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Potential of Lower Costs of Capital for Faster Decarbonisation in Developing Regions

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Executive Summary

While some clean energy solutions like solar photovoltaics are already cost-effective, many others represent a premium to fossil-fuel alternatives. The spread in prices can be bridged via carbon pricing or bypassed via other instruments such as renewable mandates.

In the cases where there is no explicit carbon price (either a carbon tax or market price determined through an emissions trading scheme), a growing number of entities use internal carbon prices (also colloquially called shadow carbon prices, though the technical meaning of a shadow price differs) to guide investments and decision-making. These are self-chosen and non-transacted (purely internal) carbon prices that are deployed either for societal benefit or, more traditionally in corporate settings, in anticipation of future high(er) carbon prices. These ostensibly prevent future stranded assets.

Similar to widely used internal carbon prices, this paper proposes the formal use of an analogous internal (and in this case *lower*) finance rate for choosing clean energy and low carbon infrastructure projects. While lower financing rates (cheap capital) are important for all infrastructure, traditional planning misses the dynamic nature of costs of capital (finance rates). Not only have these rates fallen over time, sector-specific rates will further drop as the sector matures. Planners may also not anticipate global finance that can step in post-facto (after the investment is made) and fill the gap between an internal finance rate and the initial project finance (market or equilibrium) rate.

Using the example of choosing to build a conventional coal power plant versus deploying solar power with a battery, we compare both instruments—internal carbon pricing and internal finance rates—to show that while both can be used to create a cross-over from conventional to cleaner energy, internal finance rates have several advantages.

Fundamentally, internal finance rates lower the project cost instead of raising the price like a carbon tax would. Secondly, these can rely on markets and the private sector and not just the government. Lastly, these would apply to the entire project capital costs (which are the bulk of costs for clean energy solutions) and not just fuel costs for fossil projects under a carbon tax.

This framework also aligns with global finance which is focused on emissions mitigation disproportionally through deployment of clean energy solutions. The spread in finance costs between domestic rates in developing countries and lower ones required to make clean solutions competitive can translate to global aid, other funding, or secondary risk-reduction instruments such as insurance, counter-guarantees, discounted foreign exchange hedges, etc.

Could global support pay the equivalent of a carbon tax? This appears unlikely for multiple reasons. Could global aid directly subsidise clean energy projects? The track record hasn't been encouraging. This framework is a special form of support that lends itself to lowering costs in the long-term because the finance rate spread (and, thus, support required) will decrease as projects and the industry mature, independent of learning curve and technology improvements over time. The first part of this framework is the use of internal finance cost pricing for decision-making. The second part is conversion of the internal finance rates to actual finance rates, which can benefit from global support. Even the exercise of estimating the finance rate reductions required for over the crossover to clean solutions and the commensurate scale of funding is itself a useful exercise.

Given the capital-intensive nature of clean-energy solutions and the high rates of interest prevalent in developing countries, such an instrument could help avoid substantial future emissions.

Falling clean energy technology costs haven't been enough to stop imminent investments in fossil fuels – project-level internal (lowered) financing rates can accelerate a full crossover.

The Backdrop: A Need to Make Cleaner Energy Solutions Competitive

Developing regions—more specifically, regions that have historically been low carbon dioxide (CO2) emitters—are expected to see an outsized growth of emissions in the coming years. Presently:

- Developing regions have significant infrastructure growth ahead of them.
- Clean energy solutions are overwhelmingly capital-intensive and thus have steep upfront costs.
- Developing regions have higher nominal interest rates as compared to developed regions due to a combination of inflation and perceived risk. The differential is often a spread of 4–8% or higher when considering Central Bank rates; industry's spread is much higher (Trading Economics, 2021; also see Figure S2).
- Though there is sufficient low-interest capital in the world to help spur clean energy, it is not yet available to developing regions and thus fails to be incorporated in national or even most project planning. It is simplistic to assume such low-interest capital can be directly available for developing countries' clean energy projects due to factors creating the spread in rates, including foreign exchange risk, sovereign risk, project risk, etc., but it is possible that there is still some residual risk worth addressing. Even for the above specific risks, we have a paucity of focused risk-reduction instruments, such as risk pooling mechanisms.

While there are many instruments to shift the trajectories of growth in developing regions to lower carbon pathways, many of these focus on operational instruments such as purchase obligations for procuring renewable energy. India, for instance, requires electricity distribution licensees to purchase or produce a specified minimum quantity of their requirements from renewable energy sources (MNRE, 2022).

Assuming cleaner solutions entail a premium (else they would be implemented anyway), the question becomes how do we make cleaner solutions competitive? Either fossil fuels must become more expensive through externality penalties, such as a carbon price, or we need to lower the costs of the clean energy solutions.

Carbon prices raise the cost of fossil-fuel technologies, for instance, through taxes or emissions trading markets. However, in developing regions, these are not widespread or at such a low level that they do not displace the majority of fossil fuel development—in Argentina and Poland, for instance, prices are at about or below $1/ton-CO2 (World Bank, 2020). We also find some decision-makers—especially among companies, mostly in developed countries—incorporate an internal carbon price higher than the official one into their planning. This is done to avoid future risk where high-carbon solutions would eventually become uncompetitive or stranded. Dozens of major companies in India also deploy some level of internal carbon pricing at an average of $25/ton-CO2 (CDP India & TERI, 2020).

Technically, a shadow price is the price that reflects true costs or incorporates externalities, but most companies use the terms shadow and internal carbon price interchangeably. Following this industry standard, the two terms are used interchangeably in this paper as well. While such shadow carbon pricing reflects the social cost of carbon better, it still falls short of estimated societal costs of carbon (see Table S2).[1]

On the flip side, we need to find ways to lower the costs of clean energy solutions. Technological innovation has helped lower clean technology costs, especially of solar power and batteries, but these

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[1] Shadow prices are prices for which no market exists, and which can be (internally) set equal the externality. Mathematically, Wikipedia captures shadow prices as "the value of the Lagrange multiplier at the optimal solution, which means that it is the infinitesimal change in the objective function arising from an infinitesimal change in the constraint".

reductions have not been enough to stop investments in fossil fuels. Assuming cleaner solutions still entail a premium despite falling prices, how do we make them competitive?

Making clean energy cheaper isn't just about technology costs, we can also focus on cheaper finance.

Project-Level Internal Finance Rates: Enabling a Full Crossover to Clean Energy Technology

This paper proposes an alternative instrument to spur low-carbon investments aimed at developing regions: an internal discount rate applied as an internal *project* finance rate (i.e., cost of capital).

Shadow (i.e., internal) carbon prices are entirely notional or forward-looking. Similarly, an internal shadow project discount rate or project cost of capital would be the lower rate chosen for decision-making that need not be available in the market immediately.[2] However, similar to shadow carbon prices, these would be chosen different from present rates but not necessarily matching the best-available theoretical global rates.

The rationale or gains from applying such shadow costs of capital include:

- Planning would be based on lower discount rates that better reflect climate risk *and* global financial support, thus rendering clean energy solutions competitive. The benefits, including to developing regions, are evident.
- Researchers have hitherto examined the use of shadow discount rates to correct for market discount rate distortions, but scholars such as Szekeres (2011) have also pointed out that such corrections do not lead to optimal outcomes. This paper presents a novel integration for climate change—and not a distortion being corrected.
- Battiston *et al.* (2021) have shown the lack of feedback loops between risk-linked finance and integrated assessment models (IAMs).[3] The framework suggested by this paper rectifies this paucity by presenting an instrument that formalises feedback for project planners.
- In this paper, we focus only on *investment accounting rates*, and not on societal discounting values.[4] Stern (2006) explicitly used a low discount rate for future *damages*, summarising in a follow-up paper, "However unpleasant the damages from climate change are likely to appear in the future, any disregard for the future, simply because it is in the future, will suppress action to address climate change." (Stern & Taylor, 2007, p. 204).

I illustrate the benefits of "shadow" project discount (finance) rates—applied at a project level throughout this paper—compared to a "shadow" carbon price through a case that compares a new coal power plant versus renewable energy (RE) with a battery based on present Indian data.

As of 2021, RE without storage is the cheapest for new builds and even by 2019 it was within 6% of coal power globally (International Renewable Energy Agency, 2020). But if we need to add significant storage, coal is still cheaper in many countries like India, even with aggressive battery costs as used in this paper for comparison. A new coal power plant would have slightly higher capital costs than fuel costs on a per kilowatt-hour (kWh) basis (calculated for mine-mouth or pit-head plants, avoiding major transport costs, but inclusive of royalties, taxes, levies, etc.).

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[2] Discount rates are the rate at which one values the future (money, utility, damages, etc.) lower than the present, and reflects time value of money (or utility, damages, etc.). Societal discount rates aren't necessarily the same as project discount rates that apply to capital, which itself has different discount rates, for equity and for debt.

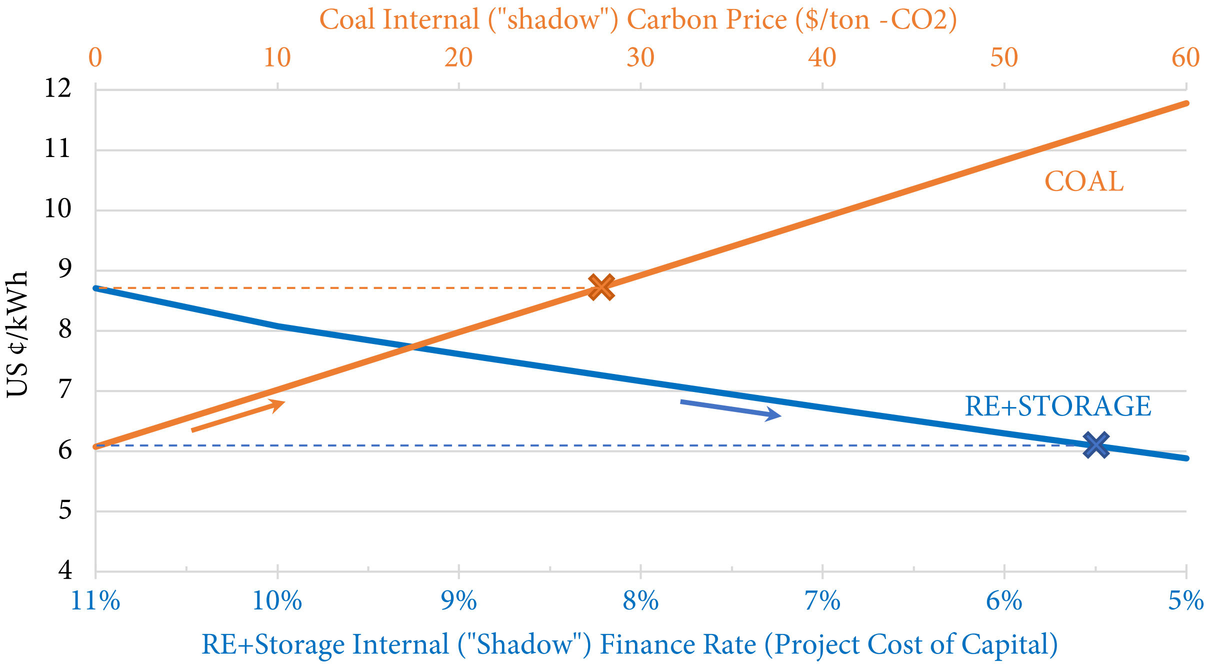
[3] Integrated Assessment Models are models for studying complex systems across both scientific and social science (especially economic) perspectives, and are used for a range of environmental analyses including climate change.

[4] Debates on discount rates are not new, and represent a disconnect between individual, private, and public time-value-of-utility preferences, financial or project interest rates, opportunity costs, as well as questions of inter-generational fairness. The United States Environmental Protection Agency [EPA] (2010) has more details on such issues.

Figure 1 shows the use of both shadow rates for project planning – shadow carbon prices and shadow project costs of capital – for comparing coal versus RE+storage. Given that these are internal rates or prices, and not market ones, there is no specific carbon price or project discount rate to apply, and thus we apply a wide range to examine crossovers. The starting point is a zero carbon price and a ~market equilibrium finance rate, which shows a premium for clean energy projects of a little under 3 US cents/kWh. From this starting point, we compare the cost of coal-based power with a carbon price (above zero) versus RE+storage with lowered finance rates (the orange and blue lines, respectively, in Figure 1). While details on the cost assumptions are given in the Supplementary Information section of this paper, it's worth stating here that these RE+storage prices are for a blended project with batteries sized below 100%—i.e., at least some of the RE is used in the grid without storage.

For coal, overcoming the present premium for RE+storage translates to a shadow carbon price of ~$27.7/ton-CO2 to match the premium for RE+storage. Conversely, for the crossover project shadow finance rate, this corresponds to a nominal finance rate of 5.5%, which is about 5.5% lower than typical rates in India.[5]

Figure 1: Comparing shadow carbon prices vs. shadow discount rates for achieving parity (India example)



Note: This compares the prices (capital costs + fuel) for coal versus grid-scale RE+storage (capital costs) power, where coal has a shadow carbon price, and RE+storage is calculated with a (lower) shadow discount rate for the project. These calculations are based on representative data for India for new builds, but are slightly higher than record low prices for pure RE. For RE+storage, these assume $175/kWh battery costs including inverter and electronics, which is an aggressive price. For coal, the capacity utilisation factor is assumed at 60%—any fall in utilisation would raise costs accordingly—and fuel is assumed at Rs 2.2/kWh, inclusive of taxes, royalties, coal cess, etc. This rate is higher than NTPC's average fuel costs in recent years, e.g., Rs 2.05/kWh fuel costs in FY21 (NTPC, 2021). Given that equity has a higher rate of return (sometimes statutory at 15.5% in regulated power projects in India), a weighted average cost of capital (WACC) is higher than debt rates. Therefore, for coal, we use a total 12.5% discount rate (fixed for coal), and an 11% discount rate for RE+storage as the reference rates. For both technologies, we do not factor in operations and maintenance (O&M) costs per kWh, as this differential is expected to be modest. While coal has non-trivial O&M costs, the same is true for grid-scale storage, more so with cooling requirements like in India. (1 US$ = Rs 73. More details in the Supplementary Information.)

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[5] Most projects combine debt and equity, with debt available at lower rates. We focus on total or Weighted Average Cost of Capital (WACC) for the project.

Hirth & Steckel (2016) point out that lower capital costs can operate in tandem with higher carbon prices for decarbonising the electricity sector. The same is true for shadow rates and shadow carbon prices. However, a shadow discount rate could be more effective in avoiding carbon lock-ins if used by technology planners. A high actual carbon tax (or other fuel tax) doesn't inherently lower the use of or avoid emissions from fossil fuels. Stern and Stiglitz (2021) suggest a carbon tax of $100/ton-CO2 for the US, but *implicit* carbon taxes (such as those on petrol in countries like India) already convert to well over $100/ton-CO2 (Tongia & Ali, 2020). Moreover, high carbon taxes face political resistance in most countries. Thus, most plans are to raise prices gradually. However, these would take time to propagate to investment planners—especially at the enterprise level and among diffuse decision-makers at the end of the chain—even if they were willing to use shadow carbon prices. In contrast, a finance rate is part of immediate decision-making, especially for new investments, and, as I subsequently propose, a shadow or internal finance rate can link to lower *actual* finance rates.

While the exact numbers for lower finance rates required for a crossover would be case-specific and change over time,[6] necessary crossover carbon prices (see Figure 1) are very high when compared to prevailing prices, if any, in developing regions. The implicit carbon tax on coal in India today (Rs 400/ton 'coal cess') translates to just over $3/ton-CO2 (Tongia & Ali, 2020); this is embedded in existing fuel prices. A ninefold increase would raise fuels cost of such electricity by 66–133%, varying by location. In contrast, a 5.5% project capital cost is available in many parts of the world today, with debt at lower rates, but not yet to Indian developers. For example, the International Renewable Energy Agency (2021) has catalogued solar prices and found that the cheapest hardware capital costs in the world (in India) don't necessarily mean the cheapest total (levelised) cost. Bids from the Middle have come in as low as 1.04 US cents/kWh, and finance is a key differentiator between countries.

There are a range of reasons capital costs are higher in developing regions, some related to foreign exchange and inflation (Figure S1) and some related to risks, both project-level and sovereign. Myrdal (1966) called accounting or shadow rates "unreal" (in the context of evaluating public projects) but acknowledged that dynamics were a key aspect of improving the equilibrium. By engaging with global finance, developing country projects will have an incentive and a means to improve transparency and management, and will also move to lower counter-party risk, which could lower the equilibrium market rates, further reducing the finance rate spread.

Making Lower Finance Rates Happen

A large portion of the differences between developed and developing finance rates could be met through global climate finance support. This would be enough to overcome the spread between many low-carbon and traditional technologies. Instead of using shadow rates as traditionally applied, (i.e., to remove distortions or even reduce future competitiveness risks), developed countries could pay for the spread to crossover technology choices as part of global climate support. This would also reduce global climate risks and could align with the annual $100 billion promised at COP15 by developed countries in 2009, meant to come into force by 2020.

Not only have such levels of funding not materialised yet, these funds should also fulfil the criteria of additionality, as opposed to debt financing for, say, solar projects without storage, which are viable anyway (Weikmans *et al.*, 2020; Weikmans & Roberts, 2017). Shadow finance rates can become markers for required viability gap funding, which can explicitly lead to further carbon reduction, and not just make already competitive technologies cheaper.

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[6] Supplementary Information details more assumptions on technology costs and trends.

For this framework to work and scale, the internal finance rate must convert to an actual project discount rate, otherwise developing countries are paying a premium for cleaner technology, and hence the suggested linkage to global support. The anticipation of subsequent project rate reductions is already being applied informally by selected clean technology companies as they bid aggressively low prices aiming to refinance their existing debt to lower cost providers, or simply exit to YieldCos that target a lower return.

For example, the dramatic fall in Indian solar (without storage) prices as bid, recently under Rs 2/kWh, or 2.7 US ¢/kWh, was driven by anticipations of flipping either the finance or the project itself as there was neither a commensurate fall in module prices nor in benchmark lending rates. However, such planning didn't lower carbon emissions per se, as these were bids for exclusively solar projects – it just made them cheaper.

However, anticipations of flipping finance need to be done with caution, lest early round financiers be left holding the bag. One difference between the earlier cycle of developing country infrastructure projects, which failed to refinance, is the immense global pressure and cash available for decarbonisation.

Indian solar companies were ready to plan for lower interest rates, but this was a sector-wide shift, driven not just by maturity of the segment but also because of fierce competition and government pushes like solar-specific bids and purchase obligations, which evolved over many years. But trillions of dollars of investments are likely to be undertaken in developing regions in the coming years. These are regions where clean technologies are needed, but which don't yet undertake planning that anticipates lower finance costs. It's an interesting question if one had the data: how much did developing country clean energy project finance rates fall over time compared to the fall in global interest rates, especially when considering refinancing? Refinancing is an important marker because this applies to up-and-running projects, which have lower risks than projects yet to be built.

Competitive Carbon Abatement

The payback from this mechanism is attractive enough to potentially reduce carbon emissions significantly. Consider the case of India ending all future coal power even before 100% clean energy (RE+storage, specifically solar+battery) is market-competitive. For 900 gigawatts (GW) of solar plus full storage (defined as batteries covering 70% of solar output), the *total* one-shot investment at present pricing with an 11% project finance rate with batteries at $175/kWh would be ~$139 billion/year (amortised). This would generate ~1,971 terrawatt-hours (TWh) annually at a solar capacity utilisation factor (CUF), also known as Plant Load Factor (PLF), of 25%. This capacity is more than 10 times higher than India's present wind and solar capacity, and almost 2.5 times its existing total electricity capacity. On an energy basis, it's almost 50% higher than the present utility electricity generation. Thus, such a volume of RE+storage would only be required over many years.

Assuming the support required to operationalise the lower project finance rate would be viability-gap funding covering a finance rate spread of, say, 5.5%, then in this case it would be $33.8 billion per year, covering all the interest rate differential for avoiding coal. This figure is much lower than the previously listed $139 billion because this calculation doesn't require support for any principal repayment, which is paid through end-user pricing. This translates to $28.6/ton-CO2, and would avoid the growth of virtually all future power-sector CO2 emissions growth. This is a high cost per ton of carbon compared to many voluntary carbon markets, but many of those are of dubious quality (Elgin, 2022). However, this per ton-CO2 cost is low compared to estimates for global societal costs per ton, and also compared to costs for physical carbon removal (which are far higher).

While this appears marginally higher compared to a direct carbon price, because of additionality requirements, carbon benefits from the shadow discount rate are calculated only on the incremental

RE+storage-based avoided emissions. They are thus not calculated on the ~30% RE presently viable as is without storage, even though it would also benefit from global funding. These calculations reference existing costs of capital and are based on existing equipment costs, which are declining steadily, more so for batteries. Baseline costs of capital have fallen over time (see Figure S2), and even with a tightening of rates post-COVID-19 economic recovery, there remains—and is likely to remain—a spread between developed and developing countries, which reinforces the value of linking global carbon support through finance rate transfers. More importantly, project-risks are also likely to decrease over time as projects, developers, and regulatory frameworks all mature with volume. Hence, this cost per ton-CO2 avoided becomes an upper bound for the India coal example through a support mechanism paying for the 5.5% finance cost spread.

Because we calculate for crossovers, both shadow carbon price and lower finance rate instruments lead to similar per ton-CO2 values. However, lower internal finance rates *lower* end-user costs of RE+storage while internal carbon prices *raise* them. Carbon prices are politically sensitive and borne by end-users, while lower finance rates can be part of global support. It's very difficult to imagine developed countries paying towards offsetting a carbon tax for a developing country to make clean energy cost-competitive. In contrast, it seems more feasible for them to pay towards a lower finance rate partly by absorbing risk because it still gives them returns, even if these are lower risk-adjusted returns than the present equilibrium. Such support would be far more worthy of counting as global carbon support than, say, non-subsidised debt for solar projects. Paying for finance rate reductions beyond what the market sets is explicitly easier to separate from business as usual (BAU) financing of infrastructure in developing regions. It's also possible that offering lower cost finance, although it involves absorbing a risk premium, can be lower risk than global carbon risks if we don't decarbonise. Carbon taxes also raise issues regarding redistribution and, if deployed asymmetrically, international concerns leading to possible border adjustment tariffs.

On the other hand, any lower price for energy solutions, no matter how clean, risks higher consumption due to the rebound effect. Stakeholders should thus prioritise such funds for avoided energy (e.g., state-of-the-art energy efficiency and infrastructure design), and ensure that lower rates don't make fossil investments cheaper.

To strengthen the feedback mechanism from domestic efforts to global funding, and to ensure the highest bang-for-buck, one could design a triangulation process for projects to determine the crossover finance rate required to become carbon-free, and then benchmark the carbon benefits against a target carbon abatement cost. Some projects could find crossovers at competitive (not as low) shadow discount rates, but their abatement may not be sufficient (see Supplementary Information Figure S3 for an example).

Keeping mechanisms competitive and dynamic could help lower the spread over time, and the process could also simplify over time once benchmarks are established. This could increasingly free up more capital for extending deeper carbon reductions, going even beyond the electricity-focused parametric estimation of avoided future emissions shown in Figure S4, and eventually down to zero future emissions across the developing world.

Conclusion

There is no dispute that a large quantum of funds will be required to transition to clean energy sources worldwide, even if there are debates on how large these will be. This paper focuses on a subset of the issue: how do we encourage the crossover for developing countries where high costs of capital are a factor in keeping a spread between fossil fuel technologies and non-carbon solutions. Assuming a high carbon price is either some time away or politically infeasible in the short run, and also assuming it will similarly take time for domestic finance rates to fall as the sectors mature and risks come down, this paper presents a planning tool—internal or "shadow" finance rates—as a complement to internal or "shadow" carbon pricing. These help calculate if and by how much a lower finance is sufficient to make non-carbon technologies cost-competitive.

A key need for such internal finance rates is to translate them to actual lower rates, and this can be achieved by global carbon support as a subset of the $100 billion aid to developing regions pledged at Copenhagen COP15. Even before such funds can materialise, there are benefits to this schema. Most importantly, this mechanism is a way for segregating incremental support, akin to viability gap funding, from overall project support, which is key to improved accounting. Based on the principles of additionality, not all infrastructure funding should count as "climate support". Secondly, lower debt rates can go hand in hand with mechanisms for shifting the risk equilibrium from today's finance rates to ones that more explicitly segregate different types of risks (such as sovereign, foreign exchange, project level, etc.) and where we can apply different tools and instruments to lower or spread the risks (such as risk pooling, sovereign forex hedges, etc.). After doing so, any residual can come as climate aid, which could help tap large global funds that are otherwise hesitant to fund specific mitigation projects in developing regions.

Could global support simply have subsidised clean energy capital investments? On paper these may appear to have similar quanta of funding, but a benefit of focusing on finance rates (specifically, reductions) is that this schema can provide feedback loops for improving the quality of such projects and reducing their risks.

As the example of RE+storage versus coal for India at today's prices shows—which by definition is an upper bound since clean technology costs are falling—the quantum of aid representing finance rate reductions is modest, translating to the equivalent carbon price of only a little over $27/ton-CO2. This imputed price is high by Indian standards but modest by global standards or ambitions. Such use of internal finance rates should be applied at the sectoral and project levels to determine the lowest hanging fruit. There will always be a frontier of carbon reduction ripe for incremental support.

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Supplementary Information

Methods

Assumptions for Figure 1 comparing two internal or "shadow" instruments (carbon price and project finance rate) for achieving parity using current Indian data are in Tables S1a and S1b, based on data that match current bids, public data, and author estimates. Coal's costs are converted into fuel and capital costs per unit. Coal's carbon emissions are taken as 950 grams of carbon dioxide per kilowatt hour (g-CO2/kWh), based on the Central Electricity Authority's coal fleet estimates (CEA, 2018), and we average coal power plants paying Rs 2.2/kWh for fuel. This is higher than the cost of the cheapest coal used in plants adjacent to the mines and lower than coal prices delivered far from the mines, but this figure allows for escalation compared to NTPC's fuel costs. NTPC provides almost a quarter of India's utility electricity generation and more when we consider coal power (NTPC, 2021), and is thus a good benchmark. This simplified average ignores locational differences, so solar can benefit from lower transmission requirements compared to concentrated coal plants in coal-rich regions. Both calculations ignore O&M costs, the difference due to which would be modest (more so with any storage that requires cooling). O&M costs are also assumed to be relatively constant, independent of discount rates or carbon prices.

RE (solar) costs as used are close to recent record-low bids (Prasad, 2020). Missing O&M costs would bring the total RE costs closer to the slightly higher recent bids. The battery is sized for 70% of the electricity going through the storage system. Thus, 30% of the solar panel's output is used directly and doesn't require viability gap funding through discount rate support, while for the balance 70%, we have costs of both solar and storage (plus the economic implications of system charge-discharge efficiency losses).

Table S1a: Baseline data for RE+storage

Base RE+storage		
	Solar	**Storage**
Capital expense (capex)	Rs 35,000/kW	\$175/kWh (12,775 Rs/kWh)
Capacity Utilisation Factor (CUF) *aka* Plant Load Factor (PLF)	25%	~Daily cycling with 70% of solar kWh needing storage
Lifespan (years)	20	12
Battery sizing	-	70% of units
Depth of discharge limit	-	90%
RE + Storage Roundtrip efficiency	-	90%
Amortised capex @ 11% base capital costs	2.01 Rs/kWh [2.75 US ¢/kWh]	5.99 Rs/kWh [8.21 US ¢/kWh]
Blended Capex	Rs 6.36/kWh [8.71 US ¢/kWh]	
Overall project internal finance rate is varied		

Table S1b: Baseline data for coal in India

Base Coal	
Capex	**Rs 85,000/kW**
Weighted average cost of capital (WACC)	12.5%
Capacity Utilisation Factor	60%
Amortised capex	Rs 2.23/kWh [2.5 US ¢/kWh]
Fuel costs	Rs 2.2/kWh [3.01 US ¢/kWh]
Capex + fuel	Rs 4.43/kWh [6.07 US ¢/kWh]
Shadow carbon price is varied	

Note: Battery prices for both tables are based on additions to the $135/kWh projected for 2020 by BloombergNEF (BNEF) (BNEF, 2020). BNEF prices are automotive battery prices, thus lacking an inverter and also designed for much lower cycle life. Today, Indian prices are much higher, partly due to import duties and small volumes. Coal capital expenses are for a super-critical coal plant compliant with new pollution emissions norms, and high flexibility, inclusive of working capital and interest during construction. Coal variable costs are based on selected pit-head pricing (Ministry of Power, 2021). India currently has zero explicit carbon tax, but the implicit taxation—Rs 400/ton-coal cess—is embedded within the existing baseline pricing, translating to just over $3/ton-CO2 for the coal cess. Coal's capex might be higher for advanced ultra-super-critical (higher efficiency) plants, but that would also lower fuel costs and emissions. ($1 = Rs 73.)

The improvements in aggregate prospective carbon emissions are modelled for 900 GW of additional RE (with 25% CUF), with batteries for 70% of such generation, equal to 3,150 GWh total battery size). We compare the amortisation of the RE+storage system for 11% versus 5.47% discount rates for this same investment (other parameters as per Table S1a and Table S1b), leaving a ~5.5% shadow project finance rate spread. To achieve such a weighted average cost of capital by relying on cheaper debt, we'd need an even greater debt rate reduction, given that equity is likely to be domestic, but the total support required is the same given debt is only about 70–80% of total project finance with the balance as equity. For support requirements, we only consider the 70% of electricity (kWh) with storage that avoids coal emissions worth 1.18 gigatons (Gt) of CO2 annually, which uses an annual shadow finance rate spread support of $33.8 billion, assuming the direct RE (non-storage) is anyways cost competitive. All numbers are based on present prices and thus this a conservative calculation.

Shadow Pricing and Risk

Shadow carbon prices are voluntary prices as used by many companies as they anticipate rising carbon prices, at levels that reflect their expectations of change and risk tolerance. Hence, shadow or internal carbon prices as deployed (surveyed by CDP India & TERI, 2020) are often measurably lower than the social cost of carbon, which Integrated Assessment Models estimate as higher, shown in Table S2.

Table S2: Global and Indian Social Cost of Carbon (SCC) estimates for 2020 as per selected Integrated Assessment Models (IAMs) ($/ton-CO2e)

IAMs	Global SCC	Indian SCC	India (%)
DICE v1	40	5	12
PAGE	74	16	22
FUND	22	1	5
DICE v2	50	6	12*
DICE v3	87	10	12*

**DICE v2 (2013) and DICE v3 (2016) SCCs for India are derived on the basis of 12% share in damages as in DICE v1 (2010), by Nordhaus.*

Source: Nordhaus DICE-2016 (Nordhaus, 2017) as adapted by Ernst & Young (2018).

The fact that global values for social costs of carbon are higher than Indian social costs of carbon is another reason that global funds may find it attractive to support deep decarbonisation in India at costs per ton-CO2 close to the illustrative ranges shown in this paper.

Project outputs (like kWh electricity or ton steel) can vary in how they are sold, and this can impact the final incentive for choosing any particular energy technology or design. If a power plant operates under a guaranteed rate-of-return contract with fixed cost coverage, it would face no risk due to future competition that might enjoy lower discount rates (or higher carbon prices). On the other hand, it would also face no risk due to cheaper future alternatives based on falling technology costs. It's only under a competitive market that such a power plant would risk being priced out of contention. Alternatively, regulatory changes could also create competitive risks for undervaluing carbon risks, e.g., through bans or clean energy purchase obligations.

There is a rise in the use of market mechanisms worldwide but these are less prevalent in developing regions. This is one reason funding or a regulatory mandate will be required to use shadow finance rates and convert them to practical rates. Note that for the rate-of-return regulatory framework, while the power plant developer can pass costs to end-users through guaranteed offtake contracts, that risk is borne downstream and simply means someone else is paying for that risk.

Discount Rates and Project Finance

The gap between accounting discount rates and societal discount rates is well documented—social discount rates are often as low as 1% (Farber & Hemmersbaugh, 1993). This has been a driver for the use of alternate instruments to spur more change, e.g., renewable purchase obligations or viability gap funding. However, there is no consensus on how to bridge the two rates. Climate rates represent a particular disconnect, where a single rate can't be applied, given damages should have low discount rate while fossil investments (with a higher risk of being stranded) should have higher rates to reflect such risks. This paper focuses only on *project* financing rates and thus avoids issues of societal discount rates.

At a project level, there is a large spread between the returns for selected global funds (in local but convertible currencies) and existing nominal rates that apply to projects in developing countries in their respective currencies. The spread is a combination of country differences including inflation and project-specific differences. Risk-adjusted, the differences are smaller. If there is, say, a capital fund in Japan or Europe or the US that would suffice with a 1.5–2% annual return (a benchmark based on recent pre-COVID-19 returns, which could change), it would be in their local currency. As Tongia (2017) has observed, “Patient capital is held by sovereign, pension and insurance funds, which seek governance, predictability, and then returns.” This emphasises the need to split up the reasons for risk and return differentials across factors and address them with respective appropriate instruments.

The first factor for different rates is the expectation of shifts in foreign exchange rates. Historical data show that many developing countries have been falling or depreciating foreign exchange values, e.g., the depreciation of the Indian rupee to the US dollar over 10 and 20 years shown via annualised compound annual growth rates (CAGRs) up to different points in time (Figure S1). India’s currency sharply devalued in 1991 but since then, its depreciation has slowed down. Discussions with bankers indicate the current market hedge that can be bought or sold is close to 6% today, and is available as a forward contract but rarely for 20 years. In contrast, foreign exchange depreciation rates are now lower than 6%, especially over a 20-year horizon.[7]

Figure S1: Indian rupee (INR) to US dollar (USD) depreciation

Note: Shown are underlying weekly data from 1973 downloaded from Stooq (2021), thus giving us 10- and 20-year CAGRs from 1983 and 1993, respectively. We round weekly closes to the nearest matching 10- or 20-year date. Estimated foreign exchange hedges available on Bloomberg’s and Reuters’ trading terminals are slightly under 6%. India devalued its currency in 1991 and allowed more of a floating rate, which explains the higher foreign exchange depreciation values for 10- and 20-years until 2001 and 2011.

While developers can hope the foreign exchange spread will come down over time, a 10-year risk might be higher than a 20-year risk, at least looking at the chart comparing the two. The former is close to the modelled battery lifespan, with solar panels modelled with an accounting life of 20 years.

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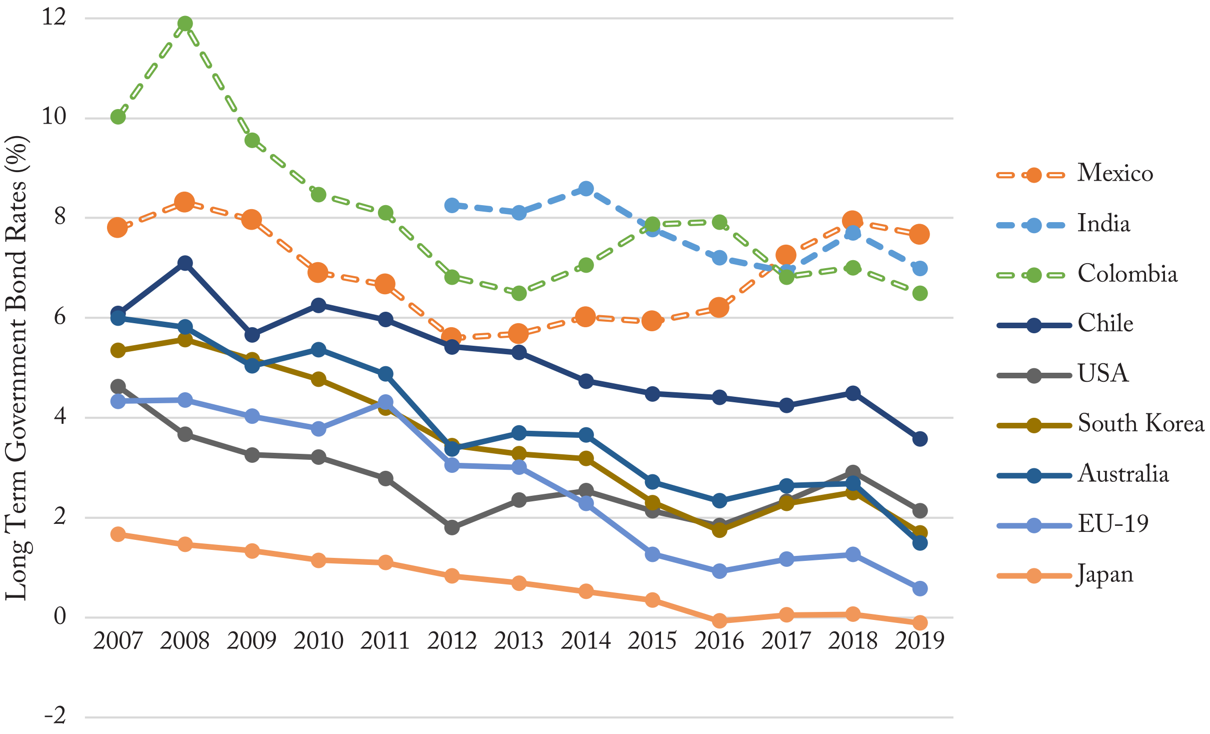
[7] The Reserve Bank of India estimates that India’s currency is overvalued. Even if we assume a 25% overvaluation, it corresponds to a 20-year CAGR shift of 1.1%. The spread between market hedges and historical 20-year INR-USD depreciation is higher.

At a project level, in addition to debt (which is notionally 70% for most projects, but up to 75–80% in some cases for Indian power projects), equity has a higher rate of return. Hence, assuming equity has a nominal 14.5% return on equity (RoE) in the local currency, the net debt rate for projects in India would need to be close to 3.2%, which at an 80:20 debt:equity ratio becomes 5.47% as the overall weighted average cost of capital (WACC). Assuming a 3% cost of the foreign exchange, this leaves just 0.2% for the US Dollar or the yen or the euro returns on debt. A more realistic return of about 1.2% may require a 1% support through global transfers such as a part of the pledged $100 billion climate support. It's worth noting that 1% support for the 900 GW RE+storage calculation is only on the order of $6 billion annually. Being conservative, a higher cost to the foreign exchange hedge as well as required debt return would still be quite low in total. The ways in which risks are to be spread between carbon support transfers, global funds, sovereign funds, multi-lateral agency counter-guarantees, etc. is outside the scope of this paper, but the bottom line is that the total figures are very manageable if the funds and risks are spread across these stakeholders.

Some of the international differentials can be benchmarked to differences in prime lending rates, which reflect inflation. Figure S2 shows selected long-term interest rates based on 10-year maturity government bonds. These are the closest to "zero-risk" instruments available in the country. We see that only developed regions (which also happen to be high carbon emitters, with per capita emissions above the global average in 2019) have low interest rates. While the downward trend cannot continue indefinitely (and is probably over with the post-COVID-19 recovery), the spread between developing and developed countries will likely remain.

Figure S2: 10-year government bonds' interest rates (selected countries)



Source: Organisation for Economic Co-operation and Development (OECD, 2021) data.

Note: Dotted lines are for countries with below-average per capita CO2 emissions from energy in 2019 as calculated using data from BP (2020). These are also all developing countries. Some high-emission countries like South Africa or China (not shown) are still emerging economies, and some more developed countries like Russia (not shown) have high interest rates. While the paper focuses on emerging economies, all sets of users would benefit from lower rates to lower emissions. Only (but not all) high-income countries have low interest rates—the lowest are in Japan and countries of the European Union (EU). These countries also display the most pronounced downward trend of lower discount rates, even though many developing countries also display a trend downwards.

These rates are amongst the cheapest market rates for zero-risk sovereign debt in the respective country, and private sector project developers typically face much higher rates. These would depend on the credit-worthiness of the developer and the project. In India, RE projects enjoy slightly lower lending rates than coal-based projects, based on published rates from the Power Finance Corporation (PFC), the public sector enterprise that is a dominant funder of generation capacity in the country. In September 2020, the available rates based on credit-worthiness of the developer ranged from 11.25–12.6% for coal plants, and 10–11.4% for RE plants (Power Finance Corporation, 2020); we thus use 12.5% and 11% as the reference rates for coal and RE+storage, respectively. Smaller enterprises face higher rates, and consumer capital finance rates are even higher.

The last category of rate differentials relates to project risks, as opposed to sovereign and foreign exchange risks. These can be mitigated through not just proactive steps by the counter-parties, but also through risk pooling mechanisms and payment security mechanisms (Clean Energy Finance Forum, 2016). While many risk-reduction instruments carry a cost to someone, such costs could be part of the global transfer from developed to developing countries under climate finance. Over time, with market maturity and experience, such costs should come down.

For developing countries with very high inflation rates (some countries show tens of percent), it may be unnecessary to plan for a large spread to be covered with global funds. One could calculate the real instead of nominal spread, which should become much closer to the India example. Doing so would align with a world where high inflation means electricity prices could rise over time in nominal terms, which would allow for a consistent coverage ratio, especially if the inflation spread roughly matches or at least covers much of foreign exchange depreciation.

Costs of Technologies

The analysis is meant to be representative of trends and focuses on comparisons across technologies rather than absolute numbers individually. This section details some of the assumptions and implications.

This bottom-up calculation reflects expected fully loaded (high utilisation) storage with RE, where there is significant storage requirement. In the short run, rising RE can be absorbed in most countries without storage as long as the share is modest, perhaps under 25–30%, depending on the share of wind versus solar. India recently bid for ‘Round the Clock’ (RTC) RE-hybrid systems, whose lowest bids came in at Rs 2.90/kWh (4.0 US¢/kWh). However, this headline figure masked the reality that this was not a flat price as with most solar or wind bids, but escalating at 3% for the first 15 years. Analysis by the Prayas Energy Group (Gambhir *et al.*, 2020) pegs the Levelised Cost of Energy (LCOE) at about 3.6 Rs/kWh over the 25-year project lifespan.

More importantly, and contrary to many reports, any quantum of storage in these RTC bids would be very small since most of the high system availability would come from blending wind and solar plus oversizing the system. The bid required capacity availability of 80% annually and 70% on a monthly basis. However, given that excess power could be sold to third parties, a larger build would be cost-effective with minimal or even zero storage (Bullard, 2020), and certainly much less storage than the 70% of RE output going through storage as sized in the calculations used in this paper.

The costs of power from coal are heavily dependent on three factors other than the discount rate: the capex up front, the CUF (aka PLF), and the cost of fuel. Capex costs may vary but there are few new coal plants being built, and there has been a temporary surplus of capacity due to a doubling of capacity between FY2011–16 (Tongia & Parray, 2019).

While Indian coal plant PLFs fell even before COVID-19, the national average masks heterogeneity. Not only do central government (NTPC) plants have higher load factors, location is also a strong predictor of CUF. Plants with lower transportation costs end up having lower variable costs in the merit order despatch of load, and consequently operate more hours per year. Thus, for future coal, we compare costs for mine-mouth or pit-head power plants, which avoid high transportation costs and end up being delivered cheaper even after accounting for long-distance electricity transmission. For these, a 60% load factor may not be aggressive—selected plants operate at over 80% PLF today. For new solar, the output is approximately 25% CUF. Given Indian daily demand curves are relatively flat, a significant fraction of demand today is outside the solar window. "Net demand"—the residual demand after subtracting variable (non-battery) RE supply, which must be met by firm or controllable power—predominantly peaks in the evening (CSEP, 2021), so 60% CUF is reasonable for favourably located new coal plants that operate outside variable RE's output window.

Combining these factors, we find coal's capex amortised at Rs 2.23/kWh, to which fuel costs add Rs 2.2/kWh, matching selected actual plants today (Ministry of Power, 2021); small O&M costs would add a few percent. These fuel prices embed coal taxes and levies that are about one-third of delivered fuel costs (Tongia, 2020), a share that varies by location. Pithead or mine-mouth plants have very low transportation costs, and thus taxes/levies are closer to half their fuel costs.

Most importantly for this analysis, we have not taken into account any dynamics of when new capacity of RE+storage versus coal may be required; 900 GW of RE+storage would easily provide 50% more electricity than the 2019 total grid-scale supply. Given India's grid electricity demand growth rate has fallen in recent years to about 5% per annum, such additional capacity could last perhaps almost 19 years at the same rate of demand growth, or even more as CUFs of RE rise. By that time, the capital costs for no-carbon solutions would fall measurably, especially for storage, which is presently much more expensive than solar on an LCOE basis.

Assuming the costs of storage decline by 7% annually in real terms, i.e., after beating inflation, this would halve the net present value (NPV) cost of abatement if spread out. In reality, the learning curve cost improvements until COVID-19 have been far higher. Thus, the calculated $29/ton-CO2 abatement through lower project finance rates converted to gap funding should fall steadily, eventually down to zero as RE+storage capex declines (and existing domestic market lending rates also fall). It's possible that a shadow finance rate instrument would only be required for a finite time period, but it can provide immediate support that is faster than waiting for technology cost improvements. The shorter lifespan for batteries than solar panels is also a plus for such gap funding as the learning curve cost improvement rates for batteries are also higher than for solar.

Example of Choosing Efficient Versus Typical Technologies

Lower costs of capital inherently improve the competitiveness of capital-intensive but more efficient solutions, but they may not always be cost-effective from a carbon perspective. Calculating the $/ton-CO2 abatement cost can help prioritise investments and support.

To illustrate the impact for an end-user technology example, we consider costs of highly efficient versus more typical air conditioners (ACs) sold in India. Using pricing and efficiency numbers listed on Amazon India (2021) for a large 1.5 ton (=18,000 BTU/hr) capacity split AC, we compare its capital cost and efficiency trade-offs. We use models from the same manufacturer, comparing inverter five-star ACs with regular (non-inverter) three-star ACs; star ratings and technical specifications are for 2021 models as shared by the sellers per Bureau of Energy Efficiency (BEE) norms. Table S3 summarises baseline parameters.

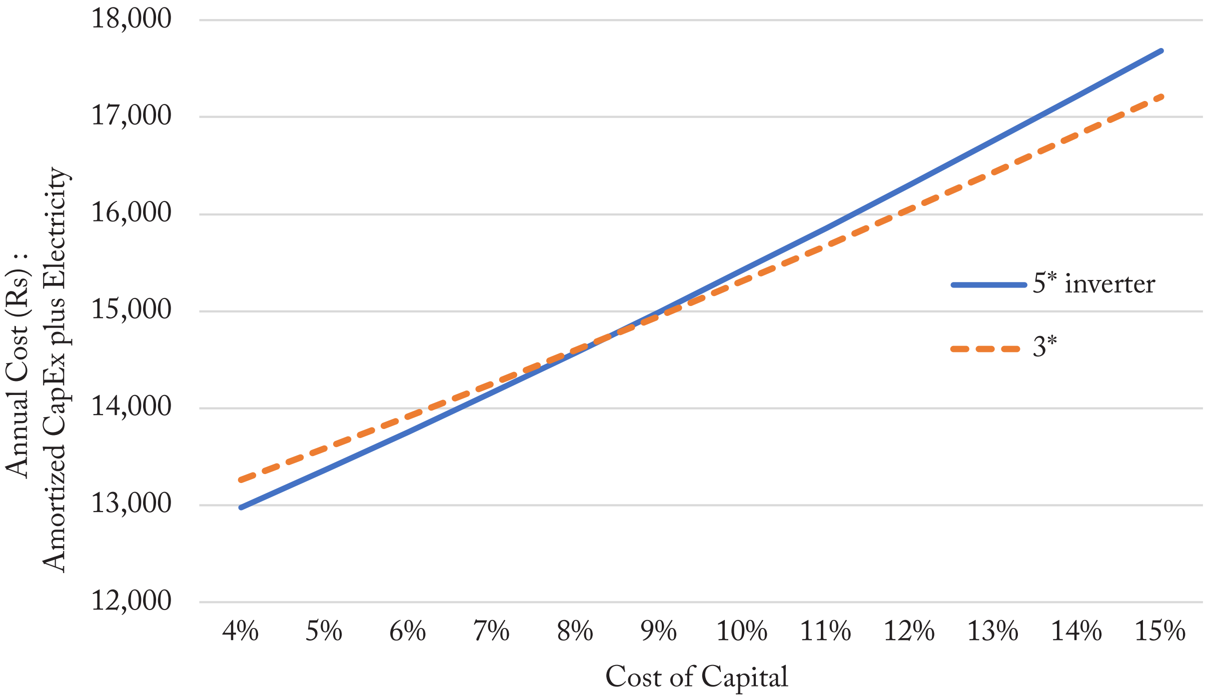
Table S3: Air conditioner parameters—India 2021

Technology	List Price (Rs)	iSEER (efficiency rating)	Normative electricity consumption (kWh/year)	Modelled Lifespan (years)	Reference Electricity Price (Rs/kWh)
5-star inverter	61,990	4.60	889	10	6
3-star	51,990	3.63	1142	10	6

Note: The list price ("MRP" = maximum retail price) is before discounts. Online prices showed similar percentage discounts from the list price. We assume non-electricity O&M costs are similar for both options. Indian efficiency ratings (iSEER = Indian Seasonal Energy Efficiency Ratio) are based on watts cooling per watt input, and thus different from American SEER ratings.

Figure S3 shows the impact of cheaper discount rates (costs of capital) on the total costs (operating plus annualised or amortised capital costs). We assume BEE normative hours of usage, for Indian SEER (seasonal energy efficiency ratio) numbers. The cost of electricity is taken as Rs 6/kWh, which is above the average of Rs 5.09/kWh all-India electricity consumer pricing in FY2019 (Power Finance Corporation, 2019), but more representative of the higher energy (variable) costs for richer consumers who are more likely to use ACs; this ignores state-wise variations. A higher electricity price hastens the crossover for making more efficient ACs competitive, or, stated another way, decreases the cost of capital rate reduction required.

Figure S3: Impact of discount rates on annual costs for ACs (India 2021)



Note: This compares highest efficiency (5-star inverter split ACs) with more typical 3-star split ACs. For both of these, amortised capital costs are higher per year than operating costs for the nameplate (rated) kWh electricity consumed per year.

While we do find a crossover a little above 8% discount rate, which appears cheaper than the crossover rate for power plants seen before, the annual cost differential between the two technology options is relatively small. For reference, typical consumer interest rates (loans) for durable goods are 13–15%, excluding manufacturer or other special promotions.

Comparing 13% and 8% discount rates, the 5% gap enough to switch technologies comes to $29.9/year of support for the capex of a single AC, but this avoids only 0.16 tons of CO2. The avoided emissions are assuming a mix of grid supply across fuel types based on CSEP (2021) data, which leads to an average of 711 g/kWh based on coal plant emissions as per CEA (2018). Thus, the carbon abatement cost of such support is very high, roughly $164/ton-CO2.

This emphasises that while shadow discount rates (filled by aid, illustrated for a 5% spread) can reduce emissions, some interventions are much more cost-effective. Countries and developers should build a portfolio of technology interventions and compare their marginal abatement costs to prioritise global funding. It's entirely possible that for ACs, there is a much greater payback possible from direct interventions in R&D to improve price-performance (efficiency). Two critical factors are AC usage profiles (including time of day) and the dwelling construction design, which impact "right sizing" the AC.

Aggregate Impact on Emissions

Dollars per ton-CO2 avoided is a good metric for choosing projects under this framework. Like the Intergovernmental Panel on Climate Change (IPCC, 2022)'s AR6 WGIII report showed, different technologies have different abatement costs (some like variable renewable energy are negative cost, i.e., they save money). We also need to understand the scale of emissions at play.

While a more detailed analysis must be country specific and will require teasing apart finance assumptions per project (IPCC uses standard ranges for finance rates), we can estimate some of the scope by examining emission trajectories for presently low-emissions regions.

How effective could shadow project finance rates be? To give an order-of-magnitude estimate, we apply a shadow finance rate only to low-emissions countries, defined as the ones with per-capita fossil fuel CO2 emissions below the 2019 global average of 4.43 ton-CO2/year (BP, 2020). This can displace, for the sake of comparison, perhaps 10–50% of upcoming emissions growth before these countries peak—the latter is close to the share of electricity in many regions like India. Thus, we calculate for *eliminating* future power sector emissions growth. Deep decarbonisation of industry and transportation is harder, but even these would also benefit from shadow (lower) discount rates. We don't calculate the system-wide investment costs, but could use the example of India to estimate the $/ton-CO2.

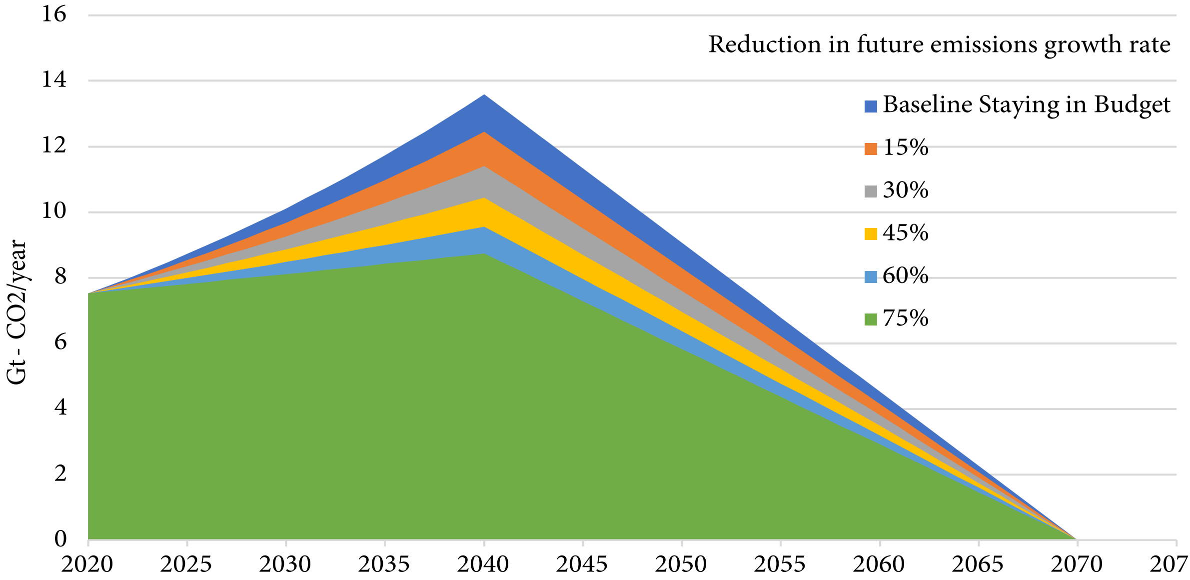
We estimate the reduction in emissions as a parametric exercise, which is, by definition, not a prediction or equilibrium analysis. Focusing only on future emissions (post 2019, and considering COVID-19 as a one-off blip, hence the dates could be 2021 and onwards), we can apply a bifurcated model of future emissions as per Tongia (2021)'s area-under-the-curve framework, which apportions a prospective carbon budget and works backwards to examine compatible emissions trajectories; Raupach *et al.*, 2014, give an overview of apportionment issues. In Tongia's framework above global average (referred to as HI) versus below global average (referred to as LO) emitters are given different trajectory shapes.

Based on Tongia's area-under-the-curve model, unless otherwise declared, all countries take 30 years to decline emissions to zero. HI emitters, i.e., those with emissions above the 2019 global average, must begin to decline immediately, benchmarked to be linear (3.33% annually), while LO emitters can continue to grow emissions at a low or modest rate until they peak and then also decline to zero in 30 years. That model solves for years of CO2 emissions growth remaining until the country must peak, while still staying within their prospective carbon budget. For LO emissions countries as a whole, this calculates to 35 years for a 2°C rise world; they would have less time available to peak by if the benchmark was for a 1.5°C rise. This is not a prediction of trajectories, but a framework for comparing emissions transparently. Our interest is not in the area-under-the-curve framework's absolute results, but the relative impact of a shadow discount rate on the trajectories. The ambition remains to improve the trajectory—ideally all countries would do better than their "allowed" emissions as per the prospective carbon budget.

The baseline without shadow finance rates indicates that if the countries all keep their cumulative prospective emissions within the prospective carbon budget, HI emissions countries would emit 41.7% and LO emissions countries would emit 58.3% of future CO2 emissions—this is nothing but the 2019 split of population. It is unlikely that HI emissions countries would stay within budget, but such corrections in the framework aren't germane to analysing the emissions impact from shadow discount rates for LO emissions countries.

Figure S4 shows the decrease in emissions based on LO emissions countries harnessing shadow discount rates to lower future emissions *growth rates* by 10–50% while peaking at the same point in time. This focuses only on the ~half of energy (and emissions) that come from the electricity sector, though shadow discount rates may also be viable beyond the power sector. In reality, gap funding to pay for lower discount rates may not only lower the peak but also advance the time when emissions peak, further reducing cumulative emissions. In addition, instead of just flattening power sector emissions, it's possible that we could decline emissions from the power sector, which means more than 50% reduction in economy-wide growth before peaking.

Figure S4: Simulated impact in CO2 emissions from LO emissions countries by lowering future growth rates via shadow discount rates



Note: The baseline for LO emissions countries allows 35 years of growth at 2.89% emissions rise, which is the average year-over-year emissions rise during 2017–2019 for LO emissions countries (based on data from BP (2020)), followed by a 30-year linear decline to zero to still remain in the prospective carbon budget, shared out of the 1,000 Gt CO2 globally to be compatible with a 2°C rise (chosen for illustration), which is within the range set by IPCC in 2018. These are CO2 emissions without offsets, and use of different CO2 budget figures or total greenhouse gas figures would simply shift the curves proportionally.

Compared to the base trajectory, for the 50% reduction in emissions growth rate scenario, with the same 35 years of growth before decline, this reduces the LO countries peak emissions by 39.0% as well as cumulative emissions by 19.0%. Given that the fraction of future emissions growth from electricity may be higher than 50%, especially considering cooling needs, these figures are only indicative and the real impact could be far greater. There would also be significant benefits possible from shadow finance rates outside the electricity sector. However, for these, a lower finance rate may not be sufficient in the near term, and hence Figure S4 only shows a decline in growth and no peaking of emissions from LO emitters until decades out.

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