Energy and Economic Growth
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Cross-border electricity trade and the potential for green grids in South Asia and Southern Africa.

A synthesis of EEG-funded research

A review of the potential impacts of cross-border electricity trade in South Asia and Southern Africa on total system costs and CO_2 emissions.

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Cross-border electricity trade and the potential for green grids in South Asia and Southern Africa

Synthesis paper authors: Saumya Vaish & Simon Trace, Oxford Policy Management

Based on findings and published material from three EEG-funded research projects and the work of their respective researchers:

- *Implications of declining costs of solar, wind, and storage technologies on regional power trade in South Asia*
  J. Parikh, V.K. Saini, P. Gosh, N. Saini
- *Accelerating large-scale renewable energy deployment in Southern Africa by bridging analysis and application through decision-support tools*
  R. Deshmukh, G. Wu, A. Trainor, A.Uppal, AFM Chowdhury, C. Baez, E. Martin, J. Higgins, A. Mileva, K Ndhlukula
- *Techno-economic and financial analysis of a Gulf-India undersea electricity connector*
  A. Shivakumar, L. Kruitwagen, M. Weinstein, S. Spiteri, C Arderne, Y Almulla, W. Usher, M. Howells, A. Hawkes

Abstract

In developing nations, with a rising population and growing energy consumption, it is essential to employ modern clean energy sources to reduce harmful emissions from the power sector and to attain a low-carbon economy. South Asia and Southern Africa have abundant clean, renewable energy resources, yet several countries in the two regions (e.g., India, Bangladesh, and South Africa) rely on domestic resources like coal or natural gas for most of the power generation, risking lock-in to carbon-intensive technologies that are likely to become redundant as the world strives to meet climate goals. This paper reviews the results of three studies funded by the FCDO-funded Applied Research Programme on Energy and Economic Growth that modelled the potential impact of cross-border electricity trade on total regional power system costs and CO_2 emissions. The studies examine a range of scenarios and find that because cross-border trade allows optimal use of regional renewable resources in both South Asia and Southern Africa, such trade leads to least-cost power system solutions and larger CO_2 emission reductions than can be achieved otherwise.

In Southern Africa the research in addition looks at the impact of applying various social and environmental constraints on electricity system planning on the energy mix, finding that increasing such constraints tends to favour the construction of more solar and wind capacity over hydro in the region. Marginal electricity system costs increase in response to more socio-environmental protections, but under many scenarios, these cost rises are modest (1 – 5%), although combining pursuing a low carbon target (50% emissions reduction by 2040 compared to 2020 levels) with all socio-environmental protections increases costs by up to 13%.

Acknowledgments

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Introduction

In developing nations, with a rising population and growing energy consumption, it is essential to employ modern clean energy sources to reduce harmful emissions from the power sector and to attain a low-carbon economy (Shashavari & Akbari, 2018). South Asia and Southern Africa have abundant clean, renewable energy resources, yet several countries in the two regions (e.g., India, Bangladesh, and South Africa) rely on domestic resources such as coal or natural gas for most of their power generation, risking lock-in to carbon-intensive technologies that are likely to become redundant as the world strives to meet climate goals. For robust economic growth, these regions require competitive supplies of energy on a long-term basis.

Although renewable technology is evolving at a fast pace, many developing countries face challenges associated with the uptake of renewables. Notably, not all countries are endowed with the same level of renewable energy resources and the intermittent nature of solar and wind energy connected to the grid requires smoothing out, which can be a particular issue in small and isolated regions.

Cross-border energy trade enables regions to integrate their power demands and challenges and offers access to a broader mix and more stable supply of renewable energy resources over a wider geographic area. With the help of technological advances, long-distance connections between centres of high renewable energy generation potential and areas of high electricity demand can be made possible. Cross-border trade is thus viewed as a long-term additional source of clean and cheap electricity supply alongside domestic generation in countries (Haque, Dhakal, & Mostafa, 2020).

This paper briefly reviews the wider literature on cross-border trade in renewable energy. It then, in that context, considers the findings of three research projects executed under the auspices of the Applied Research Programme on Energy and Economic Growth (EEG).

The EEG programme ran from 2016-2022 and was funded by the UK Foreign, Commonwealth & Development Office (FCDO). EEG focused on ground-breaking research on sector reforms, innovative technologies and practicable solutions to some of the most pressing energy-related challenges in Sub-Saharan Africa and South Asia. Priority research areas included energy access, renewable energy, power system reliability and the efficiency and productivity of energy uses.

Context

Overview of electricity demand in South Asia and Southern Africa

South Asia has made great strides in the rate of electrification in the last two decades and is a major driver of global economic growth. It consists of 8 nations[1] that account for 4% of the world's collective GDP (Abhas, et al., 2018) and 24% of the world's population (Ul-Haq, Jalal, Sindhi, & Ahmad, 2020). The region's economy is included in the list of rapidly growing and developing nations worldwide. As recent as 2017, South Asia hosted 29% of the global population without access to electricity (IEA, 2017); however, much has changed since. India, with 239 million people without access to electricity in 2016, is expected to reach full electricity access well before 2025: with other countries also making significant progress in the electrification rate (IEA, 2017). However, the level of electricity consumption per capita in the region, ranging from 139 KWh to 806 KWh, is far below the world average of 3,126 KWh (IEA, 2017b). Power demand projections suggest a significant regional increase over the past two decades, with similar trends continuing to 2030. In India, power demand is expected to increase by 5.8% annually over the next decade (CEA, 2017). Bangladesh's peak power demand is expected to grow by 8.6% from 2010 to 2030. (SARI, 2017).

Currently, electricity from coal dominates the electricity mix in India, while gas and oil predominate the installed capacity in Bangladesh. India has the largest installed capacity in the region, with 55% derived from coal (CEA, 2020). In Bangladesh, 54% of the installed capacity is gas, and 33% oil (BPDP, 2019). Recent market turbulence resulting from Russia's invasion of Ukraine has highlighted the need to safeguard the region's security of supply from the impacts of unstable international markets (Benton, et al., 2022).

Africa has one of the world's fastest-growing populations and is home to nearly 18% of the world population (IEA, 2022). Even though the continent's overall economic growth on average has been by 3% per annum between 2010 and 2019, this has not

[1] South Asia consists of the present territories of Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, India, Pakistan, and Sri Lanka

translated into high living standards for most Africans. Africa accounts for less than 6% of global energy use (IEA, 2022). South Africa, the continent's largest industrial economy, accounts for around 16% of Africa's energy consumption (*ibid.*).

The Southern African Power Pool (SAPP) comprises 12 member countries[2] who are expecting a substantial population and GDP growth, leading to an increase in energy consumption forecasted to reach 115 GW by 2040 (SAPP, 2017). Southern Africa's electricity system is heavily dominated by coal (60%) and hydropower (21%) as of 2020. Although Africa's total energy demand between 2010-2019 grew by 2.4% every year, the rise in the use of electricity has been lagging far below the average for other developing regions (IEA, 2022). In 2021, 43% of the population of Africa, around 600 million people, lacked access to electricity, and 590 million of them were in Sub-Saharan Africa (*ibid.*). With the onset of COVID-19, installation of new and off-grid connections was slowed and, as a result, the number of people without access to electricity in the region is estimated to have increased by 4% in 2021 relative to 2019, reversing all the gains made over the previous five years.

Sub-Saharan Africa faces the problem of unreliable electricity supply, impeding economic and social development and driving businesses and households to rely on costly diesel generators (Blimpo & Cosgrove-Davies, 2019). The global clean energy transition holds new promise for Africa's economic and social development. Twelve African countries that represent over 40% of the continent's total CO_2 emissions have committed to reach net zero emissions by around mid-century. This requires setting new course for energy sector amid declining clean technology costs and shifting global investment (IEA, 2022).

Distribution of renewable potential in the region and role of cross-border trade for power flexibility

The South Asia region is endowed with limited fossil fuels but abundant hydro resources as well as enormous variable renewable energy resources such as solar and wind. However, the distribution of these resources is not even throughout the region. The bulk of the hydropower potential is in India, Pakistan, Nepal, and Bhutan. India also has the highest coal reserves in the region and the largest renewable energy (solar and wind) potential. India, Bangladesh, and Pakistan also have substantial gas reserves (SARI, 2021). Dependence on gas is highest in the case of Bangladesh, whereas reliance on coal is highest in the case of India.

In contrast, Bhutan and Nepal's electricity mixes are dominated by hydropower. In 2019, 96% of the installed capacity in Nepal came from hydropower (NEA, 2020). Nepal has a considerable untapped hydro potential of 83 GW with an installed capacity of only 1.4 GW. Nepal has further planned 5,521 MW, resulting in a total capacity of about 10,000 MW by 2026 to meet domestic demand and cross-border power export (ICIMOD, 2018). Bhutan has an economic potential of about 24 GW of hydropower. Almost 75% of the power produced in Bhutan is sold to India.

Various sustainable regional energy infrastructure is already developed in South Asia, including hydropower generation plants in Bhutan and Nepal. India has developed over 91 GW of renewable energy capacity, consisting of solar, wind, small hydro, and biomass resources (CEA, 2020b). Bhutan has 8.5 MW of renewable energy capacity (BEA, 2019), while Bangladesh has 38 MW (BPDP, 2019). Along with avoiding emissions, such a large renewable energy capacity also provides a potential chance for regional use, such as cross-border trade of renewable energy.

Like South Asia, most of the power generation in Africa continues to rely on fossil-fuel based energy sources. In 2020, only 9 % of Africa's energy was generated from renewable sources, with heavy reliance (6.8%) on hydropower. The proportion of renewables in the energy mix is growing, however, with solar and wind capacity increasing by 13% and 11% respectively in the year from 2019 to 2020 alone, while hydropower grew by a massive 25%in the same period (PWC, 2021).

Southern Africa has an abundance of renewable energy resources, yet only 43% of its 177 million inhabitants have access to electricity (Hadebe, Hasna, Ndihovu, & Kibido, 2018). Coal is still a major source of energy for the largest economy in the region, South Africa, and accounts for 84.4% of electricity generation in that country (Omarjee, 2022). There also continue to

[2] SAPP member countries: Angola, Botswana, Democratic Republic of the Congo, Eswatini, Lesotho, Mozambique, Malawi, Namibia, South Africa, Tanzania, Zambia, and Zimbabwe

be plans for new coal capacity in the region, such as the Chinese-backed Kam'mwamba Coal Power Station in Malawi (McCauley, Grant, & Mwathunga, 2022)

The Southern Africa Development Community (SADC) countries have a vision of achieving 100% renewable energy by 2050. Expectations are that, to achieve this, the share of renewable energy in the Southern Africa Power Pool regional grid will have to increase from 21% in 2017 to 37% by 2027 (Hadebe, Hasna, Ndihovu, & Kibido, 2018). SADC has identified four hydropower priority projects, along with other developments, to help achieve this goal: the 1500 MW Mpanda-Nkuwa in Mozambique, the 4800 MW Inga III in the DRC, the 1600 MW Batoka Gorge project between Zambia and Zimbabwe, and the 1200 MW Lesotho Highlands Water Project Phase II in Lesotho (ibid).

Cross-border electricity trade thus provides an opportunity in both South Asia and Southern Africa to integrate neighbouring countries' grids and to tap into regional renewable energy resources. Such integration has the potential to meet regional electricity demand through supply of clean power. The diversity of resources within each region can help address some of the variability and grid stability issues associated with renewable energy because of its intermittent nature, especially for solar and wind (the larger the region the more likely the sun will be shining or the wind blowing somewhere within it). Likewise, the difference in time zones across large regions leads to diversity in peak demand durations and to the possibility that cross-border electricity trade could help meet peak demand even with less generating capacity than were countries to rely solely on resources within their borders. Electricity cooperation could also increase economies of scale, opening markets for larger plants and developing interconnected electricity markets.

Cross-border trade in renewables has obvious climate benefits. Research suggests that greater use of hydro plants in Nepal and Bhutan could reduce the use of thermal power plants in India and Bangladesh, resulting in a drop in fossil fuel use and greenhouse gas emissions. Carbon dioxide reductions due to hydropower generation transferred from Bhutan to India alone could be as high as 40 million tons annually (Wijayatunga, Chattopadhyay, & Fernando, 2015). Similarly, a case study for power trade in the Eastern African Power Pool assessed the economic and CO_2 emissions reduction benefits from different levels of integration among the 11 countries under EAPP. Significant gains from committed transmission links were highlighted, with tight integration potentially delivering a 30% CO_2 emission reduction target by 2030, while lessening a large part of the concerns around national energy security (Remy & Chattopadhyay, 2020).

Growing interest in potential for global interconnection

There is a growing interest in cross border, and indeed cross-continental trade in electricity. The Global Energy Interconnection (GEI) was proposed by China's President Xi Jinping in 2015 (GICA, 2018) to facilitate efforts to meet global power demand with clean and green alternatives at the UN Sustainable Development Summit in 2017. The Global Energy Interconnection Development and Cooperation Organization (GEIDCO) with United Nations Department of Economic and Social Affairs (UNDESA) organised a high-level symposium in 2017 to incorporate GEI into the framework for the implementation of the UN 2030 Agenda and later into the framework of Paris Agreement in 2018 to strengthen cooperation on GEI development.

More recently India Prime Minister Narendra Modi's One Sun One World One Grid (OSOWOG) vision promoted trading energy from sun, wind, and water across borders to deliver enough clean energy to meet the needs of everyone on earth. OSOWOG's mission is to create a global ecosystem of interconnected renewables via transmission lines crossing borders and connecting different time zones for mutual benefit and global sustainability. The Green Grids Initiative at COP26 in 2021 built on OSOWOG in an attempt to develop an international coalition of countries support this concept of a global modernised and interconnected series of green grids.

Research questions emerging from the literature and relevant EEG research projects contributing findings to this paper

Given the above review of literature, in the specific contexts of South Asia and Southern Africa, this paper uses the findings from research funded under the Applied Research Programme on Energy and Economic Growth (EEG) to provide insights and discussion around three research questions, namely:

1. Does cross-border trade in renewables reduce system costs in Southern Africa and South Asia?
2. Does cross-border trade in renewables reduce CO_2 emissions?

3. Beyond finance and CO_2, what other decision criteria should be folded into regional electricity trade planning?

The EEG research projects explored are summarised below.

Research location / lead researcher(s) / Institution	Research description
Parikh, J. Asia Centre for Sustainable Development, Integrated Research and Action for Development (IRADe)	Implications of declining costs of solar, wind, and storage technologies on regional power trade in South Asia (BBIN countries)
Deshmukh, R. University of California, Santa Barbara (UCSB)	Accelerating large-scale renewable energy deployment in Southern Africa by bridging analysis and application through decision-support tools
Shivakumar, S.	Techno-economic and financial analysis of a Gulf-India undersea electricity connector

Does cross border trade in renewables reduce overall system costs in Southern Africa and South Asia?

Declining solar, wind and storage costs in South Asia and the impact on power trade and total system costs across Bangladesh, Bhutan, India and Nepal region (BBIN).

In 2019-20, India exported 1839 GWh to Nepal, 6168 GWh to Bangladesh, and 7 GWh to Myanmar, while it imported 6165 GWh from Bhutan (Ministry of Power, India, 2020). Although electricity trade in the region was originally based on government-to-government treaties, more recently many new electricity trade contracts have been market-determined, a trend that is expected to further increase volumes of electricity trade in the region. Nepal and Bhutan currently have huge untapped hydro resources which, if exploited, could have the potential to dramatically change their economies through the export of hydropower to India and Bangladesh. However, the falling cost of storage technologies and other renewables (solar and wind) has raised questions over whether the cost of hydropower will remain competitive in the long term and, if not, what the impact might be on the direction and volume of cross-border electricity trade in the region in future (Parikh, Saini, & Ghosh, 2022).

The Delhi-based research institute IRADe developed a modelling framework to study the **Implications of declining costs of solar, wind, and storage technologies on regional power trade in South Asia (BBIN countries)**. The study utilised power system technology framework models for Bangladesh, India and Nepal taken from previous studies, which were updated for the base year 2015, while a new model was developed for Bhutan. Various scenarios were developed in consultation with key stakeholders to ascertain the cost declines for solar, wind, and storage technologies expected in the short-, medium-, and long-term. The power system model for each country was modelled as a least-cost, dynamic linear programming model representing the physical aspects and functioning of the power system, with technological details and covering alternative technologies options for power generation. Using the Answer TIMES software,[3] an integrated model was developed wherein all the four countries in the Bangladesh-Bhutan-India-Nepal region could trade electricity. The scenarios analysed for determining the cost implications:

- **Base**-The Base scenario assumes that the power trade among the BBIN nations will be restricted to 2017 volumes from 2017 to 2050.
- **NC** (**No Cost Decline Scenario**)- This scenario assumes no cost decline for renewable and storage technologies, and with fixed costs (2015) throughout the model horizon.

[3] This software uses TIMES (The Integrated MARKAL-EFOM System) as its model generator that quantifies new investment needs in generation and grid, including interconnection, cost of generating electricity to meet the requirement for each time-period and sub-period.

- **LCD (Lower Cost Decline Scenario)**-This scenario assumes a lower cost decline for renewable and storage technologies.
- **HCD (Higher Cost Decline Scenario)**-This scenario assumes a higher cost decline for renewable and storage technologies.

As a part of this study, sensitivity analysis on the following themes was undertaken along with analysing the scenarios:

- **PES (Political Energy Security)**-This scenario assumes that the maximum import volume for each year is capped at 20% of domestic demand for Bangladesh, Bhutan, and Nepal.
- **HiRePo (Higher RE Potential)**-This scenario assumes higher RE potential for BBIN countries than currently allowed for in national plans, based on analysis that suggests current plans underplay the true extent of RE potential.
- **CO-50 (Carbon Emission reduction of 50%)**[4]- This scenario assumes a cumulative decrease in CO2 emissions from the power sector by 50% of the Base scenario for Bangladesh and India. (Results from this scenario are discussed later in this paper)

Assuming solar, wind and storage technology costs continue to decline, the renewable energy share of total installed capacity for the BBIN region could go as high as 75 percent by 2050 under the combined HCD and HiRePo scenarios. In contrast, it reaches only 55 percent in the Base scenario. Results from the study show a positive impact of cost decline in solar, wind and storage technologies on the regional trade, which is predicted to grow from 13 TWh in 2019 to as high as 986 TWh by 2050. Even if the electricity imports are restricted (under the PES constraint scenario), the model shows regional trade reaching 416 TWh by 2050.

Amongst the four countries, Bangladesh's situation is quite different to the others as its generation options are more limited and it has to choose between power imports from the other three countries and domestic generation using imported fuels, due to limited domestic fuel availability. As a result of this, under solar, wind and storage cost decline scenarios, Bangladesh's electricity imports could be as high as 93 percent of its domestic demand by 2050 under cost decline scenarios. With the highest solar and wind potential within the BBIN region, India will benefit from the cost decline in these technologies by achieving higher levels of non-hydro renewable energy installed capacity. India could be a net exporter of power if power imports by Bangladesh are not restricted. Bhutan and Nepal remain net exporters of electricity under all scenarios.

Increase in electricity trade in the region will require expansion of existing interconnector capacity from an estimated current 3.8 GW (2020) up to a maximum of 174GW by 2050, depending on the modelling scenario followed. Table **1** summarises the regional transmission capacity required for the main scenarios.

Table 1: Maximum regional transmission capacity requirement for 2050 for different scenarios

Scenarios	Bangladesh – India (Bangladesh's imports - GW)		Nepal – India (Nepal's exports - GW)		Bhutan – India (Bhutan's exports - GW)		Total Regional Transmission Capacity Required - GW	
	2030	2050	2030	2050	2030	2050	2030	2050
Base	7	11	0.1	6	2	8	9	25
HCD	29	112	17	28	18	28	65	168
HCD+PES	15	78	17	28	18	28	51	134
HCD+ Hi Re Po	30	105	17	27	24	41	71	174
HCD _ CO-50	34	111	18	29	18	28	69	168

[4] The scenario constraint is not applicable to Bhutan and Nepal as their power system is predominantly hydropower based.

Overall, the research found that cross border trade reduces total BBIN systems costs from 2015-2050 by between 3 and 11% for the range of scenarios examined. The system cost findings presented in the report indicate a higher cost reduction for all four scenarios that assume a high rate of cost decline for solar, wind, and storage coupled with sensitivity analysis scenarios. High-cost decline of renewables paired with a high renewable potential scenario records the highest reduction in the system costs (by 11%). Only if there is no cost decline in solar, wind and storage technologies does cross-border trade increase total system costs (by 2%). The BBIN region could therefore save between 227 billion USD and 312 billion USD on the total discounted system cost (2015 to 2050) at 2015 prices under the high-cost decline and high renewable potential scenarios. Cost reductions over the base scenario indicate that open trade is better than a restricted or no-trade scenario.

The impact of greater trade in low carbon electricity across Southern Africa on system costs

Under the University of California Santa Barbara's study: **Accelerating large-scale renewable energy deployment in Southern Africa by bridging analysis and application through decision-support tools,** a detailed electricity system optimization model for Southern Africa was developed. The model selected the most cost-optimal generation, storage, and inter-regional transmission investments to meet the region's future electricity demand until 2040. The core focus of the study was to incorporate the declining costs of renewable energy and storage technologies and improve the representation of the variability of wind and solar generation, the seasonality of hydropower generation, and the inter-regional electricity trade.

A framework was developed that linked three open-source models representing renewable resources with great spatio-temporal details. The three inter-linked models were:

- **GridPath,** a detailed system model for the twelve countries of the SAPP, which can co-optimize generation, storage, and transmission investments and their operations across multiple investment periods under different economic and technical constraints.
- **MapRE,** a renewable energy resource assessment model that captures the spatial diversity and temporal variability of wind and solar resources.
- **VIC-Res-Southern-Africa,** a process-based hydrological water management model that can simulate daily river discharge and hydropower production across all existing and planned hydropower plants.

The research team set seven scenarios with varying combinations of capital costs of solar, wind, and battery storage, prices of fossil fuels, interregional transmission interconnections, retirement ages of installed coal fleets, and the setting of a specific target for 80% of generation to be from clean sources (wind, hydro, solar etc) by 2040. The seven resulting core scenarios are listed in Table **2**.

Table 2: Core scenarios and assumptions **(Chowdhury, et al., 2022)**

Scenario name	Renewable energy costs	Fossil fuel prices	Transmission	Coal generation retirement (65 years normal)	Clean energy target (wind, hydro, solar etc)
Reference	Declining	Rising	Optimised	65 years	None
Static costs	Static	Static			
Existing Tx			Existing		
Planned Tx			Planned		
Coal ret. 55y				55 years	
Coal ret. 45y				45 years	
Clean 80%					80% by 2040

The research found that, across all scenarios that optimally build new transmission, inter-regional transmission capacity increases by 40%–200%. Notably, more transmission capacity enables wind capacity by providing access to better quality but geographically dispersed wind resources across the region. Inter-regional electricity trade increases substantially across all scenarios in 2040, as compared with 2020, enabling the development of spatially heterogeneous low-cost renewable energy and natural gas resources. With the optimal transmission and higher share of renewables (reference scenario), total electricity trade could grow to five times the trade volume by 2040.

The modelling found that, if technology and fuel costs follow anticipated trends, wind and solar technologies will likely dominate future electricity generation investments in Southern Africa on the basis of cost-competitiveness. If decisions are based on cost alone, these technologies could be the dominant source of electricity in the region by 2040. Increased inter-regional transmission capacity (2–10 times more depending on the corridor), and significantly greater electricity trade (5 times more) compared to the present is critical for future cost-optimal and low-carbon power system operations in Southern Africa.

The impact on system cost of possible energy trade via a Gulf-India undersea electricity interconnector **(Shivkumar , et al., 2022)**

The EEG-funded study on **'Techno-economic and financial analysis of a Gulf-India undersea electricity connector'** was an independent techno-economic and financial analysis of an electricity interconnector between the Gulf Cooperation Council countries (GCC) and India. The project conducted a techno-economic model of a combined India-GCC power system using OSeMOSYS (Howells, et al., 2011), an open-source energy system modelling tool combined with a financial model.

A techno-economic model was developed in two phases: Phase 1 included a representation from both GCC and Indian power systems. The model was updated to include bi-directional trade, the option of multiple solar PV sites in the GCC, and battery storage deployment in India in phase 2. The models were applied across 75 scenarios covering a range of cost variables and solar PV locations in the GCC.

Results of the techno-economic modelling depicted the seasonal and daily trade flow patterns through Gulf, India undersea connector (GUI). The study also analysed the feasibility of GUI across the 75 scenarios and the impact of cost variables and solar farm location on the bi-directional trade volume. The study showed the bi-directional trade flows for 2030, 2040, and 2050 as a specific case of exploiting east-west time and seasonal differences. In 2030, the direction of trade flows is dominated by electricity from India to GCC. The flow remains consistent across all months and for most hours except the evening peak demand hours in India. Owing to the surplus hydropower generation in India, the direction of the trade flow is entirely towards GCC during the monsoon season. The pattern of India->GCC dominating the direction of trade is continued in 2040. In addition to evening peak demand hours in India, there is an increased flow of electricity from GCC->India during the daytime peak demand hours in the dry season. By 2050, a reversal in the dominant flow direction is observed (GCC->India direction making majority of trade volume).

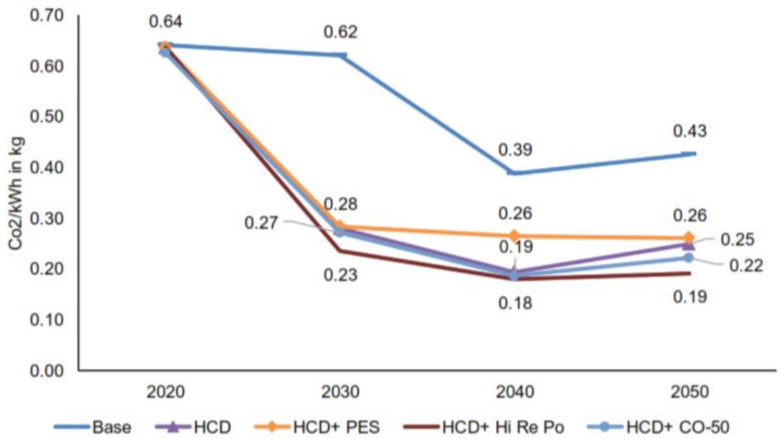
Electricity imports from the GUI represent a relatively low-cost alternative as India reaches its own technical potential for renewable energy capacity expansion. The results show that GUI is utilised extensively throughout its operational life across 75 scenarios. A techno-economic case for a GCC-India interconnector is clear: an interconnector is part of the least-cost 'optimal' power system in 64 of the 75 scenarios. The financial case for the CCG-India interconnector is less clear. Of the cost variables considered in the study, the overall discount rate is most strongly correlated with the interconnector trade volumes. Of the projections developed for the scenarios from the techno-economic model, only a small number are immediately investible. A smaller interconnector is expected to be a more attractive investment opportunity for a trade-off in total system cost reductions.

Does cross border trade in renewables reduce CO2 emissions?

The potential impact of renewable power trade in South Asia on CO2 emissions

The IRADe study referenced above (Parikh, Saini, & Ghosh, 2022) also assessed the impact of the different renewable energy cost reduction rates and resulting power trade scenarios on likely CO_2 emissions in the region. With one exception, for all the selected scenarios that were run on the BBIN electricity trade model, regional trade resulted in a reduction in CO2 emissions/kWh for the region compared to the Base scenario (power trade restricted to 2017 levels to 2050). Figure **1** compares the scenarios that assume a high rate of cost decline for wind, solar and storage against the base case, with the HCD scenarios resulting in a 60 to 70% decline in emissions per kWh by 2050. The one exception amongst the scenarios was where there was no further decline in the costs of these technologies (the NC scenario). Under the NC scenario an increase in cross border electricity trade still occurs, but it happens at the expense of higher coal utilisation and increased regional emissions. With that exception, in all scenarios examined regional trade in electricity reduces annual regional CO_2 emissions.

Figure 1: Regional emissions of CO_2 in kg/kWh under different scenarios **(Parikh, Saini, & Ghosh, 2022)**



At a country level the impact of the different scenarios for India is like the region as a whole (Figure **2**). Bangladesh looks slightly different under the PES scenario, where restricting trade to 20% of overall demand for energy security reasons means the country's growing demand must be met from increased in-country fossil fuel generation (due to limited renewable resources), leading to an increase in emissions for Bangladesh under that scenario (Figure **3**). Power sector emissions for Bhutan and Nepal remain largely unchanged under the different scenarios reviewed given their dependence on hydro.

Figure 2: CO_2 emissions in kg per kWh under different scenarios (ibid)

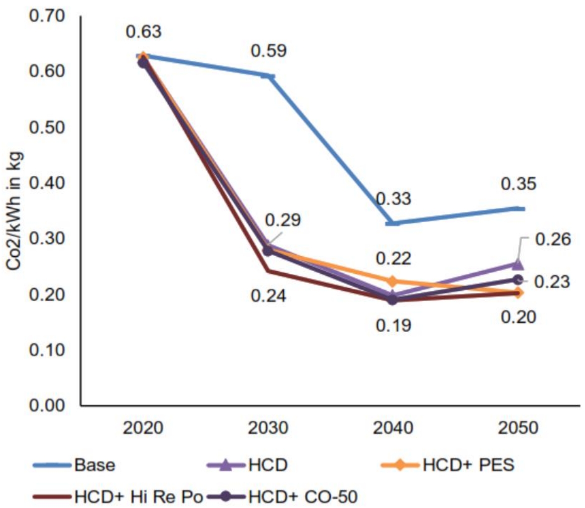
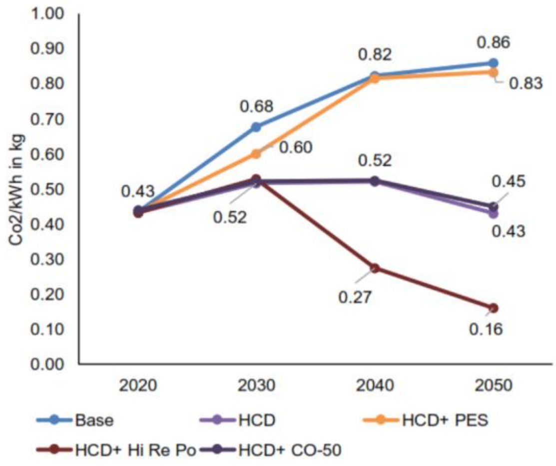


Figure 3: Bangladesh CO_2 emissions in kg per kWh under various scenarios (ibid)

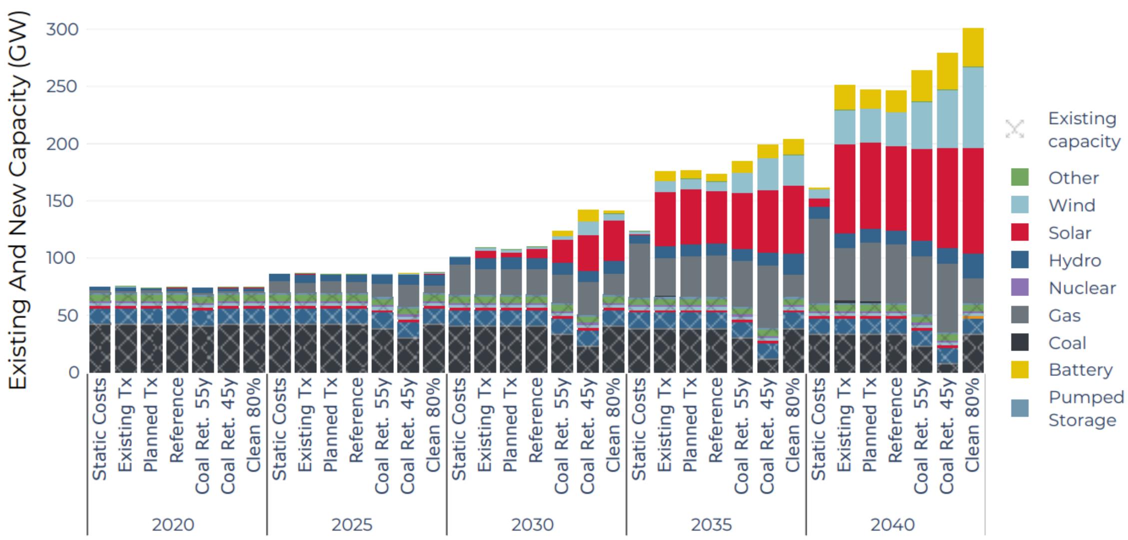


The IRADe study also included an assessment of the impact of adopting a 'green' target for the BBIN region that assumes a power sector CO_2 emission reduction of 50 percent compared to the Base scenario by 2050 (the **CO-50** scenario). For countries like Bhutan and Nepal, which are likely to fully utilise their hydro and renewable energy potential, the system costs reduce under the CO-50 scenario for both low and high declines in wind, solar and storage costs, with a negligible impact on trade. In contrast, overall system costs increase for Bangladesh by between 4% to 9% under the CO-50 scenario, depending on which level of decline in costs of wind, solar and storage scenario it is paired with. For India, the total system costs increase by 1.6% under the LCD+CO-50 compared to the LCD and remains almost the same under the HCD+CO50 scenario compared to the HCD scenario.

Regional power trade and implications on Co2 emissions in Southern Africa

Figure **4** summarises existing and new generation capacity across the SAPP region resulting from the modelling of the seven scenarios under the UCSB Southern Africa study (Chowdhury, et al., 2022) described earlier in this paper. The study shows that no new coal capacity is required in any of the twelve countries of SAPP over the next 20 years, except when transmission capacity between countries is constrained. In transmission-constrained scenarios, new coal plants are deployed in regions which are not well connected to the rest of the Southern Africa Power Pool (SAPP). Under such conditions new coal capacity is also required in South Africa, but only when renewable energy and fossil fuel costs remain static. If transmission capacity across the SAPP is adequate however, the need for new coal capacity is completely avoided, even if technology costs do not change or existing coal plants are retired early.

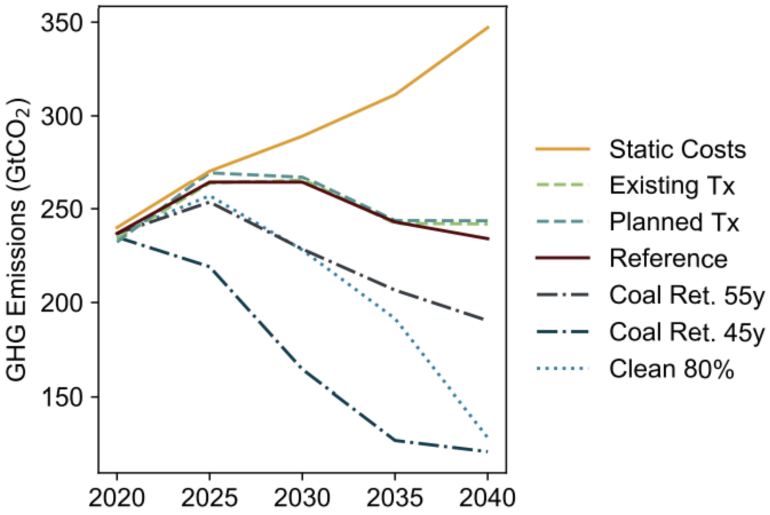
Figure 4: Existing and new generation capacity in Southern Africa across 2020–2040 for seven scenarios **(Deshmukh, Ndhlukula, Wu, & Chowdhury, 2022)**



In all scenarios except static costs, wind and solar photo-voltaic comprise the largest share of new capacity, varying from 15% to 30% and 36% to 41%, respectively, or 55% to 68% together. In the reference scenario, new solar PV and wind capacities of 73 GW and 30 GW, respectively, are deployed by 2040, which would require the addition of 5 GW of variable renewable energy capacity every year until 2040. Varying battery storage capacities are needed to balance the generation variability from new wind and solar power. However, despite the abundant availability of hydropower for future development, almost half of all currently planned hydropower capacity is uneconomic across all scenarios. Thus, either optimally built or based on current plans, new transmission interconnections do not seem to allow or encourage more hydropower development.

Taken together, findings from the study suggest that wind and solar-dominated systems are more cost competitive than fossil fuel or hydro dominated ones for the Southern Africa region, meeting demand growth without increasing GHG emissions under the cost-optimal energy modelling. The study focused on energy policies and market assumptions that can significantly reduce GHG emissions with minor annual system cost increases. However, the results showed that favourable costs encourage more fossil fuel capacity and generation, with GHG emissions increasing more than 50% over 2020.

Figure 5: GHG emissions for seven scenarios 2020 – 2040 **(Chowdhury, et al., 2022)**



As Figure 5 shows, some of the regional trade scenarios considered can significantly reduce GHG emissions. These reductions are mostly achieved with minor annual system costs increases, except if coal power plants are retired at 45 years. In the Reference scenario, GHG emissions in 2040 return to 2020 levels. The Static Costs scenario results in the highest GHG emissions by 2040 (at nearly 50% more than 2020 levels) as a result of costs encouraging more fossil fuel use in the generation mix. The Coal Ret. 45y and Clean 80% scenarios have the lowest cumulative carbon emissions by 2040, but the latter results in annual system costs by 2040 that are half that of the former. Retiring coal plants at the age of 55 instead of 65 years results in 17% lower emissions in 2040 and only 4% higher costs compared to the Reference scenario. Annual GHG emissions decrease by 48% when assuming 45 years lifetimes, but costs increase by 13%. Additional and planned transmission capacity alone only modestly increases system costs and reduces carbon emissions. This is because even in the Existing Tx scenario, electricity trade in 2040 is significantly greater than in 2020, thus capturing the benefits of utilizing existing transmission capacities for sharing resources and reducing system costs.

Beyond finance and CO_2 what other decision criteria should be folded into regional trade planning?

Inclusion of social and environmental impacts in regional electricity trade planning

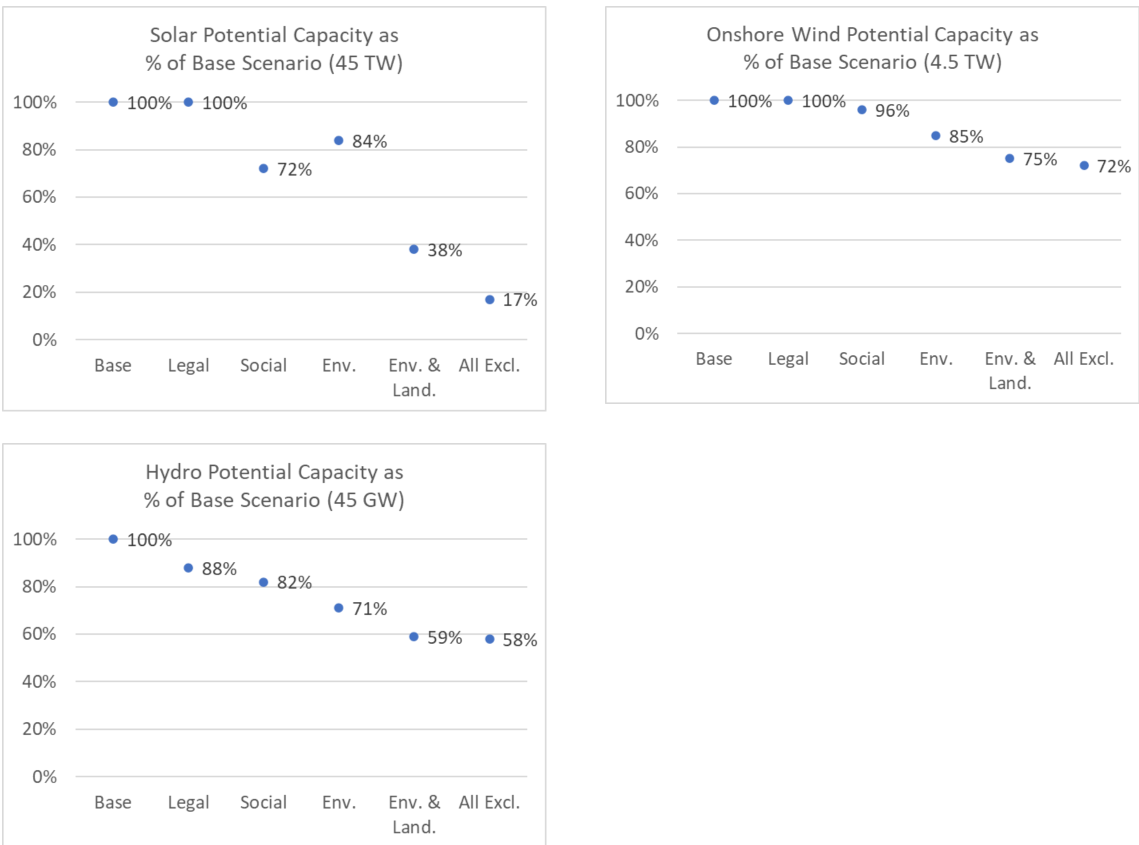
Hydropower potential is the Southern Africa region is huge and the technology has, as a result, remained a cornerstone of electricity systems in the region. Southern Africa is home to two of the five largest river basins in Africa—the Zambezi and Congo— and eight of the twelve countries of the Southern African Power Pool are dependent on hydropower for over half their electricity generation (Wu, et al., 2022). The region also has vast solar and wind energy potential. At the same time, the region has large areas with high biodiversity value. Protecting these areas and avoiding social conflicts with local communities will be critical for Southern Africa to sustainably develop its renewable and hydropower resources (ibid).

Scaling up low-carbon electricity infrastructure to meet growth, electrification, and climate goals in Southern Africa is likely to involve some conflict with environmental and social values because of the significant land use requirements of wind and solar technologies and the freshwater impacts of hydropower. To examine some of these tensions, alongside the seven power trading scenarios examined by UCSB Southern Africa study referenced above, the UCSB research team also considered the impact on technology choice and overall system costs of excluding the most socially and environmentally damaging potential wind, solar, and hydropower projects in the region (Wu, et al., 2022). To do this, the study utilised a further seven scenarios as follows:

1. **Base** in which no socio-environmental exclusions are applied (hydropower-only),
2. **Legal**, in which legally protected areas (e.g., IUCN I-III) are excluded from all renewable development,
3. **Social** in which legally protected and areas important for human livelihoods and planned hydropower plants whose reservoirs would displace more than 2000 people are excluded from development,
4. **Environment** in which legally protected and high conservation value areas and planned hydropower projects on large free flowing rivers are excluded,
5. **Environment** and **Landscape** in which **Legal**, **Environment**, and forested areas are excluded,
6. **All Exclusions** in which all **Legal**, **Social**, **Environment**, and **Landscape** areas are excluded, and
7. **All Exclusions** for renewable energy development and no new hydropower.

The study estimates that under the base case (no socio-environmental restrictions applied) the potential renewable capacity across the SAPP countries consists of 45TW of solar, 4.5TW of onshore wind and 45 GW of hydro. Figure **6** shows the impact of applying these seven scenarios on the total potential solar, onshore wind and hydro capacity, as a percentage of the base scenario.

Figure 6: Renewable resource potential capacities under different environmental and social constraint scenarios (based on **(Wu, et al., 2022)**)



Using GridPath to develop least-cost electricity pathways for Southern Africa out to 2040, the study found that without socio-environmental siting restrictions, about 50% of new generation capacity by 2040 will come from wind and solar. Figure **7**a shows the impact of increasing levels of environmental and social protections on the required installed capacities of different technologies. Generally, as protections increase across the seven scenarios, more solar, battery, and gas capacity is required, while building less hydropower.

Figure 7: (a) New generation capacity installations from 2020-2040 for the Base scenario without a carbon target and differences in installed capacities in 2040 for each scenario compared to Base. (b) Same as (a) but with a low carbon emissions target trajectory that limits annual carbon emissions in 2040 to half of the Base scenario without a carbon target. Positive differences indicate greater installed capacity and negative differences indicate lower installed capacities compared to the Base scenarios **(Wu, et al., 2022, p. 8)**

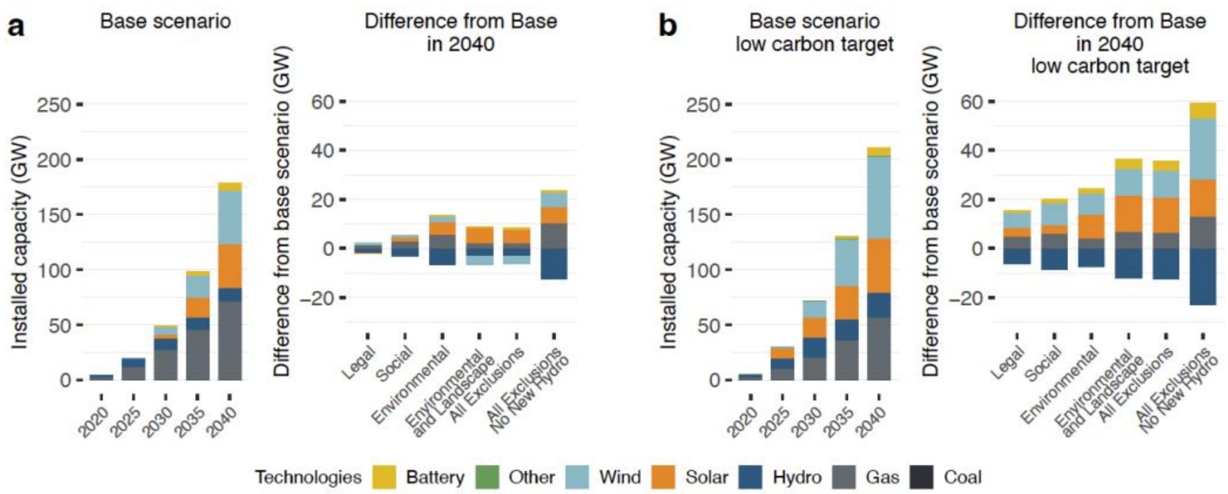


Figure 7b shows how applying a low carbon target alters the way that socio-environmental protections impact the energy portfolio. Without any additional protections in place (Base scenario), about 50 GW of additional wind, solar, and hydropower capacity (compared to the Base scenario without a carbon target) is needed to achieve a 50% reduction in carbon emissions by 2040, to fill the gap left by reduced fossil fuel generation and capacity. Achieving an increasingly high level of socio-environmental protections and a low carbon target requires a growth of largely wind (+14%), solar (+29%), and battery (+53%) capacity, and a reduction of hydropower capacity (-54%).

Marginal electricity system costs increase in response to more socio-environmental protections. However, the increases are modest, with system costs increasing by less than 1% for the **Legal** scenario, 2.5% for the **Environmental** scenario, and 5.6% for the **All-Exclusions** scenario. When combined with a low carbon target, which avoids 100 million tonnes of annual CO_2 emissions by 2040, these costs increase the **Base** scenario costs by 6%. Pursuing a low carbon target (50% emissions reduction by 2040 compared to 2020 levels) and all socio-environmental protections increases costs by 13% compared to the **Base** scenario with no carbon target. Further, cost impacts vary across the countries within the region depending upon which hydropower and renewable energy projects are excluded from consideration.

Discussion

The following key lessons emerge from the EEG-funded studies on the potential for regional power trade in South Asia and Southern Africa:

- **Regional trade in electricity has the potential to significantly reduce system costs** through exploiting regional resources (or inter-regional resources) optimally rather than relying on limited set of resources in each country. If solar and wind technologies continue to fall in cost at a relatively high rate, the BBIN region of South Asia could save between 227 and 312 billion USD on total discounted systems costs between 2015 – 2050, at 2015 prices. Increased inter-regional transmission capacity and significantly greater electricity trade compared to the present was also found to be critical for future cost-optimal and low-carbon power system operations in Southern Africa.

- **Coal is not cost competitive in the two regions across all scenarios examined where cross border trade is allowed.** The one exception to this was one modelling scenario in South Asia where it was assumed there is no further fall in the cost of renewables (a scenario unlikely to occur in practice).
- **Failure to trade regionally could mean fossil fuels (coal in particular) remaining cost-effective for individual countries with little access to renewables** (Bangladesh and some countries in Southern Africa). There is a significant danger here of countries' investments turning into stranded assets before the end of their life if global carbon regulations and prices tighten.
- **Bi-directional trade between India and Gulf countries can reduce costs and emissions across a range of scenarios and increase energy security** by exploiting different time zones and varying time of peak demand. An interconnector between the regions is part of the least-cost 'optimal' power system in most scenarios.
- **Increased regional transmission capacity reduces the annual CO_2 emissions by making renewables more widely accessible**. In both the South Asia and Southern Africa studies this was the case for all modelling scenarios except for the one assuming static costs[5].
- **Not all renewables make economic sense, and planning at a regional level is essential if cost benefits are to be realised** – for example, almost half of hydro planned in Southern Africa does not make economic sense under any scenario.
- **Biodiversity and social goals can be factored into regional planning** and, as the Southern Africa example shows, do not necessarily have huge impacts on final costs.
- **Significant investment will be required not just in generation but also in strengthening cross border connections**. In South Asia trade could potentially shift from 13TWh in 2019 to as high as 986TWh by 2050 (or even 416 TWh if countries put in place political economy restrictions to import no more that 20% of their power demand). In Southern Africa meanwhile trade needs to increase by a factor of 5 to achieve cost-optimal and low-carbon power system operations in the region.

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[5] Meaning no further decline in the cost of wind, solar or storage costs in the case of South Asia and, additionally in the case of Southern Africa no change in costs of fossil fuels.

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About the synthesis paper authors

Saumya Vaish is a Consultant in the Energy, Resources and Growth team at Oxford Policy Management

Simon Trace is a Principal Consultant at Oxford Policy Management and was the Programme Director for the Applied Research Programme on Energy and Economic Growth.