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Opportunities for South and Southeast Asian Countries to Prosper in a Carbon-Constrained World

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1. Context

Economic developmental discourse in the 21st century compared to the previous century has become more complex, reflecting the plurality in goals of a prosperous human society (Sen 2006; Simangan et al. 2025) and causal entanglement among them (Rakowski et al. in press). While examining the state of the current climate system—a global common asset—if traced back to past cumulative emissions from the countries (Ritchie 2019), the connection between pursuing the singular goal of economic growth and emissions becomes clear. There is now a better scientific understanding of causal relations and feedback mechanisms between the economy, society, environment, and the climate system.

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This is leading to the call for a broader approach for action to address intra- and inter-generational equity, climate justice issues (IPCC 2023; Gadgil et al. 2022; Future Earth, The Earth League, and WCRP 2024; Schaeffer et al. 2025). The cumulative load of CO₂ emitted in the atmosphere is directly linked to global warming level. This direct relationship provides an estimate of the remaining carbon budget (Vuuren et al. 2024), which is the threshold amount of CO₂ that can be emitted beyond which global warming passes a temperature goal, e.g., 1.5°C or 2°C. Scientific assessment reports are showing the remaining carbon budget is shrinking (IPCC 2023) as national climate actions and pledges (UNEP 2024) are falling short of required targets. The science is clear that if accumulation of CO₂ emissions is rapidly reduced by human action such as mitigation to limit global warming, it can prevent multiple deeper and wider damaging impacts of climate change (Jackson et al. 2017; IPCC 2023). However, meeting the mitigation objectives will require human society to imagine, innovate, and invest in new economic development models, adaptation solutions, shift choices in development pathways, and move to energy sources that do not lead to additional carbon and other greenhouse gas emissions.

Despite century-long global economic growth, human society is still facing rising inequality (Chancel et al. 2021) not only in income, but also in capability, indebtedness, rising cost of living (Economist Intelligence Unit 2022), uncertainty around assets in the fossil fuel sector (Roy et al. 2018), and polycrisis (Lawrence et al. 2024). Tension between mitigation and how the newly developing economies will prosper is growing, and discourse is getting divided between whether development comes first or climate. Equity and justice-rooted literature (Kartha, Athanasiou et al. 2018; Kartha, Caney et al. 2018; Winkler et al. 2018) argue in favor of leaving sufficient room for economic development for less developed countries while addressing climate change.¹ Scientific evidence is building up around new opportunities for reconfiguring developmental goals and constraints to take due cognizance of multiple human needs and go beyond the use of a single metric of Gross Domestic Product (GDP) as a measure of economic prosperity in human society (Johansson et al. 2012; Dasgupta et al. 2015; Cooley et al. 2022; Creutzig et al. 2022; Grubb et al. 2022) by incorporating multidimensional development indicators (Prados De La Escosura 2015).

¹ The South Asian region has contributed 4% and Southeast and Pacific region has contributed 8% of the historical (1850-2019) cumulative net anthropogenic CO₂ emissions compared to North America (23%), Europe (16%), and Eastern Asia that includes People's Republic of China (12%), respectively (IPCC 2023).

The Intergovernmental Panel on Climate Change (IPCC) reports that to stay on a path toward fulfilling the Paris Agreement, global per-capita GHG emissions level is required to be $\sim 5\text{tCO}_2\text{-eq}$ (Grubb et al. 2022). The South Asian region is still well below the required global per-capita GHG emissions level and has scope to improve HHID (Historical Index of Human Development) without exceeding the per-capita GHG emission threshold in the near future. In contrast, the Southeast Asian region, to some extent, and most high-income developed countries of today need to revisit their historical path of economic development, as these regions already exceed the $\sim 5\text{tCO}_2\text{-eq}$ limit needed for a safe corridor of sustainable development (Grubb et al. 2022).²

This chapter focuses on electrification options in South and Southeast Asia, focusing specifically on the lessons from four countries: Bangladesh, India, Pakistan, and Thailand. One of the policy-relevant messages of the Special Report on the Impacts of Global Warming of 1.5°C above pre-industrial levels (IPCC 2018) is that annual average investment in energy systems needs to be around \$2.4 trillion between 2016 and 2035. Subsequently, the IPCC 2022 report shows that given the current and planned infrastructure in the electricity sector in various regions, the maximum future emissions are expected to be from the Asian region (Dhakal et al. 2023). This makes power sector planning for the Asian region an important priority, where power sector decarbonization plans need to be in keeping with national economic growth targets and national decarbonization pledges in response to global decarbonization imperatives. Power sector infrastructure with a long operational lifetime, if strategically planned, can help lock the region in a new low-carbon economic pathway, synergistic with sustainable development dimensions.

Developing countries in the region who are planning to build most of their energy supply infrastructure in this decade based on their respective clean natural resource endowment can take the early mover's advantage in financial mobilization and market competitiveness of clean technologies. Simultaneously, they can provide choices in the end-use sectors selection from a large variety of granular technologies (e.g., e-bikes, smart thermostats, and efficient home appliances) for deployment (Creutzig et al. 2022; Sugiyama et al. 2024). Empirical

² Methodologically HHID (Prados De La Escosura 2015) is a better wellbeing measure over a long period of time and space as it corrects for biases in different starting points or achievement levels in the development of the countries in non-income variables of well-being (e.g., infant mortality, life expectancy at birth, literacy etc.) and considers quality improvements associated with increases in quantity.

studies show that granular energy technologies have lower investment risk, diffuse more quickly, are replicable, avoid lock-in, create equitable access, and generate more jobs.

2. Electrification: A New Mega Trend

Asian countries aspiring to achieve developed country status in the next two decades will need more energy (specifically electricity) for providing agency to achieve decent living standards for all as well as for addressing the industry sector's energy needs. But how much more? Official documents, forecasts, and plans come up with several numbers, which while varying from each other, provide a range of values to understand the countries' aspirations and expansion plans.

In this chapter, I discuss some concrete country-level examples of solutions for the energy sector problems and try to focus on both near- and long-term benefits as power sector infrastructure needs high upfront investment and has a long lifetime. While power sector expansion is going to be a megatrend in the region, this is accompanied by and complemented by (in many cases) fast penetration of digital systems across economic sectors through smart city/village programs, smart grids, smart metering distributed generation, and long distance grids including cross-border transmission of clean energy sources.

Accessible, secure, affordable, acceptable energy carriers (IPCC 2007) will continue to be of central importance over the coming decades for stabilizing economies on a higher economic growth trajectory with justice in transition, and for coping with major equitable human well-being needs. For the South and Southeast Asia regions, the majority of energy infrastructure will be built in the next 2-3 decades (Mahmud and Roy 2023). One significant opportunity is to invest in preparing plans and developing human capability within the region for advanced scientific tools and methods, thereby providing guidance for redirecting investment to accelerate the penetration of sustainable energy sources and enhance energy security.

2.1 What Can We Learn from National and Subnational Scale Model Results?

While global studies are useful for generating high-level policy-relevant messages, there is an urgent need to prepare regional and national action plans using equal scientific rigor for guiding context-specific recommendations and actions. State-of-the-art power sector capacity expansion models can be customized at the national or subnational

level to understand local developmental needs. These models can integrate high-resolution spatio-temporal input datasets to understand the resource potentials and include technology, costs, and barriers to design pathways compatible with national decarbonization pledges. The models can provide least-cost solutions, determine the optimal fuel source mix, investment and resource mobilization needs, job prospects, land requirements, and the emissions trajectory for alternative context-specific scenarios over time (Lugovoy et al. 2021; Chatterjee et al. 2024; Nahid and Roy 2025). It is extremely important to know not just the least-cost opportunities, but also the barriers (Mahmud and Roy 2021; 2023) that need to be resolved to implement sustainable decarbonized pathways.

2.1.1 Bangladesh

PyPSA-BD,³ an open-source model developed for Bangladesh (Nahid and Roy 2025) finds what is needed to achieve the national pledges and targets for 30% Renewable Energy (RE) by 2030, 40% by 2041, and full decarbonization by 2050. Techno-economically feasible and achievable solutions with available land without compromising GDP growth are a significant finding. RE expansion, dominated by solar and wind, can create an additional 6.67 million new jobs by 2050. Battery technology and hydrogen storage can ensure grid stability in the long run as RE penetration rises. Achieving these targets requires an annual investment of approximately \$9.06 billion from 2025 to transition to a decarbonized power sector in a phased manner, without adversely impacting the developmental process. This number can be juxtaposed on the global projected number of \$120 billion annual investment (IPCC 2018). Model results show that the pathway to achieve national pledges in a time-bound manner requires political will and strategies regarding financial mobilization strategy for international negotiations, and national institutional reforms for the expansion of RE at the projected rate. This can make Bangladesh's power sector secure by reducing risks of over-dependence on domestic gas supply, and help source diversification and use of Internet of Things (IoTs) for load management. Solar panels are

³ The PyPSA-BD model developed in AIT is a high-resolution, open-source energy system model adapted from the PyPSA-Earth framework and customized for Bangladesh. It integrates local inputs—including grid topology, generation assets, demand profiles, techno-economic parameters, and policy targets, sourced from national documents and open data platforms like OpenStreetMap. incorporates a spatial resolution of 30 km × 30 km solar and wind potential, hourly temporal electricity demand and dispatch. The model is for capacity expansion planning under specified renewable energy or emission targets. PyPSA-BD co-optimizes investments and operations.

a new form of energy infrastructure with a lifetime of several decades, so their spatial installation needs to be scientifically determined based on disaster maps for a country like Bangladesh. Climate mitigation discussion cannot be separated from the adaptation and development contexts and the need for triple-win solutions to support economic, social, and environmental progress in this century. Using depleted gas wells in Bangladesh, utilizing drilling technology skills and having the majority of the wells drilled onshore, expansion of geothermal energy is also a feasible solution for meeting cooling demand (Roy et al. 2020). In 2024, a new geothermal project was sanctioned in the country. To accelerate actions, international cooperation for access to appropriate technology and local human capability building for implementation is a primary need.

Bangladesh has an opportunity to manage electricity demand more effectively by focusing on demand-side solutions, creating efficient energy users, avoiding soaring energy bills, and reducing decarbonization pressure on the supply side. A simple example is to expand retail businesses and market LED bulbs as replacements for conventional tube lights or bulbs, thereby meeting the illumination needs in buildings. This enhances energy access by reducing the monthly energy bill and using fewer energy resources (e.g., 5-15 kW) to provide the same illumination service. An appliance-level-efficiency-led economic activity plan can cover fans, refrigeration, space conditioning, cars, buses, and endless home and commercial appliances, which are purchased every day in the marketplace, and create scope for economy-wide business opportunities through diffusion of granular technology that is easy to replicate.

Another aspect to consider is the cost of economic growth. Singapore, People's Republic of China, and India, could produce one unit of national GDP by paying for less than one unit of energy during their fast-economic growth phase (Roy et al. 2021). In contrast, Bangladesh needs to pay for more than one unit of energy for the same economic growth (Mahmud and Roy 2023). Therefore, Bangladesh is missing out on the more affordable economic growth path. Energy-efficiency programs in many countries and sectors have successfully reduced energy use per unit of economic output, employment, and led to net improvements in welfare, emission reductions, or both (Chakravarty and Roy 2016; Dasgupta and Roy 2017; Das and Roy 2020). There is plenty of room for improvement in many industries such as textile, steel, and so on. Progress in energy efficiency improvement in Bangladesh (Mahmud and Roy 2021) is severely undermined by a shortage of human resources for Research and Development (R&D), energy auditing, and energy management. There is a need for adequate skills for designing

nationally appropriate energy efficiency standards, implementation, monitoring, and energy audits.

Also, creating market incentives for energy-saving technologies and equipment is important. Appropriate scientific information can create a societal preference for investments in energy-efficiency projects, increase the return on limited capital invested, and encourage private investment. Informational limitation is a significant barrier to ensuring access to efficient, clean power at an affordable cost (Mahmud and Roy 2023). As an example, there is a lack of access to data in the public domain on widespread inefficiencies, resource potential, and site-specific ground-level data on solar irradiance, wind speed, and a well-developed wind map. These create barriers for least-cost expansion plans. Also, the lack of demand-side data like cultural characteristics, specific end-use service-wise demand, and the acceptability of new technologies creates a barrier for targeted actions. By making room for new institutional arrangements, involving local experts, manufacturers, businesses, and users, a sociopolitical environment to break the current inter-linked chain of barriers can be realized.

2.1.2 India

The IDEEA (Indian Zero Carbon Energy Pathways) model, developed through a regional capacity-building effort, considered 32 regions and tried to check if an ambitious solar and wind energy-based system installed in various locations can be imagined techno-economically for 100% renewable power system in India by mid-century (Lugovoy et al. 2021). High-resolution, 41-year weather data was used in the model. Results show complementarity of the resources on a spatial scale for India and the potential techno-economic feasibility and long-term reliability of a 100% renewable system. The system is designed to deliver annual energy demand that is five times higher than 2019 levels by mid-century.

The results provide insights on the need for strategic planning for expansion of energy storage technology, demand side flexibility (DSF) through digitally enabled and incentive-based shifts in demand between peak and off-peak hours within a day. DSF will need various granular IoT applications, pricing mechanisms, and supplier-consumer interface. On the supply side, spatially scattered seasonal wind energy potential will need long-distance grid expansion for balancing. Model results show that the integration of supply and Demand-side flexibility in India results in the lowest energy generation cost: 3–4 cents/kWh (≥ 5 cents/kWh average current energy generation cost), thereby ensuring future affordable energy access. This exercise gives hope, but needs more follow-up analytical exercises and stakeholder consultation

to arrive at an implementable solution, as it means shifts in infrastructure and technology choices compared to existing systems in place, and regional shifts in major generation centers.

Customization of the model (IDEAA-WB) at the subnational scale reveals that for a coal-rich region like West Bengal in India, with a medium-level solar potential, prudently integrating DSF strategies makes the coal phasedown by mid-century techno-economically feasible without compromising economic growth and energy needs. DSF with renewable energy supply integration helps avoid the premature retirement of existing thermal power plants and leads to a 13% increase in total investment flow.

Over the period from 1990–91 to 2012–13, India could achieve remarkable relative decoupling through the adoption of energy-efficiency measures across end-use sectors (Das and Roy 2020). The industrial sector was leading the process, initially to keep it competitive in the product market. Public policies, energy-efficiency enhancement through policy incentives in agriculture, industry, services, and power generation sectors came about in India as follow-up measures through the climate action plan of 2008. This policy push, incentive design, and appliance labeling by the Energy Star program of the Bureau of Energy Efficiency (BEE) helped India reduce energy use per unit of sectoral output production. Improved productivity of energy input led to a relative decoupling between economic activity growth and energy use, supplemented by structural changes through the rising share of the service sector in the gross domestic product. Results show that even by following the historical rate of energy efficiency improvements, India has the potential to exceed its Nationally Determined Contributions (NDC) without adversely impacting economic growth. If India can gradually phase out the share of coal in the energy mix, it can achieve absolute decoupling in the next two decades while maintaining GDP growth with low per capita emission growth.

2.1.3 Pakistan

Managing developmental goals through multidimensional low-emission transitions requires policy support to create an enabling environment for finance and businesses to take on new risks and opportunities across various countries in the region. One noteworthy example from Pakistan is from the period 1992–2022. The country planned an integrated economic development transition in cities over three decades to enhance the passenger mobility system, aiming to reduce the oil import bill, create new domestic business opportunities, foster entrepreneurship, promote infrastructure development, mobilize financial resources, and help reduce emissions using Compressed Natural Gas (CNG) vehicles.

It has created a very good learning for moving now to EV transition success, which is yet to be seen as it is in a nascent stage (Butt, Roy, and Some 2024).

The EV transition in Pakistan has the potential to enhance energy security by reducing dependence on fossil fuel imports. This also has a higher emission reduction potential, despite being fossil-fuel-based, due to the higher efficiency of the new technology. User acceptance initially targeted the 2- and 3-wheelers segments of the market, with local air pollution reduction benefits documented (Butt and Singh 2023). EV has made better headway in the 2-wheeler segment of the market also because that segment was not covered by the CNG transition. The latter targeted 4- and 3-wheeler segments.

A second example is from the agriculture sector's shift to electric pumps and the use of solar PV-generated electricity, which drastically reduced irrigation-related emissions during the 1990–2019 period. All these examples from Pakistan have a larger relevance in decision making in the region. India, Bangladesh, and Thailand all have EV policies and share similarities with Pakistan's vehicle markets regarding the share of 2-wheelers, CNG vehicles, and the use of irrigation pump sets.

2.1.4 Thailand

Thailand has adopted an interesting strategy to diversify energy sources by investing in cross-border power agreements. About half of all hydropower projects where Thailand invests in grid supply are in the neighboring country, Lao PDR, and many more are in the pipeline. Long-term arrangements by the Electricity Generating Authority of Thailand (EGAT) with Lao PDR for hydroelectric power are already in place. Eight power plants in Lao PDR with a combined power generation capacity of 5,420 MW are committed to exporting electricity to EGAT. The Open-source Switch-TH model⁴ for Thailand shows coal phase-out is technoeconomically feasible for Thailand within 2040, with diversification of energy sources by biomass, hydro, solar, and wind energy with battery storage, but gas will continue for one more decade (Barua 2024).

⁴ SWITCH-TH Model (Solar, Wind, Integrated with Transmission and Conventional sources and Hydroelectricity Model) developed in AIT is an open-source power system capacity expansion planning model. User interface provides flexibility for customization of the model. For cases with high renewable energy penetration helps in finding least cost solutions for decarbonization strategies while optimizing multiple period investment decisions in electricity generation, storage, and transmission, and demand response.

3. Conclusion

Research in various country contexts in the region clearly shows economic growth and emission reduction can be complementary. The fast-growing South- and Southeast- Asian countries can accelerate their economic development while contributing to mitigation, sustainable development, and adaptation needs. What is needed is appropriate prioritization of developmental goals and actions in a systemic way rather than through a piecemeal ad hoc approach.

Simultaneous realization of income growth and human well-being requires shifts in the choices of energy carriers, infrastructure design, and policy redirection to foster a low-carbon growth trajectory by avoiding the accumulation of stranded assets. National model building and use of national data sources clearly shows that even with carbon constraints, new investment opportunities in new sectors exist. They can deliver acceptable, affordable, and accessible energy service provision systems. Such scientific evidence building and communication for deliberation on a possible new development trajectory among various social actors is necessary to create a socio-political mobilization process for change. Financial mobilization, technology cooperation and new business models, new infrastructure planning, retraining, and reskilling of human capacity and policy design can be accelerated through international cooperation and multilateral funding agencies.

Regional dialogue, exchange of success stories in the near term, and action-oriented capacity building for contextualizing, replicating, and scaling need to complement the evidence-building efforts. In the very near term, demand-side solutions through granular technology diffusion can be a starting point through policy and market incentives, institution-building through regional cooperation, sometimes through South–South cooperation. Questions may arise: Why do various vision documents continue to omit an energy-efficient growth path and demand-side solutions? Ever-increasing production and consumption-led growth models obscure attention to justice through enhanced resource use efficiency and advancement of basic human needs, decentralization of businesses through more distributed production systems around granular technologies that empower consumers to make the right choices, and new business development models around service provision. It is important to keep in mind that the conventional supply-oriented planning for energy systems that ruled for several decades has created vested interest groups who have more power in any political economy and help create strategies and structural barriers for new business models and new players in the market, and influence decisions. It is important to identify the vested interest-led political economy that

might drive the accumulation of stranded assets in the region in the near to medium term and create new opportunities for the incumbents.

In the pursuit of low-carbon growth, the immediate adaptation funding gap need not be overlooked. Regional banks can support shared sustainable projects across borders, energy trade, innovative energy technologies to enhance social acceptance, help in policy development at a national scale through support for institution building like the Bureau of Energy Efficiency in India.

Energy projects that prioritize community benefits, database creation, scientific model building, technical training programs, reskilling, and upskilling by working with the vast technical institutes and university systems for policy implementation can be prioritized for funding systemic shifts.

Asian Development Bank's Energy Transition Mechanism (ETM) in Southeast Asia, aiming to accelerate the early retirement of coal-fired power plants while channeling investments into renewables and energy efficiency, fits well into the needs of the region as reflected in the model results at the national scale. Countries can frame social protection for workers affected by coal plant closures and other sector level transitions.

There has been an attempt over the past 1–2 decades within the countries in the region, like India, People's Republic of China, and Singapore, to create cap and trade mechanisms or voluntary carbon markets. It is the right time to explore whether harmonization can be attempted and whether it would aid regional economic growth. There is a huge opportunity on the supply side as well to build low-carbon energy infrastructure for low- and middle-income countries to create new path dependency to achieve high-income-wellbeing status through the least-cost solution trajectory in the long term.

To achieve net-zero globally would mean shifting employment from high- to low-carbon sectors, globally and even locally in carbon-intensive regions, as the latter reduces the economic cost to society, starting from the near term through the long term, by avoiding carbon lock-in, with a huge risk of stranded asset creation. Regional cooperation, new business, and new infrastructure are the way forward. The literature is clear that energy justice needs distributive justice of energy use to enhance well-being for all (Saunders et al. 2021). Daly's operational principles (Hanley, Shogren, and White 1997) talk about investing the income earned from exhaustible resources to develop service flow from renewable resources, reducing cumulative pollutants to zero, and reducing inefficiency in energy and materials' use to operationalize sustainable development. These can guide principles for development models for the 21st century.

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