.0
56	Finland	All Developed	50.6	49.8	34.2	6.0	0.8	1.1	7.7	806.0	52.7	27.4	5.0
57	Belgium	All Developed	50.1	38.7	29.9	3.3	0.4	1.1	4.0	11,378.0	1,091.2	45.7	9.0
58	Singapore	Developing	49.3	47.4	28.8	7.8	1.2	0.9	8.8	1,894.0	102.5	85.3	17.0
59	Libya	Developing	48.8	47.4	24.9	8.9	1.1	0.8	11.6	1,411.0	10.9	127.8	24.0
60	Qatar	Developing	41.1	38.7	20.4	7.4	1.0	0.7	9.3	2,336.0	141.1	90.7	18.0
61	Bahrain	Developing	38.2	37.6	18.6	7.7	1.0	0.6	9.7	574.0	7.8	48.7	10.0
62	Ireland	All Developed	36.7	35.5	23.2	5.0	0.8	0.7	5.9	1,197.0	75.1	43.7	8.0
63	Romania	All Developed	35.7	34.3	23.5	4.4	0.6	0.5	5.3	1,391.0	62.6	75.1	14.0
64	Senegal	Developing	33.5	33.4	23.1	4.3	0.7	0.7	4.6	138.0	4.0	9.7	2.0
65	Lebanon	Developing	33.5	32.3	26.0	2.6	0.4	0.0	3.3	1,191.0	44.7	72.9	14.0
66	Belarus	All Developed	32.7	31.0	19.5	4.4	0.6	0.7	5.8	1,726.0	141.4	30.6	6.0
67	South Sudan	Developing	31.8	31.1	24.2	2.9	0.4	0.0	3.5	746.0	6.0	67.3	12.0
68	Denmark	All Developed	31.5	31.1	23.5	2.8	0.4	0.8	3.6	455.0	22.6	22.5	5.0
69	Oman	Developing	30.1	29.1	19.2	5.4	0.7	0.6	3.2	936.0	9.4	82.6	17.0
70	Azerbaijan	Developing	28.7	27.9	21.9	2.8	0.4	0.3	2.4	773.0	53.3	23.5	5.0
71	United Republic of Tanzania	Developing	27.5	27.2	21.1	2.6	0.4	0.0	3.1	352.0	5.2	29.4	6.0
72	Hong Kong	N/A	27.2	25.7	16.6	3.7	0.6	0.5	4.4	1,496.0	21.7	125.5	24.0
73	Dominican Republic	Developing	26.9	25.2	15.6	3.8	0.5	0.4	4.8	1,675.0	135.2	31.7	6.0
74	Zimbabwe	Developing	25.8	24.4	15.2	3.6	0.5	0.5	4.5	1,413.0	0.0	138.6	27.0
75	Serbia	Developing	24.6	24.2	14.7	3.8	0.5	0.6	4.5	412.0	14.2	26.4	5.0
76	Tunisia	Developing	24.2	24.0	13.0	4.4	0.6	0.4	5.6	169.0	4.6	12.0	2.0
77	Jordan	Developing	22.5	21.7	12.6	3.8	0.5	0.4	4.3	814.0	49.1	31.6	6.0
78	Austria	All Developed	22.5	19.9	12.4	3.0	0.4	0.4	3.7	2,616.0	240.0	21.2	4.0
79	New Zealand	All Developed	22.3	22.1	14.3	3.3	0.5	0.2	3.7	280.0	3.2	24.4	5.0
80	Democratic People's Republic of Korea	Developing	19.0	18.9	14.9	1.7	0.2	0.0	2.1	130.0	2.0	10.8	2.0
81	Portugal	All Developed	18.7	17.2	11.9	2.2	0.3	0.2	2.6	1,533.0	133.8	19.1	4.0
82	Slovakia	All Developed	18.2	17.7	13.7	1.7	0.2	0.1	2.0	467.0	36.8	9.7	2.0
83	Lao People's Democratic Republic	Developing	15.5	15.1	10.4	2.0	0.3	0.0	2.4	359.0	2.3	32.9	6.0
84	El Salvador	Developing	15.5	15.4	10.6	1.8	0.3	0.3	2.3	121.0	5.7	6.3	1.0
85	Angola	Developing	14.8	14.6	10.9	1.5	0.2	0.1	1.9	237.0	2.4	21.0	4.0
86	Sri Lanka	Developing	14.3	13.8	10.2	1.4	0.2	0.2	1.8	538.0	16.7	36.3	7.0
87	Hungary	All Developed	13.9	13.4	8.3	2.0	0.3	0.3	2.5	496.0	14.6	34.4	6.0
88	Sweden	All Developed	13.7	13.6	9.5	1.5	0.2	0.3	2.0	104.0	0.0	10.2	2.0
89	Cameroon	Developing	13.3	13.1	9.6	1.53	0.23	0.00	1.76	195.0	2.8	16.3	3.0
90	Cambodia	Developing	13.1	12.7	9.6	1.3	0.2	0.2	1.5	393.0	3.0	35.5	7.0
91	Kosovo	N/A	12.5	12.5	8.7	1.5	0.2	0.2	1.8	0.0	0.0	0.0	0.0
92	Zambia	Developing	12.2	12.1	8.8	1.37	0.21	0.06	1.58	179.0	1.9	15.8	3.0
93	Macau	N/A	10.9	10.8	9.3	0.5	0.1	0.3	0.6	166.0	3.9	12.4	2.0
94	Ecuador	Developing	10.9	10.4	7.8	1.1	0.2	0.0	1.4	462.0	30.4	15.5	3.0
95	Panama	Developing	10.2	9.7	6.4	1.3	0.2	0.2	1.6	460.0	36.6	9.2	2.0
96	Myanmar	Developing	9.6	8.4	5.8	1.1	0.1	0.0	1.2	1,221.0	0.1	119.6	23.0
97	Trinidad and Tobago	Developing	9.5	8.8	6.3	1.3	0.2	0.2	0.9	728.0	66.9	5.8	1.0
98	Bolivia (Plurinational State of)	Developing	9.2	8.5	5.6	1.3	0.2	0.1	1.2	707.0	64.7	5.8	1.0
99	Honduras	Developing	8.4	8.0	5.1	1.2	0.2	0.1	1.5	397.0	29.7	9.8	2.0
100	Botswana	Developing	8.1	7.4	5.3	0.9	0.1	0.1	1.0	615.0	0.4	59.9	12.0
101	Republic of Moldova	Developing	7.7	7.3	3.7	1.4	0.2	0.1	1.8	489.0	44.7	4.2	1.0
102	Bosnia and Herzegovina	Developing	7.6	7.4	6.2	0.8	0.1	0.0	0.2	219.0	0.0	21.4	4.0
103	Cyprus	N/A	7.4	7.2	5.2	0.8	0.1	0.2	1.0	141.0	4.1	9.9	2.0
104	Cuba	Developing	7.2	6.8	4.5	1.1	0.1	0.1	1.0	386.0	38.6	0.0	0.0
105	Slovenia	All Developed	7.1	6.9	4.3	1.1	0.2	0.0	1.2	195.0	13.0	6.4	1.0
106	Estonia	All Developed	7.0	7.0	4.4	1.1	0.1	0.1	1.3	15.0	0.0	1.5	0.0
107	Montenegro	Developing	6.9	6.8	5.1	0.7	0.1	0.1	0.8	70.0	0.0	6.9	1.0

#	Country Name	UNFCCC Development Status	Total CF Need ($ Bn) (2025-2050)	Renewables Investment Costs ($ Bn) (2025-2050)						Opportunity Costs ($ Mn) (2025-2050)			
				Total RE Investment	Renewable energy	Short-term storage	Long-term storage	Renewables to power electrolyzers	Grid extension	Total OC	Owners	Workers 5 yr wages	Workers retraining
108	Mali	Developing	6.9	6.7	5.3	0.58	0.09	0.08	0.64	210.0	1.4	19.2	4.0
109	Guatemala	Developing	6.9	6.7	4.5	0.9	0.1	0.1	1.1	175.0	10.6	6.7	2.0
110	Latvia	All Developed	6.9	6.7	5.5	0.5	0.1	0.0	0.6	190.0	14.7	4.2	1.0
111	Croatia	All Developed	6.0	5.8	4.5	0.54	0.08	0.10	0.63	161.0	2.9	13.0	3.0
112	Kyrgyzstan	Developing	4.9	4.8	3.2	0.66	0.08	0.00	0.84	65.0	0.8	5.6	1.0
113	Jamaica	Developing	4.7	4.6	3.2	0.6	0.1	0.1	0.6	64.0	2.4	4.0	0.0
114	Mauritania	Developing	4.5	3.8	2.3	0.61	0.09	0.07	0.72	764.0	65.9	10.4	2.0
115	Gabon	Developing	4.5	4.5	3.1	0.58	0.08	0.00	0.71	18.0	0.6	1.2	0.0
116	North Macedonia	Developing	4.4	4.2	3.3	0.36	0.04	0.04	0.47	131.0	5.1	7.9	1.0
117	Bahamas	Developing	3.9	3.7	2.8	0.37	0.05	0.07	0.44	135.0	7.4	6.0	1.0
118	Brunei Darussalam	Developing	3.2	3.2	2.1	0.43	0.06	0.06	0.52	55.0	2.2	3.2	1.0
119	Kenya	Developing	3.1	2.6	1.6	0.42	0.06	0.04	0.49	485.0	0.5	47.2	9.0
120	Georgia	Developing	3.0	2.9	2.2	0.29	0.04	0.00	0.34	113.0	5.2	5.9	1.0
121	Benin	Developing	2.8	2.8	2.3	0.22	0.038	0.068	0.194	7.0	0.2	0.5	0.0
122	Armenia	Developing	2.7	2.6	2.3	0.12	0.01	0.00	0.15	113.0	3.9	7.3	1.0
123	Malta	N/A	2.6	2.5	1.4	0.45	0.07	0.05	0.53	67.0	4.6	2.1	0.0
124	Aruba	N/A	2.4	2.3	1.3	0.43	0.06	0.04	0.50	127.0	8.5	4.1	1.0
125	Norway	All Developed	2.2	1.7	1.1	0.25	0.04	0.02	0.30	519.0	49.2	2.7	1.0
126	Mozambique	Developing	2.1	2.0	1.3	0.28	0.04	0.04	0.34	60.0	0.3	5.6	1.0
127	Madagascar	Developing	2.0	1.9	1.2	0.28	0.04	0.03	0.33	86.0	0.5	7.9	1.0
128	Nicaragua	Developing	1.9	1.8	1.1	0.28	0.04	0.02	0.35	105.0	5.6	4.8	1.0
129	Mongolia	Developing	1.9	1.5	1.5	0.00	0.00	0.00	0.00	372.0	0.4	36.1	7.0
130	Djibouti	Developing	1.5	1.4	1.1	0.14	0.02	0.03	0.17	70.0	0.3	6.6	1.0
131	Equatorial Guinea	Developing	1.4	1.4	1.1	0.13	0.02	0.00	0.15	48.0	0.2	4.5	1.0
132	Burkina Faso	Developing	1.4	1.4	0.8	0.21	0.03	0.03	0.25	76.0	0.5	6.9	1.0
133	Congo	Developing	1.4	1.4	1.0	0.17	0.03	0.00	0.17	23.0	0.2	2.1	0.0
134	Chad	Developing	1.3	1.2	0.9	0.12	0.02	0.02	0.15	67.0	0.3	6.2	1.0
135	Tajikistan	Developing	1.3	1.2	0.9	0.15	0.02	0.00	0.18	84.0	2.0	6.3	1.0
136	French Guiana	N/A	1.2	1.2	0.8	0.15	0.022	0.010	0.179	30.0	3.0	0.0	0.0
137	Sierra Leone	Developing	1.2	1.1	0.7	0.19	0.03	0.02	0.23	73.0	0.5	6.7	1.0
138	Mauritius	Developing	1.1	1.1	0.6	0.21	0.03	0.02	0.21	35.0	0.0	3.4	1.0
139	Togo	Developing	1.1	1.1	0.7	0.14	0.022	0.023	0.164	4.0	0.1	0.2	0.0
140	Somalia	Developing	0.9	0.8	0.5	0.15	0.021	0.016	0.173	31.0	0.4	2.7	1.0
141	Barbados	Developing	0.8	0.8	0.5	0.14	0.020	0.015	0.163	40.0	2.8	1.3	0.0
142	Uganda	Developing	0.7	0.6	0.4	0.09	0.012	0.003	0.101	121.0	0.2	11.7	2.0
143	Papua New Guinea	Developing	0.6	0.6	0.4	0.08	0.012	0.000	0.094	0.0	0.0	0.0	0.0
144	Seychelles	Developing	0.6	0.6	0.3	0.10	0.015	0.011	0.121	27.0	0.2	2.4	0.0
145	Namibia	Developing	0.6	0.6	0.5	0.05	0.008	0.010	0.043	0.0	0.0	0.0	0.0
146	Niger	Developing	0.6	0.5	0.3	0.05	0.008	0.009	0.065	150.0	0.2	14.6	3.0
147	Antigua and Barbuda	Developing	0.6	0.6	0.4	0.06	0.009	0.010	0.073	31.0	3.0	0.1	0.0
148	Costa Rica	Developing	0.6	0.6	0.4	0.06	0.009	0.005	0.059	28.0	1.0	1.8	0.0
149	Afghanistan	Developing	0.5	0.5	0.4	0.04	0.005	0.002	0.044	11.0	0.7	0.4	0.0
150	Western Sahara	N/A	0.5	0.5	0.3	0.06	0.009	0.010	0.069	32.0	0.1	3.0	1.0
151	Maldives	Developing	0.4	0.4	0.3	0.04	0.006	0.007	0.051	9.0	0.8	0.1	0.0
152	Rwanda	Developing	0.3	0.3	0.2	0.05	0.007	0.005	0.059	2.0	0.0	0.2	0.0
153	Switzerland	All Developed	0.3	0.3	0.2	0.03	0.004	0.000	0.034	10.0	0.8	0.2	0.0
154	Suriname	Developing	0.3	0.2	0.2	0.04	0.007	0.001	0.026	21.0	0.6	1.5	0.0
155	Central African Republic	Developing	0.2	0.1	0.1	0.02	0.004	0.003	0.028	22.0	0.1	2.1	0.0
156	Eritrea	Developing	0.1	0.1	0.0	0.01	0.001	0.001	0.009	67.0	0.0	6.6	1.0

APPENDIX C

EMISSION AND POWER MIX BY REGIONS

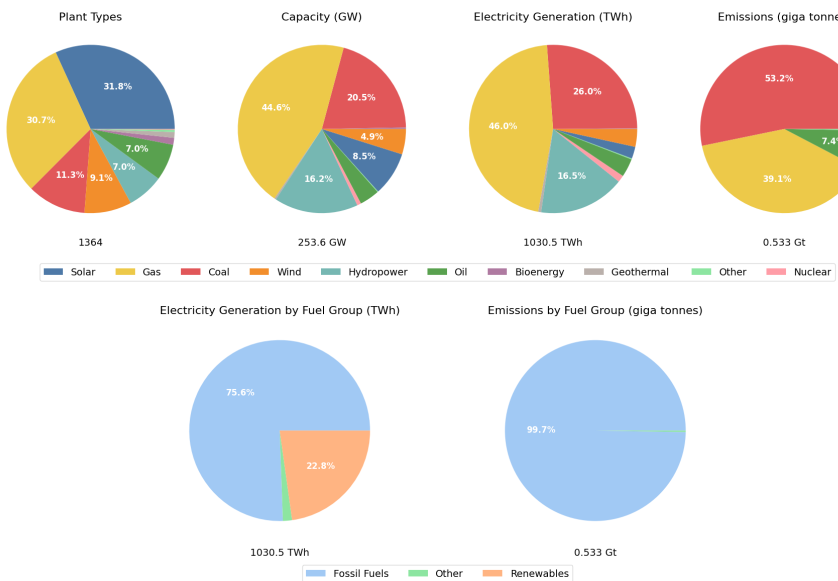

Figure C.1: Power sector descriptive statistics Africa.

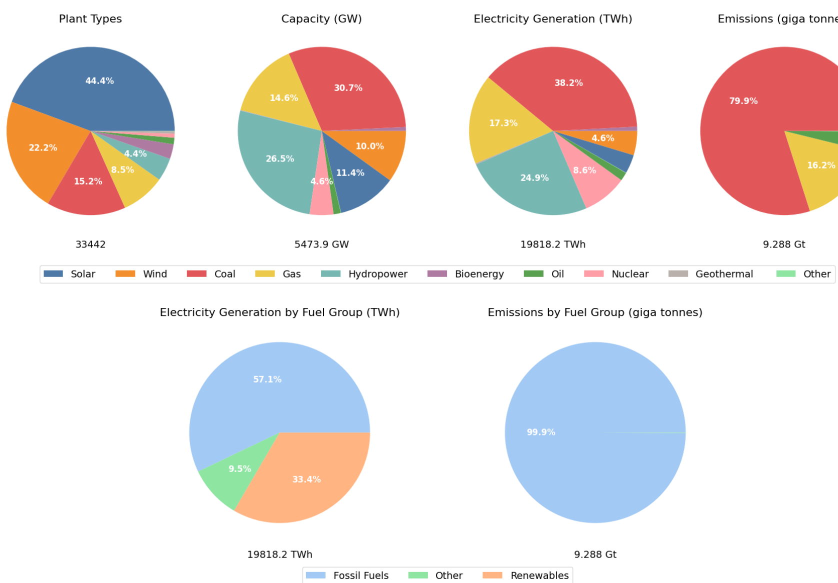

Figure C.2: Power sector descriptive statistics Asia.

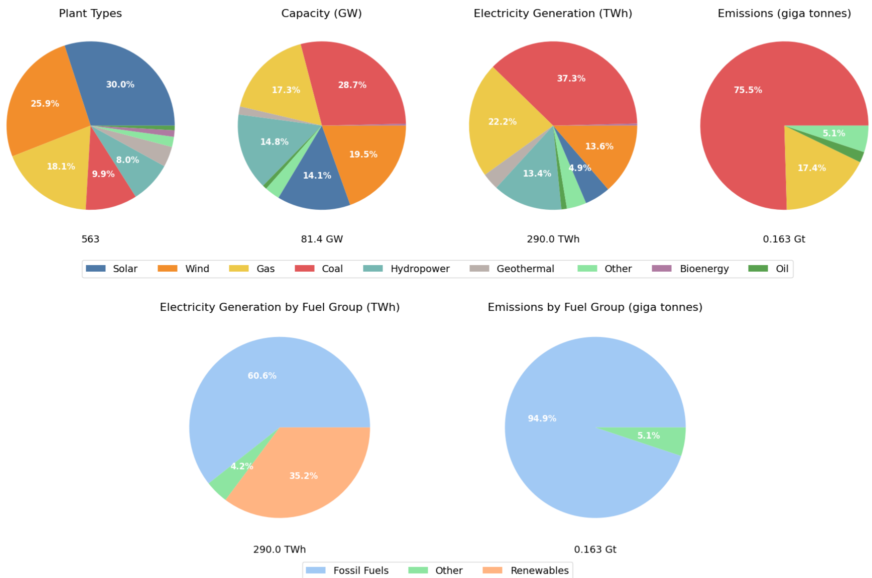

Figure C.3: Power sector descriptive statistics Australia and New Zealand.

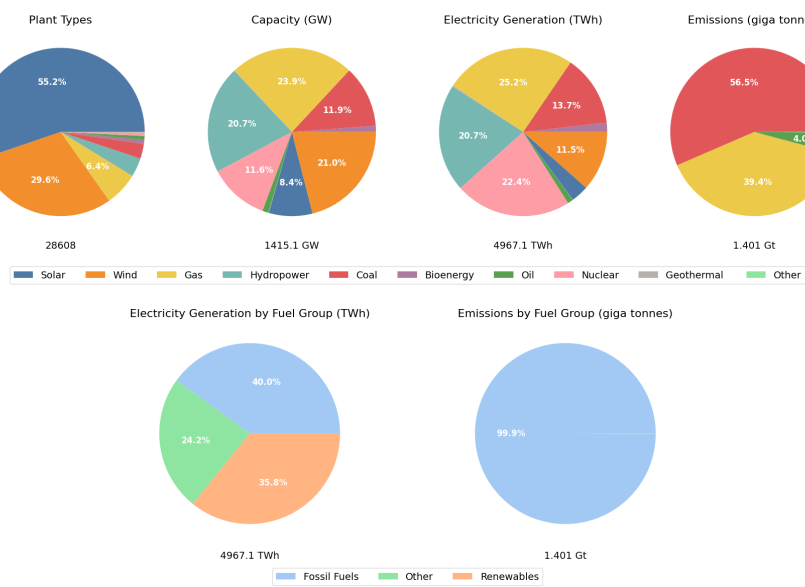

Figure C.4: Power sector descriptive statistics Europe.

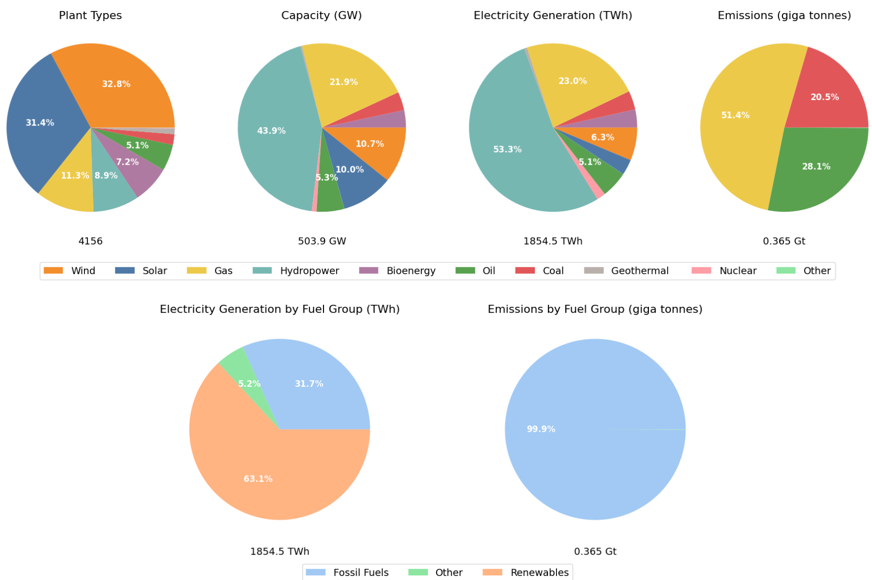

Figure C.5: Power sector descriptive statistics Latin America and the Caribbean.

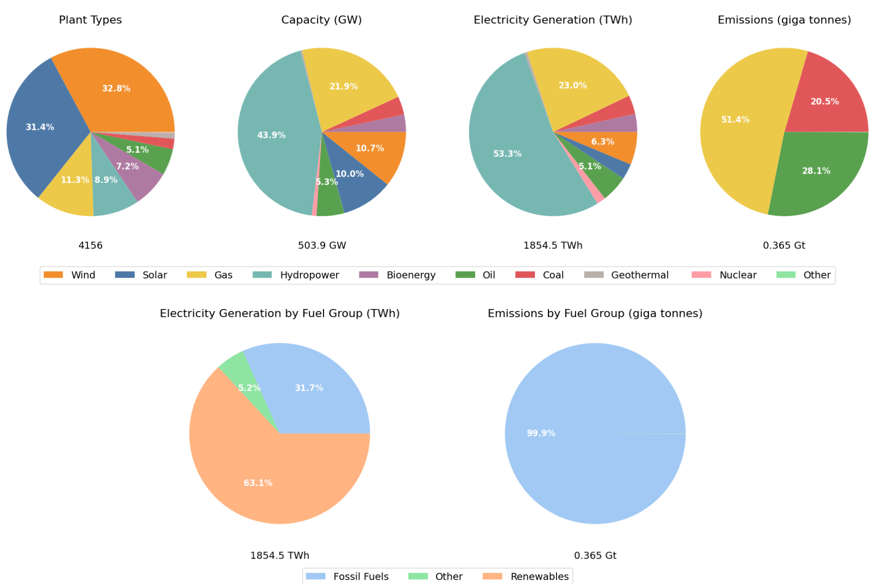

Figure C.6: Power sector descriptive statistics North America.

REFERENCES

Adrian, T., Bolton, P., & Kleinnijenhuis, A. M. (2022). The Great Carbon Arbitrage.

Anthoff, D., & Tol, R. S. (2019, November). *Fund.* Economics Software Archive, Department of Economics, University of Sussex Business School. Retrieved from https://ideas.repec.org/c/sus/susesa/0519.html

Arrhenius, S. (1896). Xxxi. on the influence of carbonic acid in the air upon the temperature of the ground. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, *41*(251), 237–276.

Bilal, A., & Känzig, D. (2024, May). *The Macroeconomic Impact of Climate Change: Global vs. Local Temperature* (Tech. Rep. No. w32450). Cambridge, MA: National Bureau of Economic Research. Retrieved 2025-04-23, from http://www.nber.org/papers/w32450.pdf doi: 10.3386/w32450

Bolson, N., Prieto, P., & Patzek, T. (2022, December). Capacity factors for electrical power generation from renewable and nonrenewable sources. *Proceedings of the National Academy of Sciences*, *119*(52), e2205429119. Retrieved 2025-04-18, from https://www.pnas.org/doi/abs/10.1073/pnas.2205429119 (Company: National Academy of Sciences Distributor: National Academy of Sciences Institution: National Academy of Sciences Label: National Academy of Sciences Publisher: Proceedings of the National Academy of Sciences) doi: 10.1073/pnas.2205429119

Bolton, P., Edenhofer, O., Kleinnijenhuis, A., Rockström, J., & Zettelmeyer, J. (2025, 3 13). Why coalitions of wealthy nations should fund others to decarbonize [Comment]. *Nature*, *639*(8055). Retrieved from https://

www.nature.com/articles/d41586-025-00779-9

Bolton, P., & Kleinnijenhuis, A. M. (2024). *Cop29: The economic case for a new common quantified goal of climate finance (ncqg) at scale* (Policy Brief). E-axes Forum. Retrieved from https://e-axes.org/wp-content/uploads/2024/11/COP29-PB_11_20_2024b.pdf

Bolton, P., & Kleinnijenhuis, A. M. (2025). *The economics of decarbonizing the power sector.* (Forthcoming)

Bolton, P., Kleinnijenhuis, A. M., & Zettelmeyer, J. (2024, June 11). *The economic case for climate finance at scale* (Policy Brief). Bruegel. Retrieved from https://www.bruegel.org/policy-brief/economic-case-climate-finance-scale

Butler, C. (2024, November). *Closing the climate finance gap: How to raise the money the world needs to support climate action* (Tech. Rep.). Royal Institute of International Affairs. Retrieved 2025-04-21, from https://chathamhouse.soutron.net/Portal/Public/en-GB/RecordView/Index/205754 doi: 10.55317/9781784136307

Carter, L. (2025, February). Lobbying. *Global Investigative Journalism Network*. Retrieved 2025-04-21, from https://gijn.org/resource/guide-investigating-fossil-fuels-lobbying/

Change, I. P. o. C., & Group 1, I. P. o. C. W. (1990). *Scientific Assessment of Climate Change: The Policymakers' Summary of the Report of Working Group I to the Intergovernmental Panel on Climate Change*. World Meteorological Organization/United Nations Environment Programme ....

Climate Policy Institute, A. . O. (2023). *How big is the net zero finance gap?* (Tech. Rep.). Climate Policy Institute. Retrieved 2025-04-23, from https://www.climatepolicyinitiative.org/publication/how-big-is-the-net-zero-finance-gap/

Conference of the Parties. (2015, December 12). *Adoption of the paris agreement.* U.N. Doc. FCCC/CP/2015/L.9/Rev/1. Retrieved from https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

Creutzig, F., Agoston, P., Goldschmidt, J., et al. (2017). The underestimated potential of solar energy to mitigate climate change. *Nature Energy*, *2*, 17140. Retrieved from https://doi.org/10.1038/nenergy.2017.140 doi: 10.1038/nenergy.2017.140

Hope, C. W. (2008). Optimal carbon emissions and the social cost of carbon over time under uncertainty. *Integrated Assessment Journal*, *8*(1).

Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., ... Johnson, C. A. (2001). *Climate change 2001: the scientific basis* (Vol. 881). Cambridge university press Cambridge. (Issue: 9)

Howarth, R. W. (2024). The greenhouse gas footprint of liquefied natural gas (lng) exported from the united states. *Energy Science & Engineering*, *12*, 4843–4859. doi: 10.1002/ese3.1934

Hunt, K. M. R., & Bloomfield, H. C. (2024). Quantifying renewable energy potential and realized capacity in India: Opportunities and challenges. *Meteorological Applications*. Retrieved 2025-04-23, from https://rmets.onlinelibrary.wiley.com/journal/14698080

IEA. (2023). *Hydrogen production and infrastructure projects database.* Paris. Retrieved from https://www.iea.org/data-and-statistics/data-product/hydrogen-production-and-infrastructure-projects-database

IEA. (2023). *World energy employment 2023.* https://www.iea.org/reports/world-energy-employment-2023. International Energy Agency.

IEA. (2024). *Batteries and secure energy transitions.* Paris. Retrieved from https://www.iea.org/reports/batteries-and-secure-energy-transitions

IEA. (2024). *World energy outlook 2024.* https://www.iea.org/reports/world-energy-outlook-2024.

IEA. (2025). *Global energy review 2025* (Tech. Rep.). Paris: International Energy Agency. Retrieved from https://www.iea.org/reports/global-energy-review-2025 (Licence: CC BY 4.0)

Igbokwe, N. (2025, January 28). *If foreign aid and climate action is out, blended finance must step in.* Convergence Finance. Retrieved from https://www.convergence.finance/news/4jhGXUYt0pnYDShsBhk3LK/view (Op-ed originally published in Impact Alpha)

IPCC. (2023). *Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (1st ed.). Cambridge University Press. Retrieved 2025-04-23, from https://www.cambridge.org/core/product/identifier/9781009157896/type/book doi: 10.1017/

9781009157896

IRENA. (2024a). *Renewable energy statistics 2024.* https://www.irena.org/Publications/2024/Jul/Renewable-energy-statistics-2024. International Renewable Energy Agency.

IRENA. (2024b). *Renewable power generation costs in 2023.* https://www.irena.org/Publications/2024/Sep/Renewable-Power-Generation-Costs-in-2023. International Renewable Energy Agency.

Isah, A., Egli, F., Schmidt, T. S., & Stünzi, A. (2025, February). Quantifying climate finance needs in the nationally determined contributions of developing countries. *Climate Policy*, 1–18. Retrieved 2025-04-23, from https://www.tandfonline.com/doi/full/10.1080/14693062.2025.2460607 doi: 10.1080/14693062.2025.2460607

Jhujhunwala, G., Mehta, T., Dileep, G., & Malhotra, M. (2024, July). *Assessing worker and community dependence on thermal power plants: A case study* (Report). Council on Energy, Environment and Water. Retrieved from https://www.ceew.in/sites/default/files/worker-and-community-dependence-on-coal-based-thermal-power-plants.pdf

Lantushenko, V., & Schellhorn, C. (2023). The rising risks of fossil fuel lobbying. *Global Finance Journal*, *56*(C).

Lenton, T. M., Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S., & Schellnhuber, H. J. (2008, February). Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences*, *105*(6), 1786–1793. Retrieved 2025-04-23, from https://pnas.org/doi/full/10.1073/pnas.0705414105 doi: 10.1073/pnas.0705414105

Louie, E. P., & Pearce, J. M. (2016, June). Retraining investment for U.S. transition from coal to solar photovoltaic employment. *Energy Economics*, *57*, 295–302. Retrieved 2025-04-18, from https://www.sciencedirect.com/science/article/pii/S0140988316301347 doi: 10.1016/j.eneco.2016.05.016

M. Crippa, D. G., F, P., M, B., M, M., E, S., F, M.-F., ... F, P. (2024). *GHG emissions of all world countries* (Tech. Rep. Nos. KJ-01-24-010-EN-N (online),KJ-01-24-010-EN-C (print)). Luxembourg (Luxembourg): Publications Office of the European Union. (ISBN: 978-92-68-20572-3 (online),978-92-68-20573-0 (print) ISSN: 1831-9424 (online),1018-5593 (print)) doi: 10.2760/4002897(online),10.2760/0115360(print)

Ministry of Environment and Forestry, Government of Indonesia. (2021). *Indonesia third biennial update report* (Tech. Rep.). Indonesia: Directorate General of Climate Change, Ministry of Environment and Forestry. Retrieved from https://unfccc.int/sites/default/files/resource/IndonesiaBUR%203_FINAL%20REPORT_2.pdf

Ministry of Environment, Forest and Climate Change, Government of India. (2024). *India: Fourth biennial update report to the united nations framework convention on climate change* (Tech. Rep.). Ministry of Environment, Forest and Climate Change, Government of India.

Montague, Raiser, & Lee. (2024, July). *Bridging the clean energy investment gap: Cost of capital in the transition to net-zero emissions* (OECD Environment Working Papers No. 245). Retrieved 2025-04-23, from https://www.oecd.org/en/publications/bridging-the-clean-energy-investment-gap_1ae47659-en.html (Series: OECD Environment Working Papers Volume: 245) doi: 10.1787/1ae47659-en

NASA. (2025). *Temperatures Rising: NASA Confirms 2024 Warmest Year on Record - NASA.* Retrieved 2025-04-23, from https://www.nasa.gov/news-release/temperatures-rising-nasa-confirms-2024-warmest-year-on-record/ (Running Time: 69 Section: Goddard Institute for Space Studies)

Network for Greening the Financial System. (2023). *Ngfs climate scenarios for central banks and supervisors.* Retrieved from https://www.ngfs.net/ngfs-scenarios-portal/

Nordhaus, W. (2020). The climate club. *Foreign Affairs*, *99*(3), 10–17. Retrieved from https://williamnordhaus.com/files/williamdnordhaus/files/p161-2020-nordhaus-clubs-foreignaffairs-2020.pdf

Nordhaus, W. D. (1992). The 'DICE'model: background and structure of a dynamic integrated climate-economy model of the economics of global warming.

Pauw, W. P., Klein, R. J. T., Mbeva, K., Dzebo, A., Cassanmagnago, D., & Rudloff, A. (2018, March). Beyond headline mitigation numbers: we need more transparent and comparable NDCs to achieve the Paris Agreement on climate change. *Climatic Change*, *147*(1), 23–29. Retrieved from https://doi.org/10.1007/s10584-017-2122-x doi: 10.1007/s10584-017-2122-x

Pindyck, R. S. (2019, March). The social cost of carbon revisited. *Journal of Environmental Economics and Management*, *94*, 140–160. Retrieved 2025-04-18, from https://www.sciencedirect.com/science/article/pii/S0095069617307131 doi: 10.1016/j.jeem.2019.02.003

Powering past coal and gas: the Greens' climate and energy plan to fight the climate crisis, grow jobs and repower the economy with net-zero emissions by 2035. (2022). Retrieved 2025-04-23, from https://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22library%2Fpartypol%2F8552391%22;src1=sm1?afd_azwaf_tok=eyJhbGciOiJSUzI1NiJ9.eyJhdWQiOiJwYXJsaW5mby5hcGguZ292LmF1IiwiZXhwIjoxNzQ1MzcxODA0LCJpYXQ.A7bJir2nnE2Tuv3JZG7jAttcTvHKTPfY3iNXmomXlIojaE-IPJaJMu64flfkpxgYC5TG8bHuJmDO7y5UphtAH5hY9PrYjOMhpS_cg4x5wR9QWy9j-uIWGmnvZDswl43gYPotTPGkqfex24kkiPmsGe8aagKt5_c8XSAGlk_6IHTB8-nL4cIy_A_5M9KOaaiSAcLL3YMhGuOPkeKRYdM8IV3r1sOAk3CTVVK-f5HDf4x8bim5yVfUj5ZCwC2JNj4CVgMHGYva4zf6jvOovgEme1eqONwFreosWKorCNR.WF3obl2IDtqgvMFRqVdYkD5s

Rathi, A. (2024). *Climate Capitalism: Winning the Race to Zero Emissions and Solving the Crisis of Our Age*. Greystone Books. Retrieved from https://books.google.com/books?id=i1zbEAAAQBAJ

Rennert, K., Errickson, F., Prest, B. C., Rennels, L., Newell, R. G., Pizer, W., ... Anthoff, D. (2022, October). Comprehensive evidence implies a higher social cost of CO2. *Nature*, *610*(7933), 687–692. Retrieved from https://doi.org/10.1038/s41586-022-05224-9 doi: 10.1038/s41586-022-05224-9

Ricke, K., Drouet, L., Caldeira, K., & Tavoni, M. (2018, October). Country-level social cost of carbon. *Nature Climate Change*, *8*(10), 895–900. Retrieved 2025-04-18, from https://www.nature.com/articles/s41558-018-0282-y (Publisher: Nature Publishing Group) doi: 10.1038/s41558-018-0282-y

Ripple, W. J., Wolf, C., Gregg, J. W., Rockström, J., Newsome, T. M., Law, B. E., ... King, S. D. A. (2023, December). The 2023 state of the climate report: Entering uncharted territory. *BioScience*, *73*(12), 841–850. Retrieved 2025-04-22, from https://doi.org/10.1093/biosci/biad080 doi: 10.1093/biosci/biad080

Rockström, J., Gupta, J., Qin, D., Lade, S. J., Abrams, J. F., Andersen, L. S., ... Zhang, X. (2023, July). Safe and just Earth system boundaries. *Nature*, *619*(7968), 102–111. Retrieved from https://doi.org/10.1038/s41586-023-06083-8 doi: 10.1038/s41586-023-06083-8

Rockström, J., Steffen, W., Noone, K., Persson, , Chapin, F. S., Lambin, E. F., ... Foley, J. A. (2009, September). A safe operating space for humanity. *Nature*, *461*(7263), 472–475. Retrieved from https://doi.org/10.1038/461472a doi: 10.1038/461472a

Rogelj, J., Fransen, T., Den Elzen, M. G. J., Lamboll, R. D., Schumer, C., Kuramochi, T., … Portugal-Pereira, J. (2023, June). Credibility gap in net-zero climate targets leaves world at high risk. *Science*, *380*(6649), 1014–1016. Retrieved 2025-04-23, from https://www.science.org/doi/10.1126/science.adg6248 doi: 10.1126/science.adg6248

Roser, M. (2020). Why did renewables become so cheap so fast? *Our World in Data*. (https://ourworldindata.org/cheap-renewables-growth)

Samadi, S. (2018). The experience curve theory and its application in the field of electricity generation technologies–a literature review. *Renewable and Sustainable Energy Reviews*, *82*, 2346–2364.

Semieniuk, G., Holden, P. B., Mercure, J.-F., Salas, P., Pollitt, H., Jobson, K., … Viñuales, J. E. (2022, June). Stranded fossil-fuel assets translate to major losses for investors in advanced economies. *Nature Climate Change*, *12*(6), 532–538. Retrieved 2025-04-17, from https://www.nature.com/articles/s41558-022-01356-y (Publisher: Nature Publishing Group) doi: 10.1038/s41558-022-01356-y

Spain guarantees a just transition for miners | ETUC. (2018). Retrieved 2025-04-17, from https://www.etuc.org/en/spain-guarantees-just-transition-miners

Stocker, T. F., Jones, R. G., Hegglin, M. I., Lenton, T. M., Hegerl, G. C., Seneviratne, S. I., … Wood, R. A. (2024, June). Reflecting on the Science of Climate Tipping Points to Inform and Assist Policy Making and Address the Risks they Pose to Society. *Surveys in Geophysics*. Retrieved from https://doi.org/10.1007/s10712-024-09844-w doi: 10.1007/s10712-024-09844

-w

U.S. Department of Energy. (2023). *U.s. energy & employment jobs report (useer)* (Government Report). U.S. Department of Energy. Retrieved from https://www.energy.gov/policy/2023-us-energy-employment-jobs-report-useer

Way, R., Ives, M. C., Mealy, P., & Farmer, J. D. (2022). Empirically grounded technology forecasts and the energy transition. *Joule*, *6*(9), 2057–2082.

Weart, S. R. (1997, January). The Discovery of the Risk of Global Warming. *Physics Today*, *50*(1), 34–40. Retrieved 2025-04-22, from https://doi.org/10.1063/1.881664 doi: 10.1063/1.881664

Welsby, D., Price, J., Pye, S., & Ekins, P. (2021, September). Unextractable fossil fuels in a 1.5 °C world. *Nature*, *597*(7875), 230–234. Retrieved 2025-04-17, from https://www.nature.com/articles/s41586-021-03821-8 (Publisher: Nature Publishing Group) doi: 10.1038/s41586-021-03821-8

Zagema, B., Kowalzig, J., Walsh, L., Hattle, A., Roy, C., & Dejgaard, H. P. (2023, June 5). *Climate finance shadow report 2023: Assessing the delivery of the £100 billion commitment* (Tech. Rep.). Oxfam International. doi: 10.21201/2023.621500