The Coalition of Finance Ministers for Climate Action

Climate finance at scale to implement NDCs: decarbonizing the power sector

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Summary[1]

Avoided emissions from the phaseout of fossil fuel-fired power plants by emerging and developing market economies (EMDEs) can be monetized to generate more private finance for renewable (RE) development. One source is from the de-risking and leveraging impact of greater flows of international public financing that should be forthcoming based on the large net benefits to these countries from EMDE decarbonization. Simulations based on recent data show that if the G7 and European Union countries were to cover 25% of the total costs of replacement RE, storage, and grid investments plus closure-related opportunity costs from the phaseout of largely coal-fired power plants just from India, Indonesia, Türkiye, and Vietnam, their own net benefits would be over US$3 trillion. A second source of untapped financial synergies is from the additional private finance generated by a new high-integrity carbon offset market that monetizes these identifiable, additional, and permanent avoided emissions. To achieve such large net benefits, a granular system-wide country plan that matches an optimal phaseout pipeline with a simultaneous RE phase-in pipeline is essential for the effective, Paris Agreement-aligned implementation of Nationally Determined Contributions (NDCs) rather than a project-by-project approach. This contribution provides a step-by-step recipe for how countries can formulate, finance, and implement NDCs that are Paris-aligned for both EMDEs and DEs. The financing strategies for NDC implementation take into consideration a country's wealth differences but do not compromise the necessity to be Paris-aligned, so that the aggregation of a country's NDCs is aligned with the Paris Agreement goal of limiting global warming to 1.5°C.

Outline: climate finance at scale to implement Nationally Determined Contributions to decarbonize the power sector

This contribution discusses the *method* for implementing and financing NDCs for power sector decarbonization as well as showing the *results*, which focus on how the economics of power sector decarbonization through climate finance at scale can be made to work.

Those who are most interested in the results can skip the method section but may have to occasionally refer back to it to understand the methodology employed.

Method: a recipe to implement and finance Paris-aligned NDCs for power sector decarbonization

This section specifies a recipe (a step-by-step action guide, like in a cookbook) for how a country can set, finance, and implement NDCs in line with the Paris Agreement (see Figure 1). It focuses specifically on the part of the NDC specifying how a country will decarbonize its power sector. The power sector is responsible for around 40% of emissions on average globally, and thus of first-order importance to decarbonize. In particular, with the projected growth in energy demand driven by artificial intelligence (AI) and other factors, ensuring this is met with clean energy is of paramount importance for meeting the Paris Agreement goals. Decarbonizing the power sector is also the lowest-hanging fruit. All the scalable technologies already exist. Hence, there is no excuse not to do it *now*. While the results in this report are based on default settings, the authors have created an *NDC and climate finance tool*[2] that countries can use to formulate, finance, and implement Paris-aligned NDCs and tailor any assumptions of this recipe to their country's preferences.

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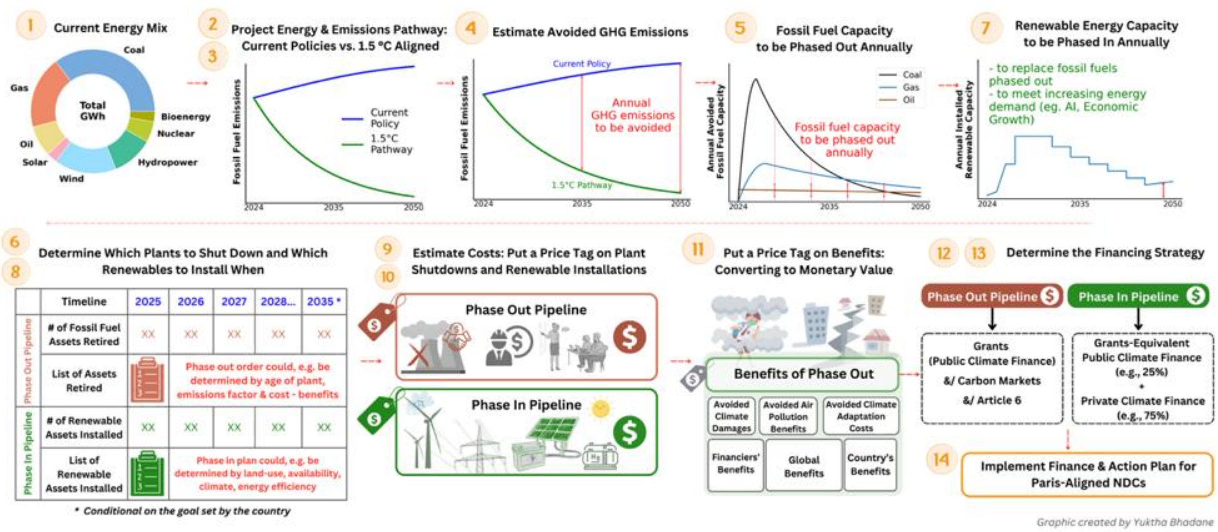
2 See https://forwardglobalinstitute.com/dashboard.

Figure 1. Schematic overview: a recipe to implement and finance Paris-aligned NDCs for power sector decarbonization



Source: Bolton and Kleinnijenhuis (2024b)

The steps in the recipe to implement and finance NDCs for the power sector are specified below.

1. Take the current energy mix

Step 1 of formulating the NDC for the power sector is to determine the country's current energy electricity mix. This can be, and is valuably, expressed in terms of capacity (Figure A1), used capacity, electricity generated (Figure 6), and emissions (Figure A3) of each energy type.

Energy types in a country encompass oil, coal, gas, solar, wind onshore, wind offshore, hydropower, thermal power, nuclear, etc. The energy mix calculation should ideally also specify the capacity of the existing electricity grid's short-term batteries (e.g., Li-ion batteries) and long-term energy storage capacity (green electrolysis), as well as the grid structure.

2. Project future energy demand, energy mix and associated emissions under current policies (current policy scenario, s1)

Step 2 of formulating the NDC for the power sector is to project energy demand under current policies involves projecting how much electricity must be generated to meet the demand, how the current energy mix (step 1) would evolve under current policies to meet projected energy demand, and what the associated emissions are under current policies (as a whole [Figure A3] and by fossil fuel type [Figure A5]).

A Government can use different methodologies to project future energy demand. A common way is to use scenarios from the International Energy Agency (IEA), shared economic pathway scenarios (SSPs), representative concentration pathways (RCPs), or scenarios of the Network for Greening the Financial System (NGFS). This contribution uses the country-level scenarios of the NGFS for each fossil fuel (and clean energy) type for "Current Policies" to inform the projected future energy demand and associated emissions under current policies.[3]

3. Project the emission pathway required to be Paris- and carbon-budget aligned (carbon-budget-aligned, net zero scenario, s2)

3 The NGFS scenario portal can be found at: https://www.ngfs.net/ngfs-scenarios-portal/. This contribution specifically uses the GCAM6.0 model.

Step 3 of formulating the NDC for the power sector is to project the pathway of how emissions would need to come down over time to make the country's power sector transition consistent with the Paris Agreement. As in step 2, a government can use the net zero scenarios of the IEA, the SSPs, RCPs, or scenarios of the NGFS to do so.

While, in principle, a country can choose any decarbonization scenario, when choosing its own decarbonization pathway and implied speed of emission reductions,[4] it is critical that each country choses a pathway that is ideally consistent with the Paris Agreement objective to limit the increase in temperatures to 1.5°C. Every 0.1°C significantly increases adverse climate risks.

Steps 12 and 13 of the recipe discuss how not only developed economies, but also EMDEs, which are often not as wealthy and not responsible for most of historical emissions, should chose a 1.5°C-consistent decarbonization pathway, as EMDEs can design proper strategies to getting this decarbonization pathway financed without having to rely solely on their own public coffers. In sum, to formulate the NDC the country should first plan a Paris-aligned pathway to see how it can get this financed rather than formulating a Paris-misaligned decarbonization pathway for fear of not being able to finance it without taking away finance from other Government development purposes.

In the example here the "NGFS Net Zero 2050" scenario is used to inform the emission reduction pathways of fossil fuels in the power sector.

For a country choosing a net zero scenario for its decarbonization pathway, it is important to check whether the chosen scenario is consistent with the remaining carbon budget for the chosen temperature goal (say 1.5°C with 50% certainty). The chosen net zero scenario may thus need to be adjusted to be made more stringent to reflect the shrinking carbon budget. Figures A3 and A5 in the appendix show the country-level "Net Zero 2050" scenario of the NGFS adjusted in stringency to make it consistent with the estimated 358 Gt of carbon budget (1.5°C with 50% certainty) left at the beginning of 2023. See Bolton and Kleinnijenhuis (2024) for methodological details for how to make net zero scenarios consistent with the chosen carbon budget. In essence, this example uses the NGFS GCAM6.0 Net Zero 2050 scenario, and adds up the implied annual CO_2 emissions from 2024 to 2050. The emissions are found to be consistent with the 1.6°C (50%) remaining carbon budget as of 2023. To make the NGFS GCAM6.0 Net Zero 2050 Scenario consistent with the 1.5°C (50%) remaining carbon budget as of 2023, the annual rate of emission reductions is increased such that emissions between 2024 and 2050 exactly add up to the 1.5°C (50%) remaining carbon budget as of 2023. This method retains the NGFS's heterogeneity in country rates of emission reductions and fossil fuel type rates of emission reductions, while homogenously slightly increasing the country-fossil-fuel-year-specific decarbonization rate.

4. Calculate the annual greenhouse gas emissions and air pollution (and other environmental damages) that are avoided between the current policy (s1) and net zero scenario (s2)

Step 4 of formulating the NDC for the power sector is to compute the annual avoided emissions (Figure A6) and cumulative avoided emissions (Figure A7) between the current policy and net zero scenarios. This will be used in step 11.

Step 4 also involves computing what the reduction in air pollution levels would be by implementing the net-zero scenario compared with the current policy pathway and any other environmental benefits. See Bolton and Kleinnijenhuis (2024) for the air pollution reduction methodology.

5. Calculate the annual fossil fuel capacity that must be phased out each year to meet the net zero emission pathway (s2).

Step 5 of formulating the NDC for the power sector involves calculating the fossil fuel capacity that must be phased out each year (Figure 6). In this step it is also valuable to compute the cumulative

4 A country is free to choose its own decarbonization scenario, as the recipe here works regardless of the country's chosen decarbonization pathway.

fossil fuel capacity that must be phased out over time as a whole (Figure A8) and by fossil fuel type (Figure A9).

6. Determine the *phaseout pipeline* of when and which fossil fuel assets must be phased out to meet the annual fossil fuel emissions, and capacity reduction

Step 6 of formulating the NDC for power sector involves determining the *phaseout pipeline*. The phaseout pipeline stipulates when and which fossil fuels should be phased out to implement the emission reduction pathway s2 of step 3, and (in the case of equal emission intensities and capacity factors) hit the annual fossil fuel reduction targets of step 5.

The fossil fuel assets to phase out each year to hit emission and fossil fuel capacity targets can be informed by cost-benefit ranking criteria, such as:

I. Phase out fossil fuel assets with the shortest time to maturity first
II. Phase out fossil fuel assets with the highest emission intensity first
III. Phase out fossil fuels with the highest net benefits of phaseout first (i.e., where social benefits exceed the cost of phaseout).

See Bolton and Kleinnijenhuis (2024) for details.

The set of fossil fuel assets to be phased out each year to hit an annual retirement target of fossil fuel capacity can also be informed by auctions (see Srivastav et al. (2024). Germany held a successful auction where coal-fired power plants voluntarily took part in return for compensation. As such, Germany could hit its annual capacity targets for coal-fired power-plant capacity reductions.

The *phaseout pipeline* stipulates in what year what set of fossil fuel assets would be retired. Additional specification could add whether it is a full or partial retirement (i.e., by what percentage or capacity).

7. Determine how much renewable capacity would need to be installed annually to meet energy demand, given the annual shortfall in energy supply due to fossil fuel phaseout and projected demand growth

Step 7 of setting the NDC for the power sector involves determining how much renewable capacity would need to be installed each year (Figure A10) to meet energy demand, taking into account both the reduction in supply because of the phaseout of assets and any increase in demand because of energy demand growth.

Importantly, this step must formulate not only the renewable capacity to be added but also the capacity of supporting technologies to be added, such as short-term batteries (Li-ion) and electrolyzers for green hydrogen. In line with Adrian et al. (2022), this example conservatively assumes that 20% of daily generated renewable electricity must be able to be stored in short-term batteries and one month's worth of annual renewable electricity must be able to be stored long term.

8. Given the renewable capacity factors, existing uses of land, and country grid structure, determine the "optimal" energy mix to replace fossil fuels and keep up with any growth in energy demand, in order to determine the *phase-in pipeline* of renewables

Step 8 of setting the NDC involves determining the *phase-in pipeline*. This stipulates how many renewable assets of each type must be installed each year to meet energy demand (it is interlinked with step 7). Specifying the phase-in pipeline requires the (time-varying) energy mix of renewables for replacing fossil fuels to be specified. This should be informed by the country's capacity factors of renewables (i.e., the natural resource energy generation ability), existing uses of land, and the existing grid structure.

It is assumed that each country chooses an energy replacement mix, at each future phaseout year, equal to its current (2024) renewable energy composition (percentage-wise). So, if country A currently has 30% solar PV, 20% wind onshore, 10% wind offshore, and 30% coal and 10% gas, it can be assumed that each time fossil fuel capacity is phased out or energy demand increases it is met with

50% solar, 33.33% wind onshore, and 16.67% wind offshore, and the necessary storage capacity and grid extension are also installed. A country can choose any time-evolving renewable energy mix to meet the projected demand.

The phase-in pipeline stipulates the capacity of each renewable type to be installed annually (Figure 11A). Given the depreciation rates and lifetime of renewables, the country can then also calculate the cumulative renewable capacity in operation in each future year (Figure 12A); Adrian et al. (2022) provide a methodology for how to do this.

9. Put a price tag on the phaseout pipeline

Step 8 of setting the NDC involves putting a price tag on the phaseout pipeline (defined in step 6); see Figure 4. This involves determining what the costs are of phasing out fossil fuel assets. Adrian et al. (2022) discuss that the cost of phasing out fossil fuels consists of its *opportunity costs*. These, have a minimum of three components, including: (i) the stranded asset value (i.e., the present value of expected missed free cash flows from closing a fossil fuel plant early); (ii) compensation for lost wages of workers who lose their jobs; and (iii) retraining costs to employ fossil fuel workers elsewhere.

Adrian et al. (2022) propose a method to compute this cost for coal, and Bolton and Kleinnijenhuis (2024a) extend it for fossil fuels. Clearly, a country can use its own methodologies to refine estimation of the price tag of the phaseout pipeline. Importantly, the estimation of cost should stipulate this in both annual terms and present-value terms.

10. Put a price tag on the phase-in pipeline

Step 10 of setting the NDC involves putting a price tag on the phase-in pipeline (defined in step 8); see Figure 4. As a recap, the phase-in pipeline stipulates how much capacity of renewables of each type (including storage technologies) and how much grid capacity must come online each year. So, putting a price tag on these involves determining what the *investment costs* are each year to install the specified capacity of each renewable type in the phase-in pipeline, and computing their present value.

The present value can be estimated easily based on the prevailing investment costs for each renewable type. Importantly, future estimations of the renewable investment cost need to take into consideration learning-by-doing effects, which make renewables cheaper as a function of global cumulative deployment (Way et al., 2022). Estimations must ideally also need to take into consideration countervailing forces, such as any raw material shortages or supply chain issues that could drive up prices. Adrian et al. (2022) propose a methodology for estimating future investment cost declines for each renewable type as a function of projected deployment.

11. Put a price tag on the country, financier, and global benefits of the phaseout

Step 11 of setting the NDC involves putting a price tag on the economic benefits of phasing out fossil fuels in the power sector, for the country itself and for any group of financier countries that may help pay for the country's implementation of its NDC, as well as the world as whole.

The economic benefits consist of at least two components, including: (i) those from avoided climate damages and avoided climate adaptation costs; and (ii) those from avoided mortalities (and disability-lived life years) from avoided air pollution. Other economic benefits that a country could consider and quantify are the opportunities to become part of the global renewable value chain, the economic opportunities created by the renewable transition, reduced global instability, and reduced migration flows.

This contribution focuses on (i) and (ii). To estimate (i) and (ii) one can make use of step 4, which computes the annual and cumulative avoided CO_2 emissions, as well as the reduction in country air pollution levels (PM2.5).

On (i):

- The global economic benefit (see Figure 3) from the country's implementation of its NDC in line with a net zero carbon-budget-consistent pathway (step 3) is given by the cumulative avoided emissions (resulting from implementing step 3 compared with the current policies in step 2, giving step 4) times the global social cost of carbon (SCC). The global SCC estimates the present value of the climate damages and adaptation costs from one extra ton of CO_2e emitted today. While the SCC is uncertain, a country can choose a conservative value, such as US$180/t$CO_2$ (the Biden administration SCC). Figure 3 shows the estimated global benefit based on a global SCC of US$180/t$CO_2$.

- The country's economic benefit (see Figure 2 and 3) from its implementation of its NDC in line with a net zero carbon-budget consistent pathway (step 3) is given by the cumulative avoided emissions (step 4) times the country's SCC. The sum of the country-level SCCs gives the global SCC. In Figure 2, it can be seen that India's SCC is, for instance, estimated to be 6.52% of the global SCC (Ricke et al., 2018), resulting in an SCC of US$11.74/t$CO_2$ for India. A county can choose its own country-level SCC estimate here, or use one from the literature, such as provided by Ricke et al. (2018).
- The financier countries' economic benefit (see Figure 5) from the country's implementation of its NDC in line with a net zero carbon-budget-consistent pathway (step 3) is given by the cumulative avoided emissions (step 4) times the collective financier countries' SCC. Assuming that the group of financier countries that may help pay for the recipient country's implementation of its NDC is the set of developed countries, then their SCC share is around 50%. So, the country's avoided emissions are multiplied by US$90/t$CO_2$, when a global SCC of US$180/t$CO_2$ is assumed.

On (ii):

- A country can estimate air pollution benefits (see Figure 2 and 3) based on a methodology developed by Bolton and Kleinnijenhuis (2024a), which is itself an extension of that of McDuffie et al. (2021). See Kleinnijenhuis (2024) for details.

Importantly, air pollution benefits are largely local and materialize immediately whenever fossil fuels are phased out, whereas the benefits from avoided climate damages are dispersed across the world and in part materialize in the future. Both benefits have significant economic magnitude and oftentimes offset the country's cost to implement its NDC.

12. Determine the financing strategy for the phaseout pipeline

Step 12 of setting the NDC to decarbonize the power sector involves determining the financing strategy for the phaseout pipeline. There are at least three ways to finance the NDC phaseout pipeline (consisting of the opportunity costs of coal; see step 9), including:

i. Grant compensation by domestic and/or international financiers
ii. Article 6
iii. Carbon markets.

The key element is that avoided emissions (step 4) are an asset that can be monetized. The avoided emissions result in economic benefits for the country, financiers, and the world as a whole (step 11). Hence, whenever the economic benefits exceed the cost to close fossil fuels early, there is an economic case to do so.

Importantly, even when there is no global carbon price (say of US$190/t$CO_2$) or country-level voluntary or regulatory carbon price, the economic benefits of financing domestic or foreign decarbonization are *tangible*. Because any phaseout of fossil fuel power plants is tied to the concurrent phase-in of renewable (clean energy) power plants, brown energy is simply replaced with green energy, leaving overall supply relative to demand unchanged. This means that climate finance directed at replacing fossil fuels with renewables will generally not lead to carbon leakage. In other words, climate finance directed at replacing fossil fuels with renewables results in an absolute emission reduction relative to the current policy baseline. This absolute emission reduction is worth money (it is a valuable asset). Concretely, 1 ton of avoided emissions is worth US$190/t$CO_2$ globally (taking a conservative estimate of the global SCC of US$190/t$CO_2$). A ton of avoided emissions is worth US$94.6/t$CO_2$ to the United States. So, if, say, the U.S. offers climate finance to India that results in 0.5Gt emission reductions in Indonesia, this gives, US$28.38 billion economic benefits to the U.S. These economic benefits to the

U.S. from offering Climate Finance to India are not abstract; they are concrete. Concretely, those benefits are expressed as an estimated US$28.38 billion in avoided climate damages and avoided adaptation costs to the U.S. Illustratively, Hurricanes Helene and Milton in 2024 are collectively estimated to have caused US$300 billion of economic damages, and were both exacerbated by climate change. These economic damages and adaptation costs are not abstract; they are very real, and will be escalating beyond 2024, unless climate finance is offered at scale globally to abate emissions.

While the country-level net-benefit (= benefits – costs) of implementing a Paris-Aligned NDC (step 3) is sometimes negative (Figure 2), even when air pollution benefits are taken into account, the net benefits to a financier coalition, such as the G7+EU, of paying to implement a country's NDC are typically positive (Figure 5). Similarly, the global net benefits (Figure 3) are almost always high and positive.

Since closing fossil fuel assets early does not generate a revenue stream, subsidies (grants) must be offered to do so. Another option is to use the avoided emissions to sell carbon credits. It is not clear, however, whether carbon credits can be sold at a high enough price and are always additional. It is more foolproof to simply pay for closure.

Adrian et al. (2022) and Bolton et al. (2024) (see also Figures 2 and 5) show there is an economic case for paying the polluters to stop polluting by compensating for their opportunity cost of fossil fuels by means of grants. The economic benefits (step 11) to the financiers far exceed the cost (step 9) of doing so.

A country implementing the Paris-aligned NDC can pay for part of the NDC implementation itself (possibly up to its private benefits; see Figure 2), and international financiers can pay for the rest. In particular, in EMDE countries, which are less wealthy, there is often a need for international financiers to co-pay to implement their NDCs.

Adrian et al. (2022) and Bolton et al. (2024) establish that climate finance provided at scale by financier countries to a recipient country to help it implement its NDCs is not just a moral obligation (e.g., given their greater historical emissions and wealth), but also in their economic interest, for the reasons given before.

Under Article 6 of the Paris Agreement, international financiers that pay for avoided emissions (step 4) can count those toward domestic NDCs. Besides the economic case, there is thus also an accounting case for (developed) countries to help pay for emission avoidance in EMDEs. Article 6 allows the financier country offering climate finance to the recipient country to count the latter's emission reductions embedded in the financier-recipient climate finance deal toward its own NDCs. This could motivate wealthy financier countries to pay for foreign decarbonization to achieve domestic net-zero goals. Wealthy financier countries could also potentially benefit from lower marginal emission abatement costs abroad than at home, thereby reducing their overall costs to reach net zero. (The tricky part of Article 6 is that a country that is the recipient of climate finance cannot count its emission reduction toward its domestic NDC, to avoid double counting, necessitating it—if it was bent on achieving domestic NDC net zero—to pay for another country's decarbonization.)

In sum, the financing strategy a country chooses to pay for its phaseout pipeline typically involves finding co-payment between itself and international partners driven by net economic interest. While carbon credits are an option, simple subsidization for early closure is the most sound option. Wealthier countries typically can afford to pay for early closure themselves. Compared with the investment costs in renewables, and with the global/national climate damages and costs of air pollution, paying for early fossil fuel closure is an economic bargain.

Importantly, while many policy discussions focus on the "just transition" and the need to compensate fossil fuel workers and retrain them, this contribution has clearly identified the need to compensate fossil fuel owners as well. This payment does not just rest on economic logic but also helps alleviate strong lobbying power against any country transition taking place. Compensating for the three components of the opportunity cost of coal is thus also a ticket politicians can buy to get the social license to begin their country's power sector transition at the speed and scale required by the Paris goals in the first place.

13. Determine the financing strategy for the phase-in pipeline

Step 13 of setting the NDC to decarbonize the power sector involves determining the financing strategy for the phase-in pipeline.

Unlike the phaseout pipeline of fossil fuel assets to be closed early, the phase-in pipeline consists of renewable capacity to be installed. Renewables generate a revenue stream from sold electricity. Hence, investors from international and local financial markets can help pay for the phase-in of renewables.

While different strategies to pay for the phase-in of renewables could be designed, one principal way this could be done, proposed by Adrian et al. (2022) and Bolton et al. (2024), is to use *system-wide blended finance*. Either domestic public funds or international public climate finance, or both, could be used to de-risk investments by the private sector, so that their risk-adjusted return exceeds their hurdle rate. Figure 5 shows the net benefit to the G7+EU whenever they pay for *x*% of the investment cost and a 100% of the opportunity cost in the recipient country, and investors pay for (100 – *x*%) of the investment cost.

By pooling together the assets in the renewable pipeline in a country (or even regional) fund, the ticket size of renewable investments increases, making it more attractive for institutional investors, who hold vast pools of capital, to enter a cofinancing arrangement. Thus far, international institutional investors have barely invested in EMDE renewables. *System-wide blended finance* refers to the idea that the financing of renewables is done not at the project level but at the level of the phase-in pipeline, which is itself intimately tied to the phaseout pipeline; so the blended finance is offered to execute the countrywide NDC (particularly the phase-in part).

14. Execute the finance and implementation plan for the Paris-aligned NDCs

Steps 1–13 of the above recipe explained how to formulate an NDC that is Paris Agreement aligned and how to finance it so that the NDC is not just a plan, but a plan with finance backing, in order that the plan can become reality.

At COP29 leaders negotiated a New Common Quantified Goal of Climate Finance (NCQG), aiming to lift annual public climate finance from developed to developing countries from a floor of a US$100 billion to over US$1 trillion. Such climate finance is instrumental to help many EMDEs finance the implementation of their Paris-aligned NDCs. Climate finance for EMDEs is not just "just," but also in the economic interest of advanced countries (Adrian et al., 2022; Bolton et al., 2024). By helping EMDEs implement their NDCs, advanced countries, and indeed the world as a whole, will be able to grasp the economic opportunities of the transition and avert a climate disaster.

Data and methodology

The estimates are based on the *Digital Transition Twin Data* from Forward Analytics,[5] a new granular dataset with global coverage of a total of 126,350 power plants at the asset level. For each plant, the data includes the asset name, the direct owner, the geolocation, the power type and subtype (e.g., for coal: bituminous, subbituminous; for wind: onshore, offshore), the capacity (in MW), the emission intensity (kg CO_2/TJ), the heat rate, the capacity factor (country and technology-type specific), the activity (in MWh), the status (announced, shelved, canceled, pre-permit, construction, operating, retired), and the lifespan (start year, planned retirement year, retirement year). The data is updated biannually and checked for robustness against trusted sources. In replacing fossil fuels with RE, the Forward Analytics data considers the country-specific capacity factors for the different renewables. Whenever fossil fuel plants are phased out according to the NGFS Net-Zero Scenario that is made consistent with the 50% 1.5°C carbon budget, it is currently assumed that these fossil fuel plants are

5 See https://forwardanalytics.co.

replaced with an RE mix that is equal weightwise to the country's current RE mix. The phase-in mix can be set in any way a country deems suitable.

The methodology expands on those of Adrian et al. (2022) and Bolton et al. (2024), which provide an economic framework for a global cost-benefit analysis of decarbonization through the gradual phaseout of coal. The methodology is extended by: (1) applying it to the global power sector (and country-specific breakdown) rather than to coal mining; (2) aligning the net-zero-2050 NGFS scenario with the remaining 1.5°C carbon budget of 200Gt as of 2024 and updating the business-as-usual (BAU) scenario with the updated current policies as of 2024; (3) deploying power-sector-specific decarbonization scenarios of the NGFS for coal, gas, and oil; (4) considering a cost-optimal renewable replacement mix of fossil fuel power assets (to be included in the future), accounting for country-specific capacity factors of renewables, existing uses of land (to be included in the future), and the country's current electricity grid structure (to be included in the future); (5) estimating the opportunity cost of each of the power-sector assets; and (6) explicitly modeling the economic health benefits from reduced air pollution. A more detailed description of the data and methodology is provided by Bolton and Kleinnijenhuis (2024a).

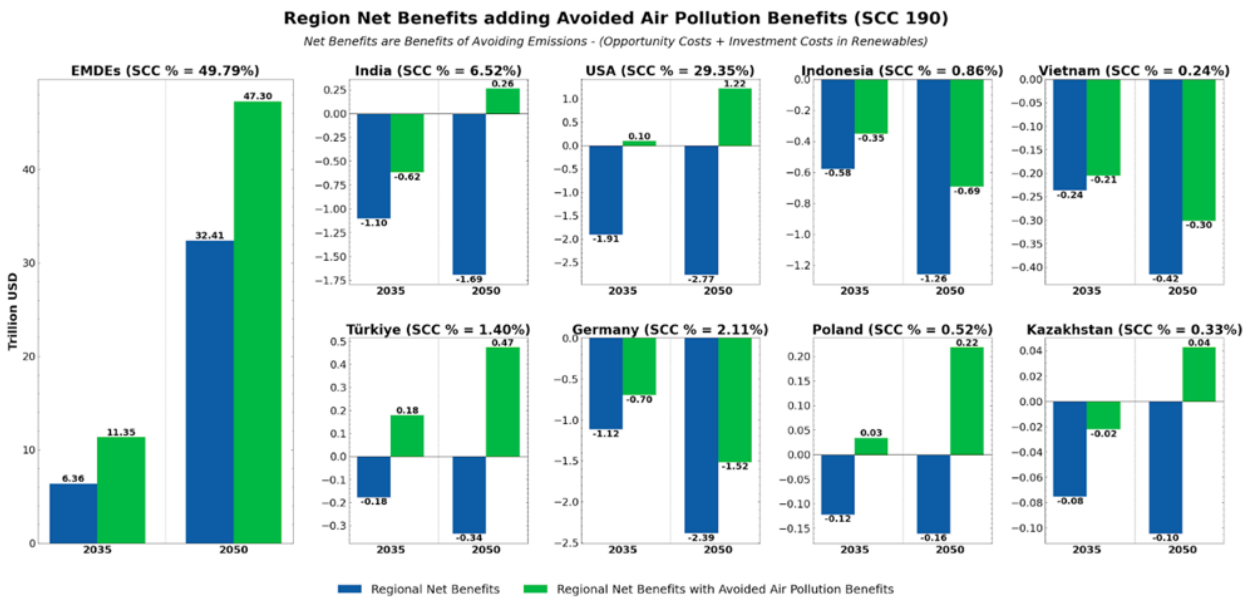
Results: the economics of decarbonizing the power sector via NDCs

1. The global and country-level benefits of a bundled fossil fuel phase-out and RE replacement are large. It is not in the self-interest of most EMDEs to close fossil fuel-fired power plants and replace them with RE. However, each country can benefit if its energy decarbonization policy is part of a broader cross-EMDE decarbonization plan and if avoided emissions can be monetized.

The economic benefits to a country from its own decarbonization consist of at least two components, including: (i) the economic benefits from its avoided climate damages and its avoided climate adaptation costs; and (ii) the economic benefits from its avoided mortalities (and disability-lived life years) from avoided air pollution. Component (i) is estimated by multiplying the country's SCC by the emission reduction embedded in its decarbonization. The sum of each country's SCC is equal to the global SCC. Hence, the country-level SCC captures the fraction of the global benefit to the country of reducing 1 ton of CO_2. It captures country-level variations in the severity of future climate damages resulting from emitting an extra ton of CO_2, and thus, conversely, also the country-level benefit from reducing 1 ton of CO_2 today.

The economic benefits to a financier country from offering climate finance to decarbonize another country is given by the emissions avoided embedded in the climate finance deal multiplied by the financier country's SCC. This multiplication captures the climate damages and adaption cost the financier country avoids because of its climate finance provision. The financier country will typically not enjoy air pollution benefits from financing another country's decarbonization, as these are largely localized to where air pollutants are reduced.

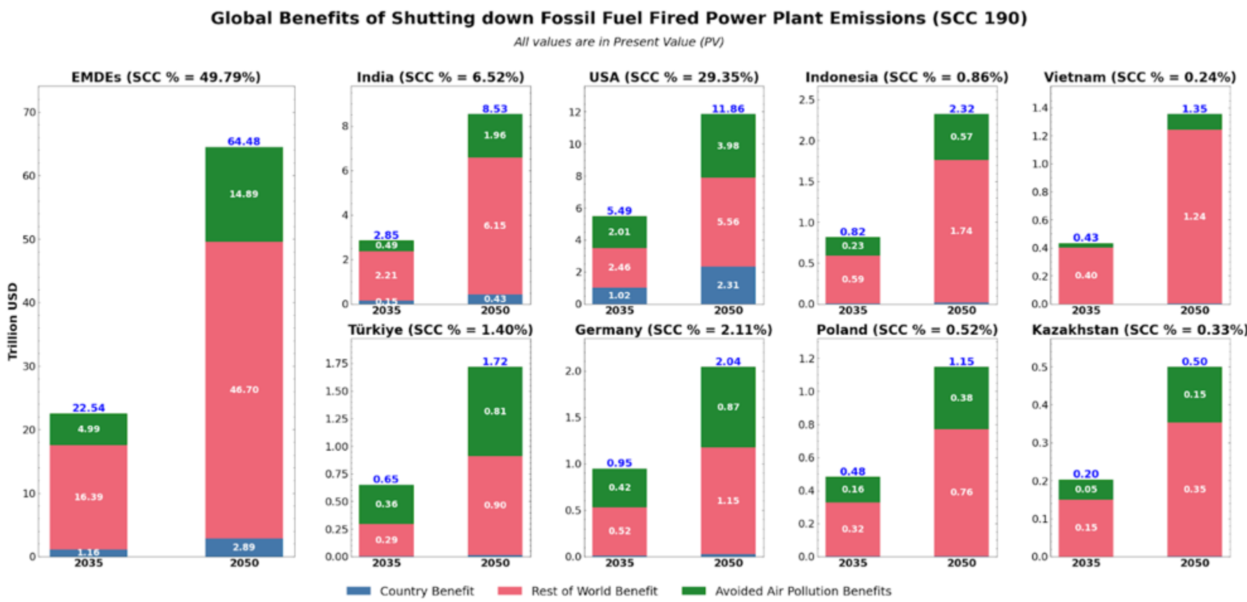
Figure 2. Country and EMDE net economic benefits of decarbonizing the power sector



Notes: The net benefits, defined as the difference between the benefits and costs, of eight countries with large power sector emissions (i.e., India, U.S., Indonesia, Vietnam, Türkiye, Germany, Poland, and Kazakhstan) are displayed for both the time horizon to 2035 and the time horizon to 2050. For the global SCC is assumed to be US\$190/tCO_2, in line with the Biden Administration estimate of the SCC. EMDEs are estimated by Ricke et al. (2018) to hold 49.79% of the global SCC, giving EMDs an SCC of US\$94.6/tCO_2. Similarly, the country-level SCC of India and the U.S. are estimated to be 6.52% and 29.35% of the global SCC, giving these countries a country-level SCC of US\$12.4/tCO_2 and US\$55.8/tCO_2, respectively, for a global SCC of US\$190/tCO_2. Country costs of decarbonization consist of (i) the opportunity costs to phase out fossil fuel power plants early (i.e., the stranded asset value of a power plant, the compensation to power plant workers for missed wages, and retraining costs); the (ii) investment costs in renewable power plants (plus supporting short- and long-duration energy storage and grid extensions) to replace the fossil fuel power plants that are closed down early in order to keep up with any growth in electricity demand. It is assumed that each country (and EMDEs as a whole) pays for all its decarbonization costs (i.e., no foreign climate finance offerings or private sector co-payment). Country benefits of decarbonization consist of: (a) avoided climate damages and adaptation costs (computed by multiplying a country's emission reductions by its SCC); and (b) avoided air pollution costs. In the blue bars, only (a) is taken into account, whereas the green bars also take (b) into account. For each country, and for EMDEs as a whole, decarbonization is assumed to occur via a decarbonization pathway in line with the NGFS GCAM6.0 net-zero 2050 scenario. Importantly, the NGSF net-zero 2050 scenario turns out not to be aligned with the 1.5°C (50%) remaining carbon budget as of 2023. Therefore, the decarbonization speed is homogenously increased to make the GCAM6.0 net-zero 2050 scenario consistent with the 1.5°C (50%) carbon budget. Thus, the NGFS NZ2050-1.5°C-50% decarbonization scenario is applied. The NGFS GCAM6.0 current policy scenario is used to project electricity demand for each fossil fuel power plant type, in each country, under business-as-usual.

Source: Authors

Figure 3. Country, EMDE, and global economic benefits of decarbonizing the power sector



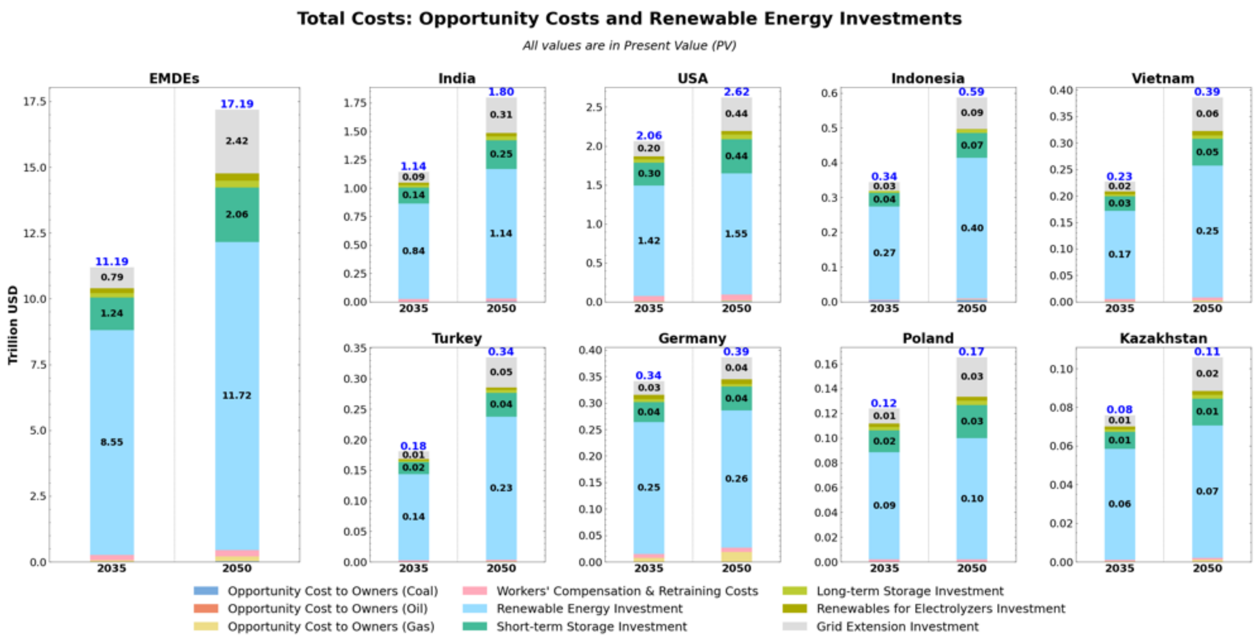
Notes: The economic benefits for EMDEs and eight countries with large power sector emissions (i.e., India, U.S., Indonesia, Vietnam, Türkiye, Germany, Poland, and Kazakhstan) are displayed, for both the time horizon to 2035 and the time horizon to 2050. The global SCC is taken to be US\$190/tCO_2, in line with the Biden Administration estimate of the SCC. EMDEs are estimated by Ricke et al. (2018) to hold 49.79% of the global SCC, giving EMDs an SCC of US\$94.6/tCO_2. Similarly, the country-level SCC of India and the U.S. are estimated to be 6.52% and 29.35% of the global SCC, giving these countries a country-level SCC of US\$12.4/tCO_2 and US\$55.8/tCO_2, respectively, for a global SCC of US\$190/tCO_2. Country economic benefits of decarbonization consist of: (a) avoided climate damages and adaptation costs (computed by multiplying its emission reductions with its SCC), shown in blue; and (b) avoided air pollution costs, shown in green. The emission reductions embedded in a country's decarbonization of the power sector, and that of EMDEs as a whole, also have a global economic benefit. This is given by the emission reduction achieved by power-sector decarbonization times the global SCC (of US\$190/tCO_2). For each country, and for EMDEs as a whole, decarbonization is assumed to occur via a decarbonization pathway in line with the NGFS NZ2050-1.5°C-50% decarbonization scenario. The NGFS GCAM6.0 current policy scenario is used to project electricity demand for each fossil fuel power plant type, in each country, under business-as-usual.

Source: Authors

2. Tying the coal phaseout to renewables crowds in additional private finance. Avoided emissions are like an asset that can generate more private finance. The required financing for EMDEs must blend profit-seeking private finance for RE development (plus storage and grid expansion) with the monetization of avoided emissions through two channels: (1) public finance, to cover any opportunity costs of phasing out fossil fuels (which include the cash flow of closed power plants forgone by owners plus the lost wages and retraining compensation to laid-off workers) and to mitigate the higher private investment–related risks in EMDEs; (2) additional private finance from a new high-integrity carbon offset market that monetizes avoided emissions. A prototype example of such a transaction is the planned early retirement of the South Luzon Thermal Energy Corporation (SLTEC) CFPP in Batangas, Philippines, by 2030 and its replacement with a compensating solar facility and battery storage system, which is to be accelerated through the origination and sale of transition credits to crowd-in catalytic financing. This project could also come under Article 6 of the Paris Agreement, generating additional finance from helping other countries meet their climate targets; see the discussion under point 12 of the methodology above.

3. The opportunity costs of phasing out fossil fuels are relatively low. For most EMDEs, the amount of public financing required to fund the opportunity costs is small relative to the amount of financing required to fund RE, storage, and grid extensions, and also relative to the avoided emissions offsets they could generate.

Figure 4. Breakdown of the costs to decarbonize the power sector



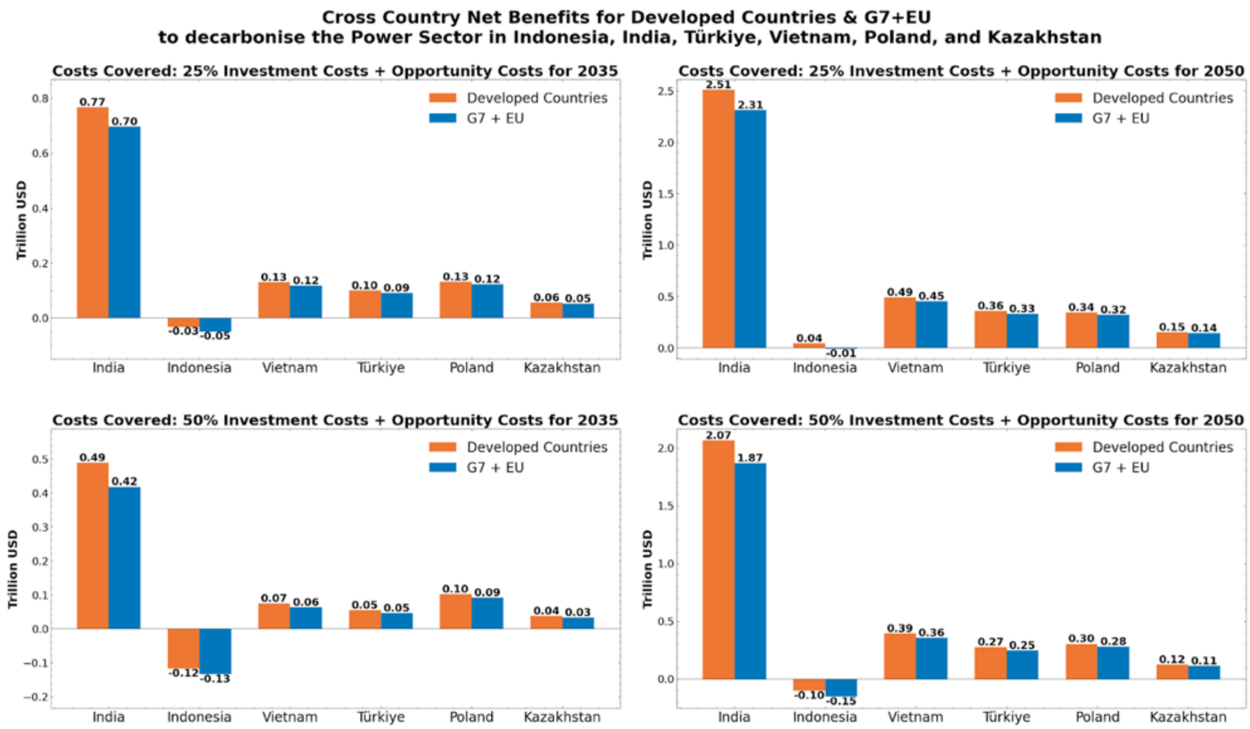
Notes: The breakdown of the decarbonization costs of EMDEs as a whole and eight countries with large power sector emissions (i.e., India, U.S., Indonesia, Vietnam, Türkiye, Germany, Poland, and Kazakhstan) are displayed, for both the time horizon to 2035 and the time horizon to 2050. Country costs of decarbonization consist of (i) the opportunity costs to phase out fossil fuel power plants early (i.e., the stranded asset value of a power plant (defined as the expected discounted value of future missed cashflows of the power plant resulting from closing it down early according to the NGFS NZ2050-1.5°C-50% decarbonization scenario relative to free cashflows earned in the NGFS GCAM6.0 current policy scenario), the compensation to power plant workers for missed wages; and retraining costs); (ii) the investment costs in renewable power plants (plus supporting short- and long-duration energy storage and grid extensions) to replace the fossil fuel power plants that are closed early to keep up with any growth in electricity demand. Here that each country, and the EMDEs as a whole, is assumed to pay for all its decarbonization costs (i.e., no foreign climate finance offerings or private sector co-payment). For each country, and for EMDEs as a whole, decarbonization is assumed to occur via a decarbonization pathway in line with the NGFS NZ2050-1.5°C-50% decarbonization scenario. The NGFS GCAM6.0 current policy scenario is used to project electricity demand for each fossil fuel power plant type, in each country, under business-as-usual.

Source: Authors

In the example in the technical note, the estimates for transitioning the power sector of EMDCs until 2035 are around US$11 trillion (i.e., around US$1 trillion per year) broken down for each country, taking into consideration their unique asset base. It is fairly difficult to compare this number directly with that of the 2023 report by the Independent High-Level Expert Group on Climate Finance (IHLEG, 2023), which only provides an aggregate number of US$2.4 trillion a year until 2030. This equals roughly US$14.4 trillion until 2030, and US$26.4 trillion until 2035. Importantly, the IHLEG estimate consists of the climate finance needs to cover the just energy transition, adaptation and resilience, loss and damage, and the conservation and restoration of nature, so it goes way beyond the power sector and there is no clear breakdown of the costs (which is the problem statement that that the work in the technical note tries to solve). Overall, the ballpark comparison does seem sensible, as the authors' estimate of the power sector is a relatively important subset of the overall climate finance need. Indeed, this contribution offers a methodology and granular breakdown of costs, at the asset and country level. These are lacking from the IHLEG estimate, for which it is unclear how the aggregate numbers are derived and no granular breakdown of climate finance costs is offered.

4. The net benefits flowing to some of the larger developed countries provide a strong justification for greater international public financing. There is a strong case for a consortium of developed countries (in collaboration with development institutions) to provide more global public financing across EMDEs based on the large benefits to these countries from EMDE decarbonization. By some estimates, public catalytic funds, as part of a blended finance arrangement that crowds-in private capital, only need to cover 25%–50% (or less) of the total investment costs.

Figure 5. Net economic benefits to financier countries (either the developed countries, or the G7+EU) of offering climate finance at scale to EMDE countries for power sector decarbonization



Notes: The net economic benefits to financier countries of offering climate finance to pay for the decarbonization costs of six individual countries with large power sector emissions (i.e., India, Indonesia, Vietnam, Türkiye, , Poland, and Kazakhstan) are displayed, for both the time horizon to 2035 (left column) and the time horizon to 2050 (right column). The net economic benefits to financier countries (here taken to be either the group of developed countries (in orange) or the G7+EU (in blue)) are given by the economic benefits to the financier countries minus the climate finance costs the financier countries pay for the complete decarbonization of an EMDE country (i.e., India, Indonesia, Vietnam, Türkiye,, Poland, and Kazakhstan). The economic benefits to financier countries are given by the emission reduction embedded in the EMDE country climate finance deal (i.e., the difference in cumulative emissions between the NGFS GCAM6.0 current policy scenario and NGFS NZ2050-1.5°C-50% decarbonization scenario) times the financier country group's social cost of carbon. The developed country SCC is 50.21% of the global SCC, and the G7+EU's SCC is slightly less than that. The costs to financier countries consist of the climate finance they offer to each EMDE to decarbonize. This climate finance cost consists of the EMDE country's (i) opportunity costs to phase out fossil fuel power plants early (i.e., the stranded asset value of a power plant (defined as the expected discounted value of future missed cashflows of the power plant resulting from closing it down early according to NGFS NZ2050-1.5°C-50% decarbonization scenario relative to free cashflows earned in the NGFS GCAM6.0 current policy scenario), the compensation to power plant workers for missed wages; and retraining costs); and (ii) investment costs in renewable power plants (plus supporting short- and long-duration energy storage and grid extensions) to replace the fossil fuel power plants closed early to keep up with any growth in electricity demand. In the top row, financier countries are assumed to pay for 100% of the opportunity costs of fossil fuels and 25% of the investment costs in renewables of the recipient country's decarbonization needs. The assumption is that 25% of public climate finance can crowd-in 75% of private finance, via blended finance. In the bottom row, financier countries are assumed to pay for 100% of the opportunity costs of fossil fuels and 50% of the investment costs in renewables of the recipient country's decarbonization needs. The assumption here is that 25% of public climate finance can crowd- in 75% of private finance, via blended finance.

Source: Authors

For each country, and for EMDEs as a whole, it is assumed that decarbonization occurs via a decarbonization pathway in line with the NGFS NZ2050-1.5°C-50% decarbonization scenario. The NGFS GCAM6.0 current policy scenario is used to project the electricity demand for each fossil fuel power plant type, in each country, under business-as-usual.

5. Phasing out fossil fuel power assets (coal in particular) is operationally most urgent. What lies behind these investment and financing needs are (1) the current fuel mix across power plants with a heavy reliance on coal across EMDEs, and (2) the amount of emissions that must be avoided per year to attain a carbon-budget-consistent net zero scenario with a 50% likelihood, highlighting the imperative of shutting down coal across EMDEs, largely by 2030.

Figure 6. Share of each energy type in the power sector

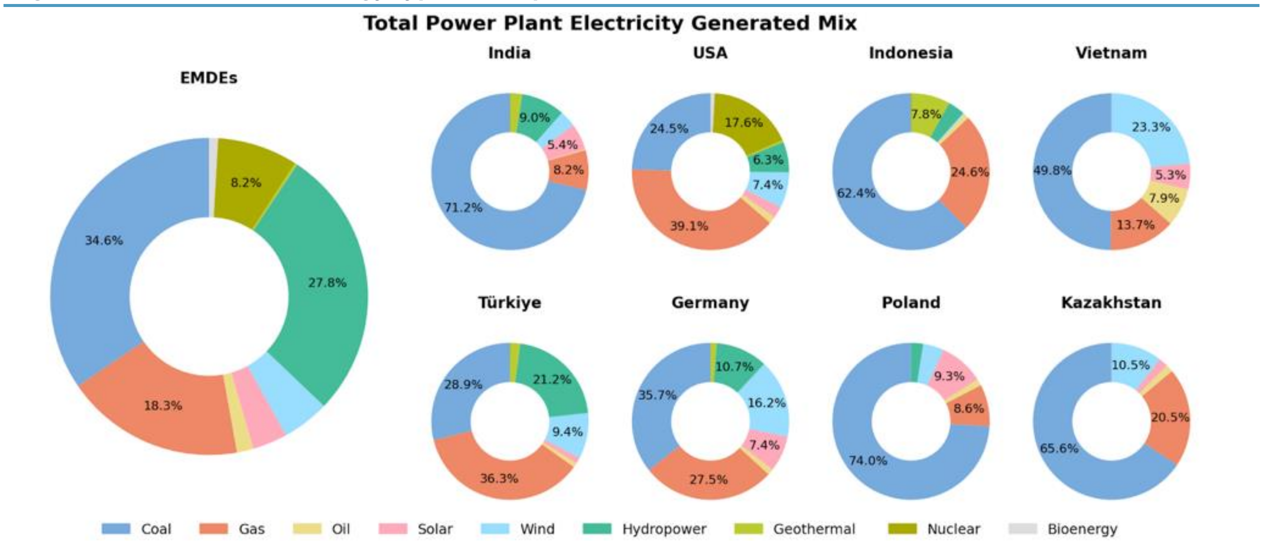


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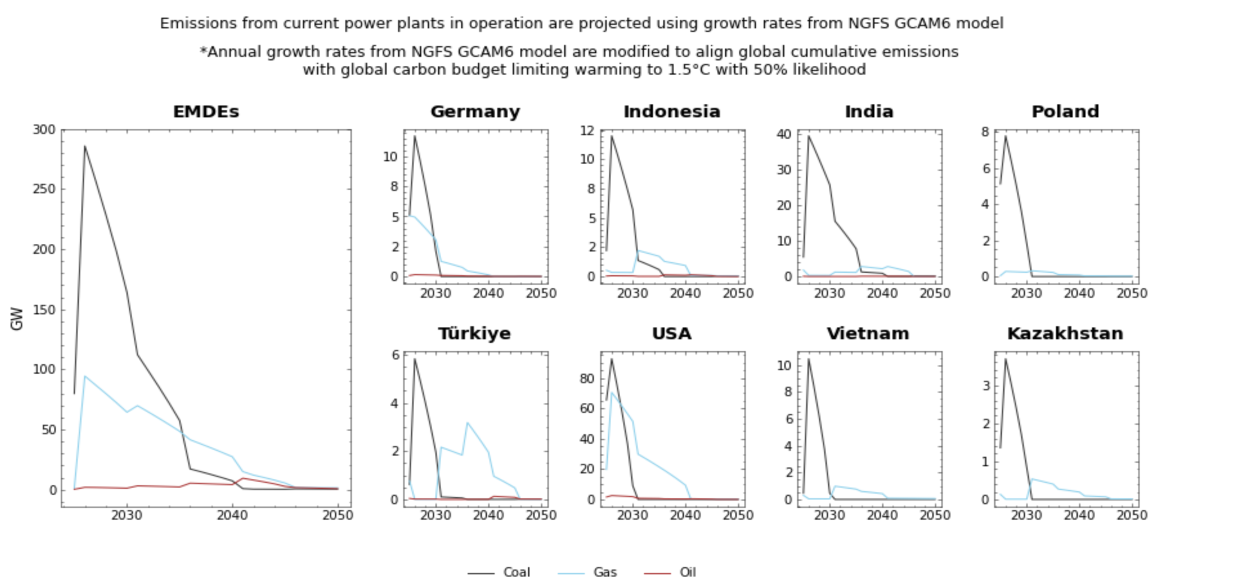
Figure 7. Annual avoided fossil fuel capacity in the power sector: current policies vs carbon budget consistent with net zero*



*Notes: Emissions from current power plants in operation are projected using growth rates from NGFS GCAM6 model. *Annual growth rates from NGFS GCAM6 model are modified to algin global cumulative emissions with global carbon budget limiting warming to 1.5°C with 50% likelihood.*

Source: Authors

6. To achieve these large national and global net benefits, it is essential to adopt a granular system-wide country plan rather than a project-by-project approach. Such a plan, to be worked out as quickly as possible over the coming months by each country setting an updated NDC, should match an optimal phaseout pipeline (specifying the time and extent of decommissioning of specific power sector assets for each year of the decarbonization pathway) with a simultaneous replacement phase-in pipeline (specifying how much RE capacity and of what RE types should be installed when and where; how much RE storage capacity and of what type should be installed and when; and how much grid extension should be made, and where, in each year) to keep up with projected energy demand.

7. Repurposing fossil fuel subsidies reduces the burden on additional public financing. Globally, fossil fuel subsidies were US$7 trillion in 2022, or 7.1% of GDP (Black et al., 2023). The opportunity costs of early coal closures can be financed to a large extent through repurposed fossil fuel subsidies by host countries for a significant number of EMDEs. A large fraction of these subsidies will be freed up as loss-making coal operations are shut down.

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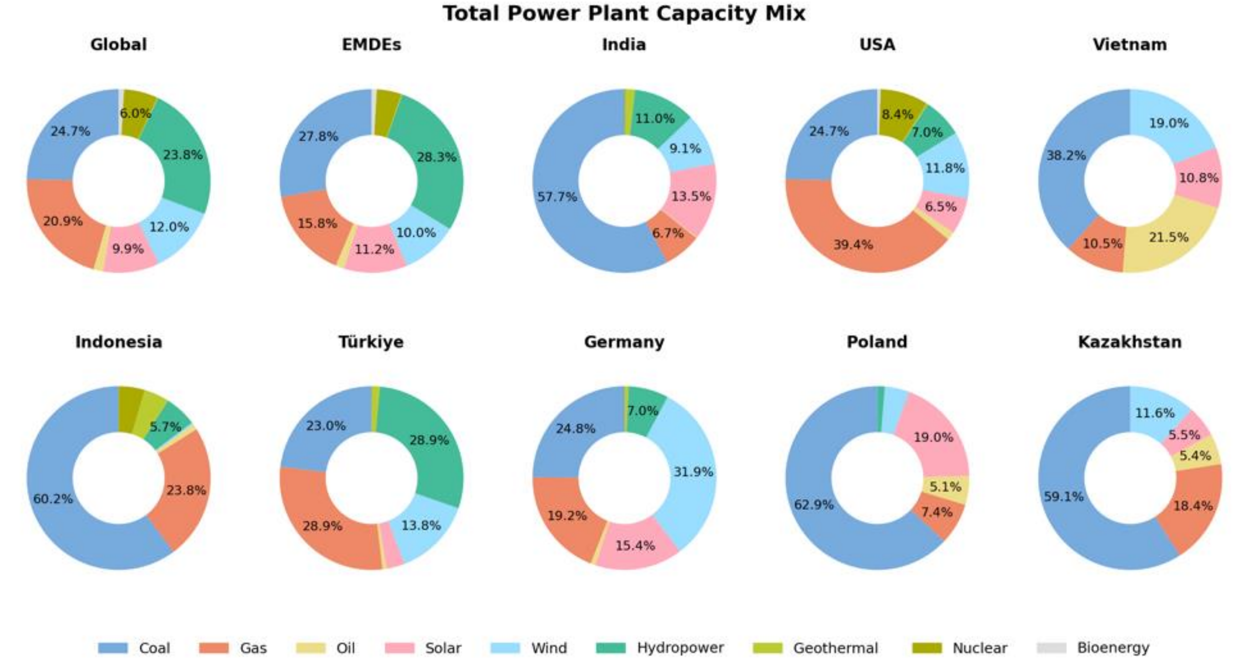
Appendix

Figure A1



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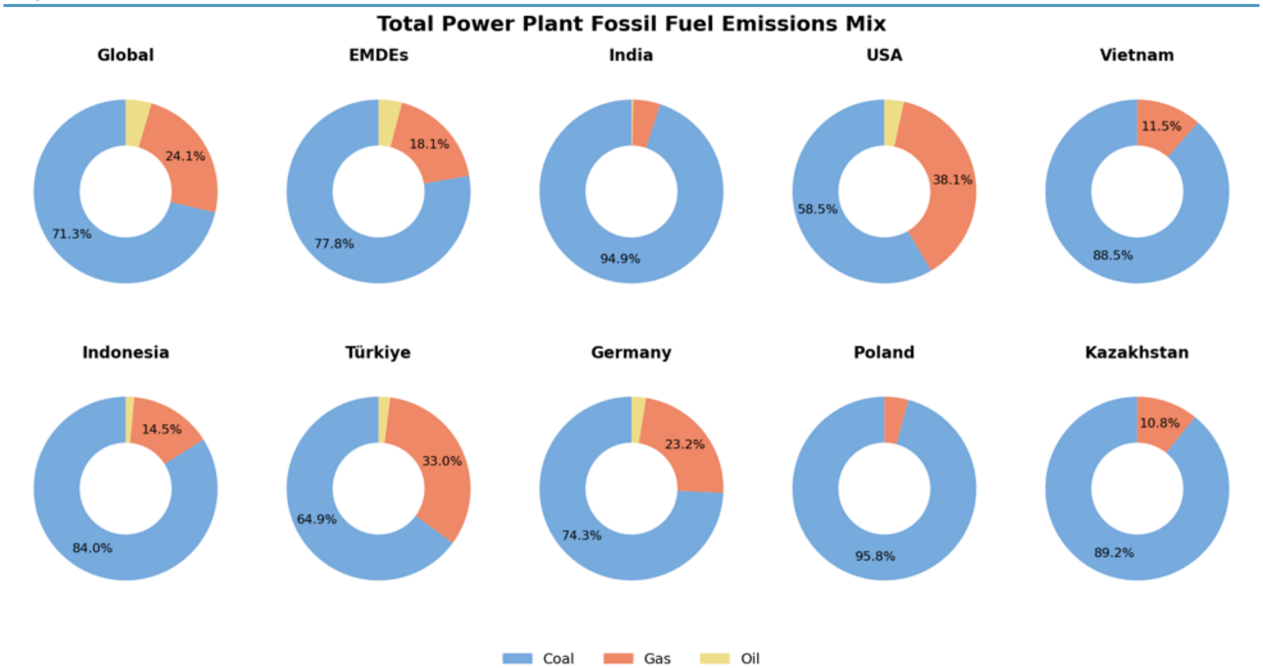

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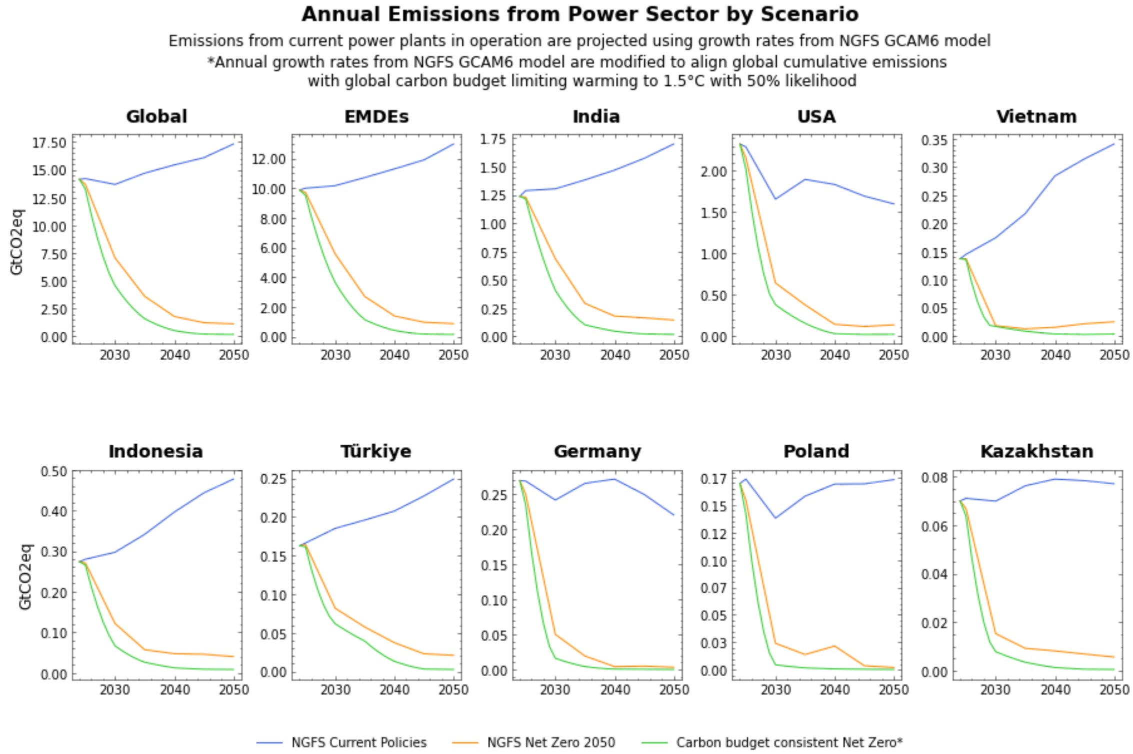

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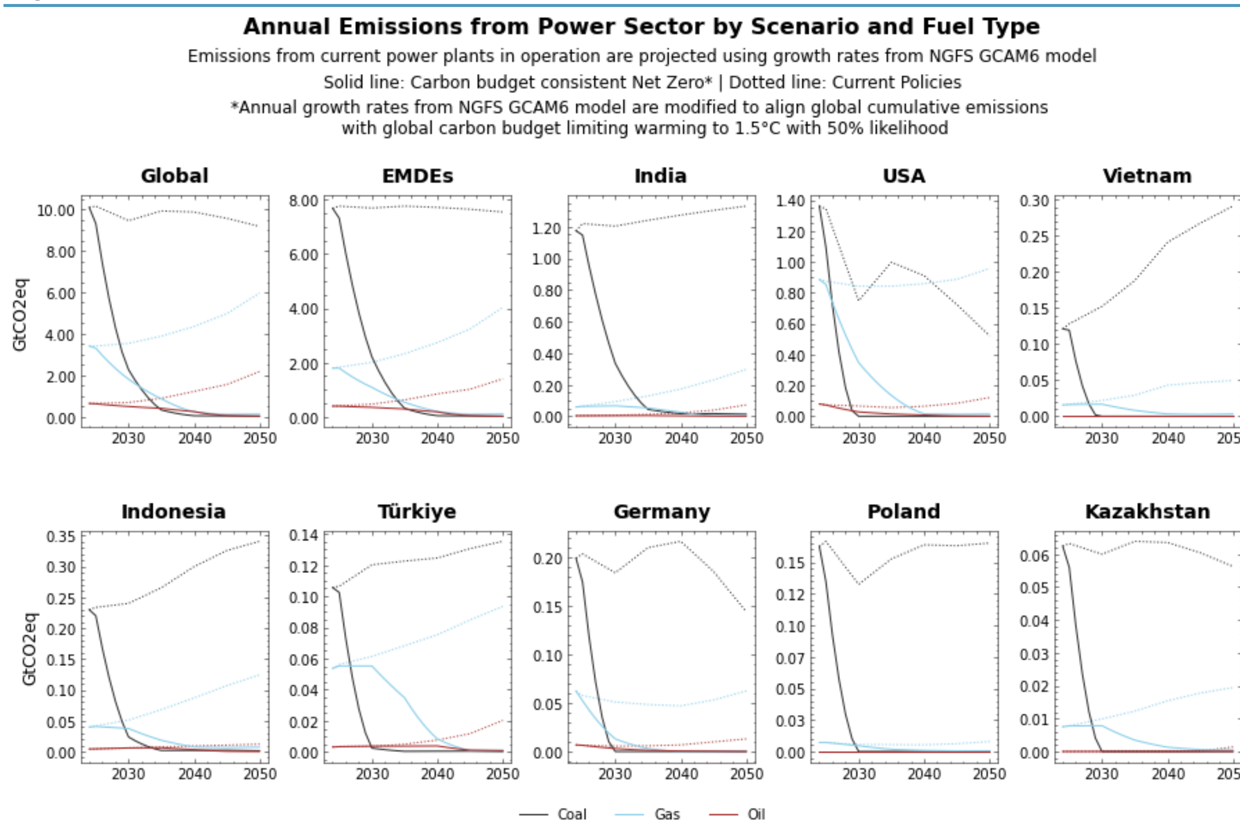

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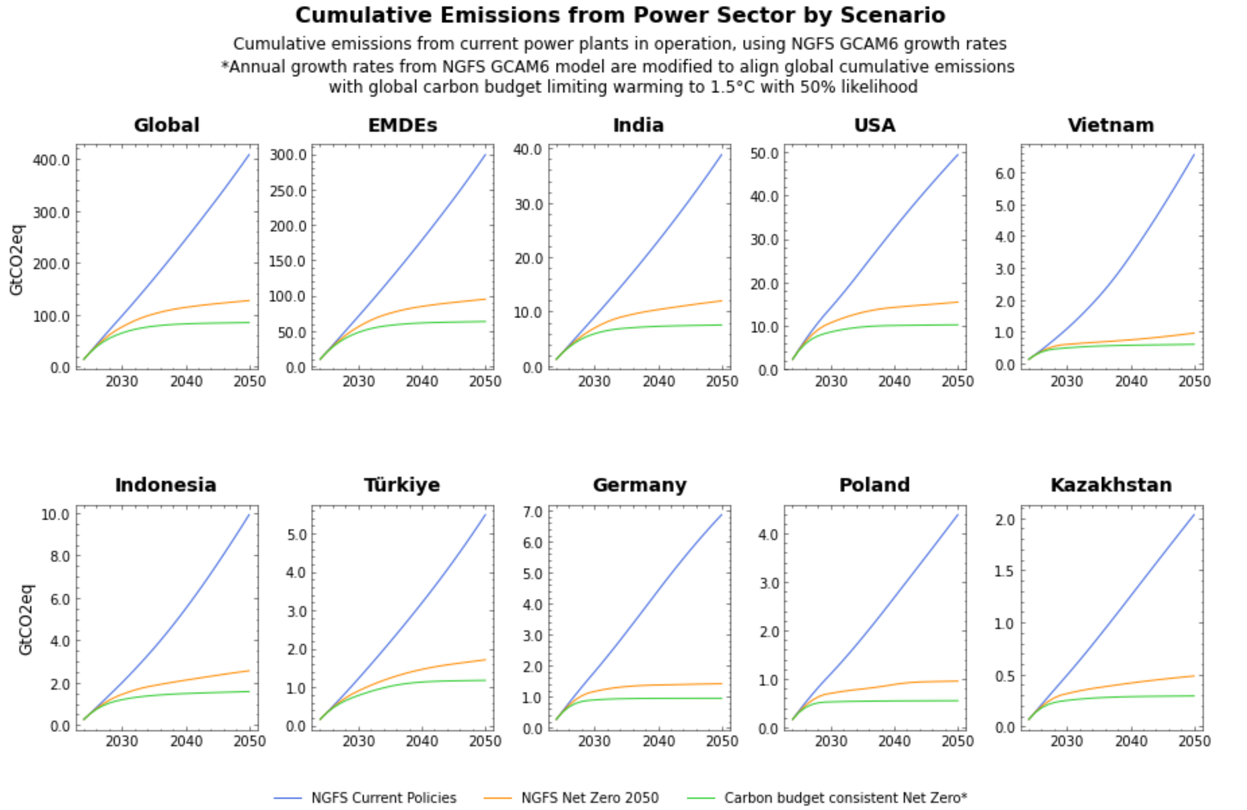

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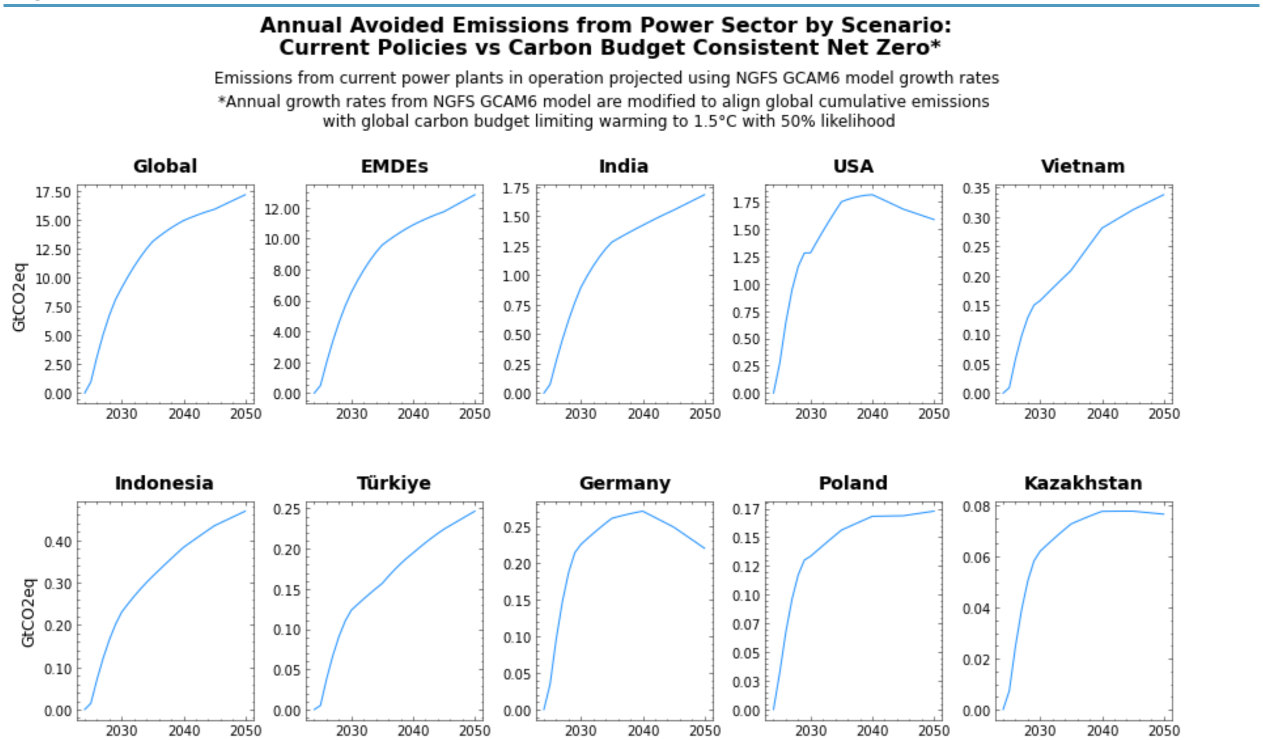

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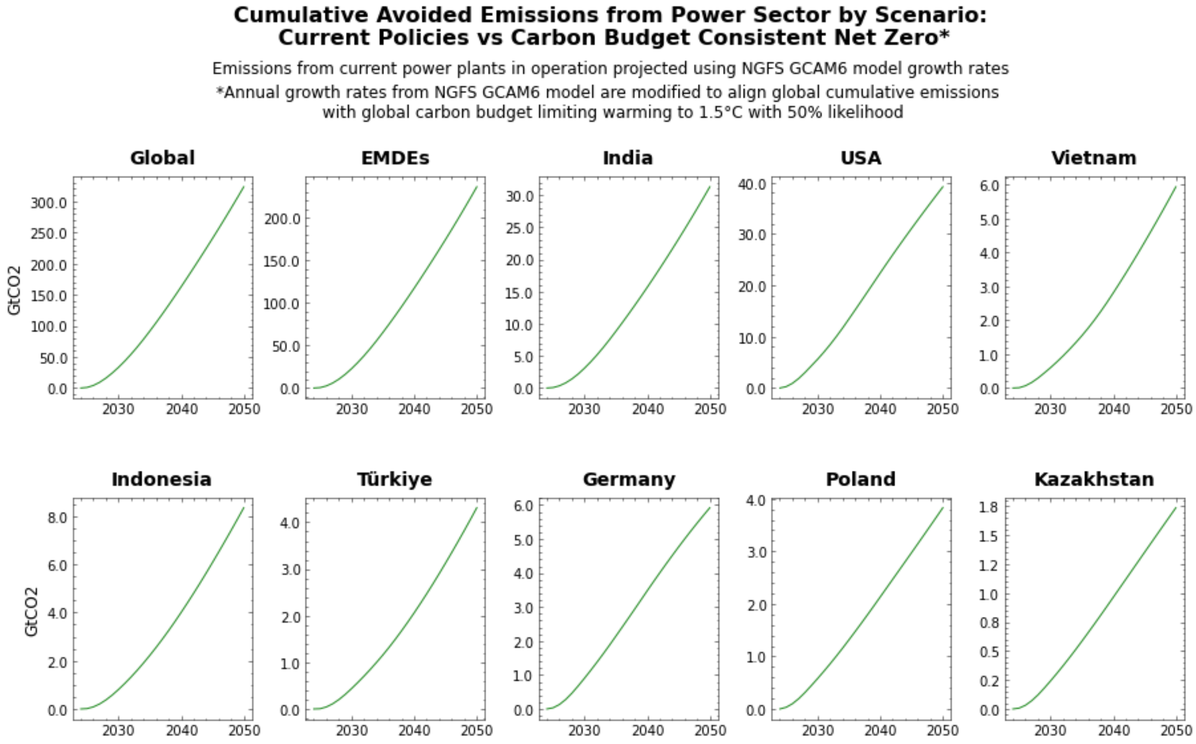

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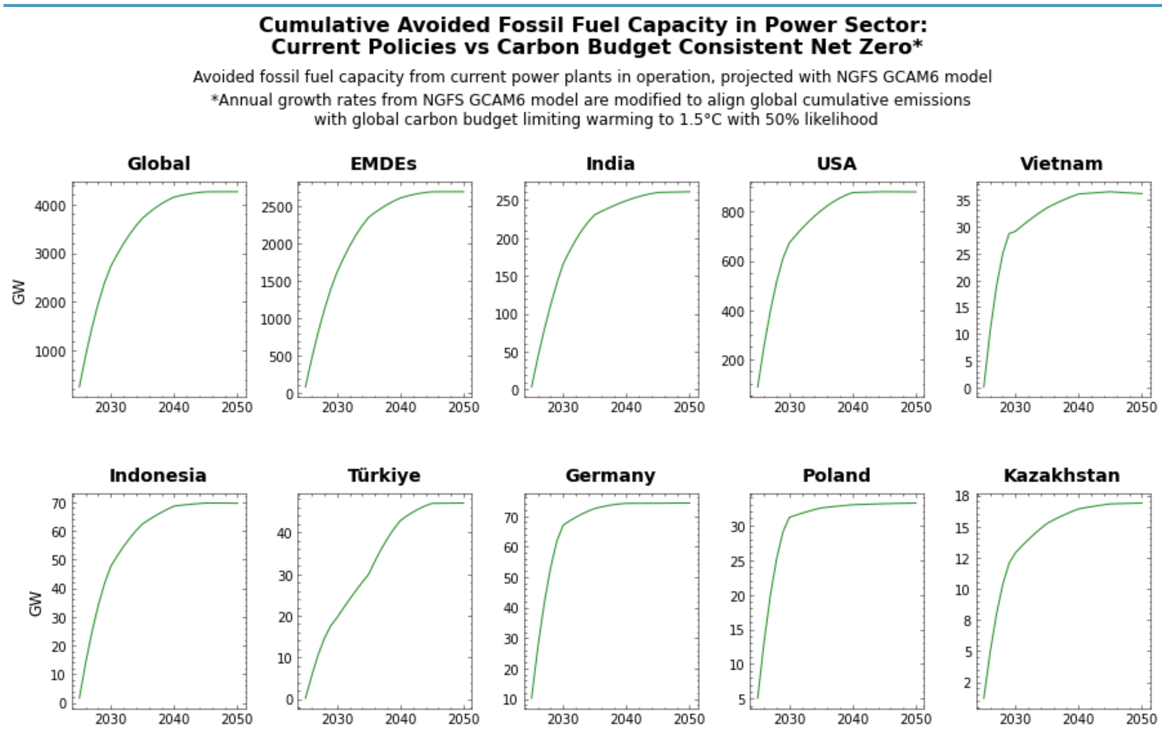

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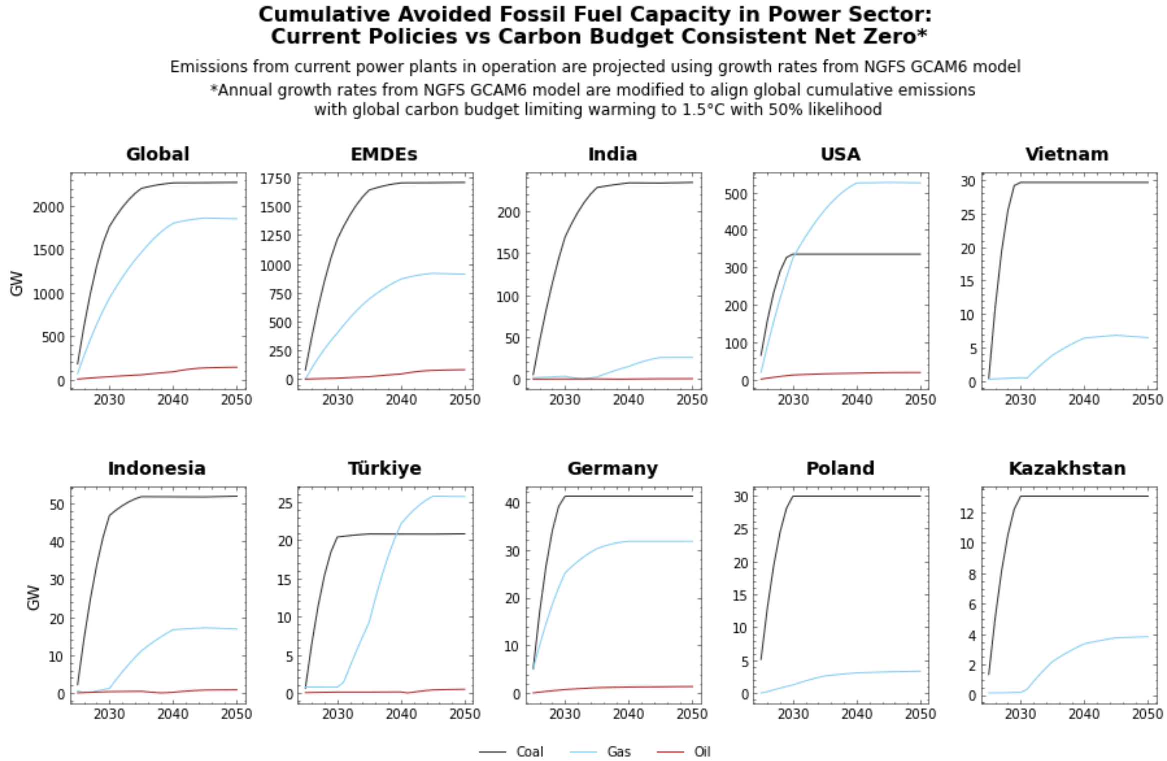

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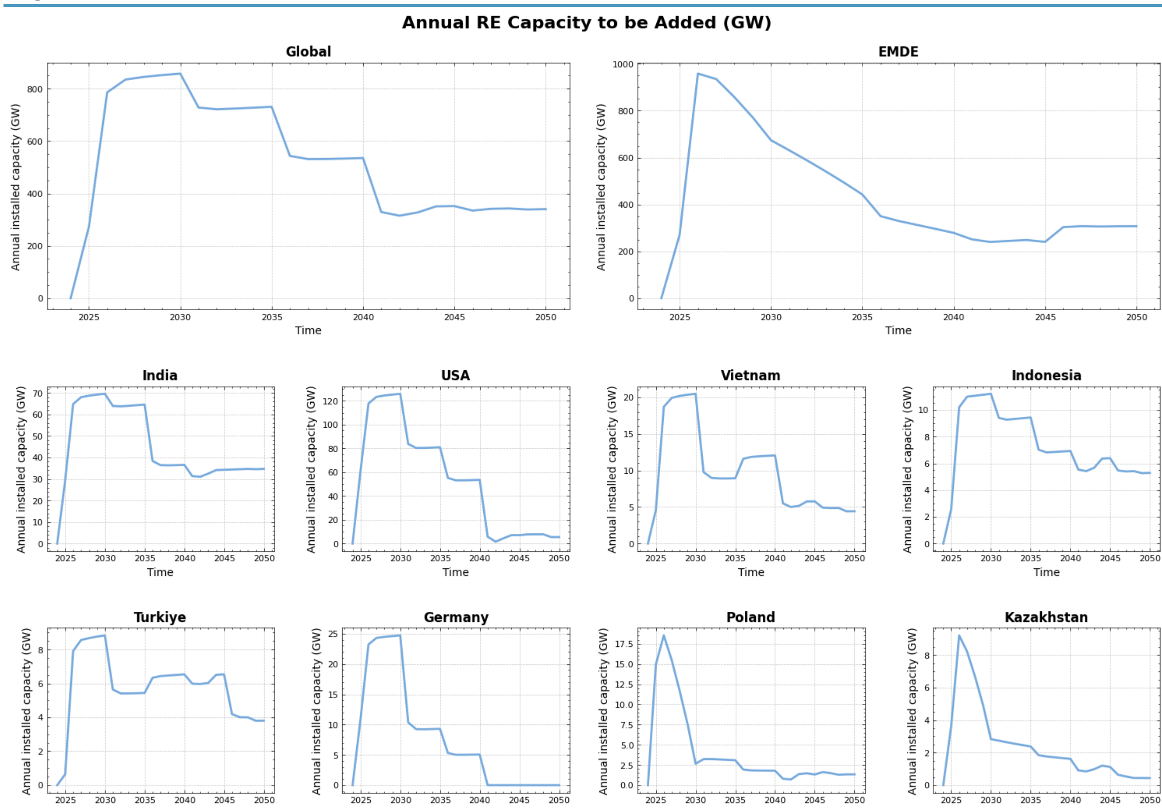

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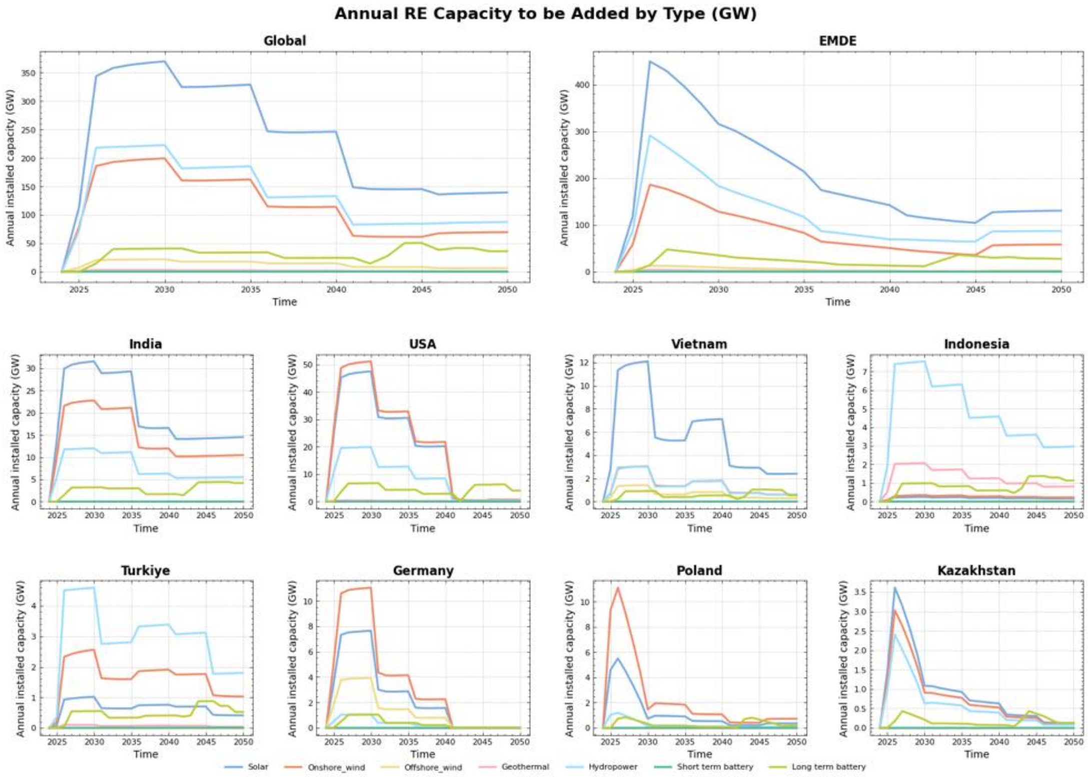

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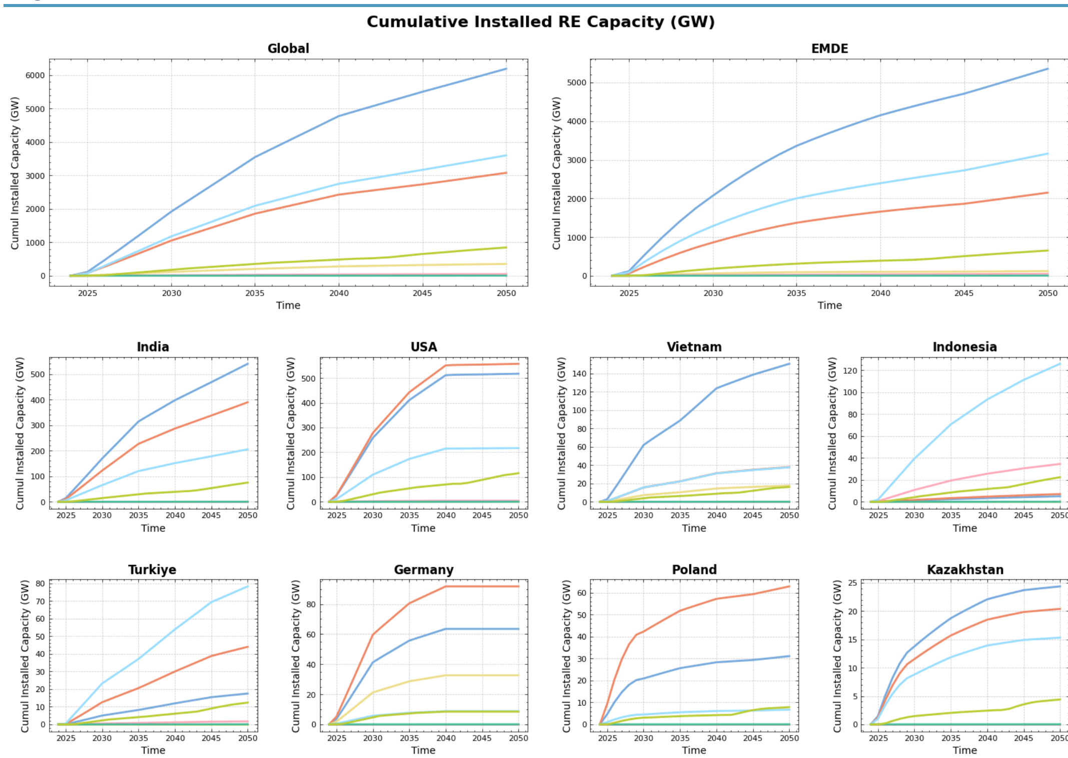

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