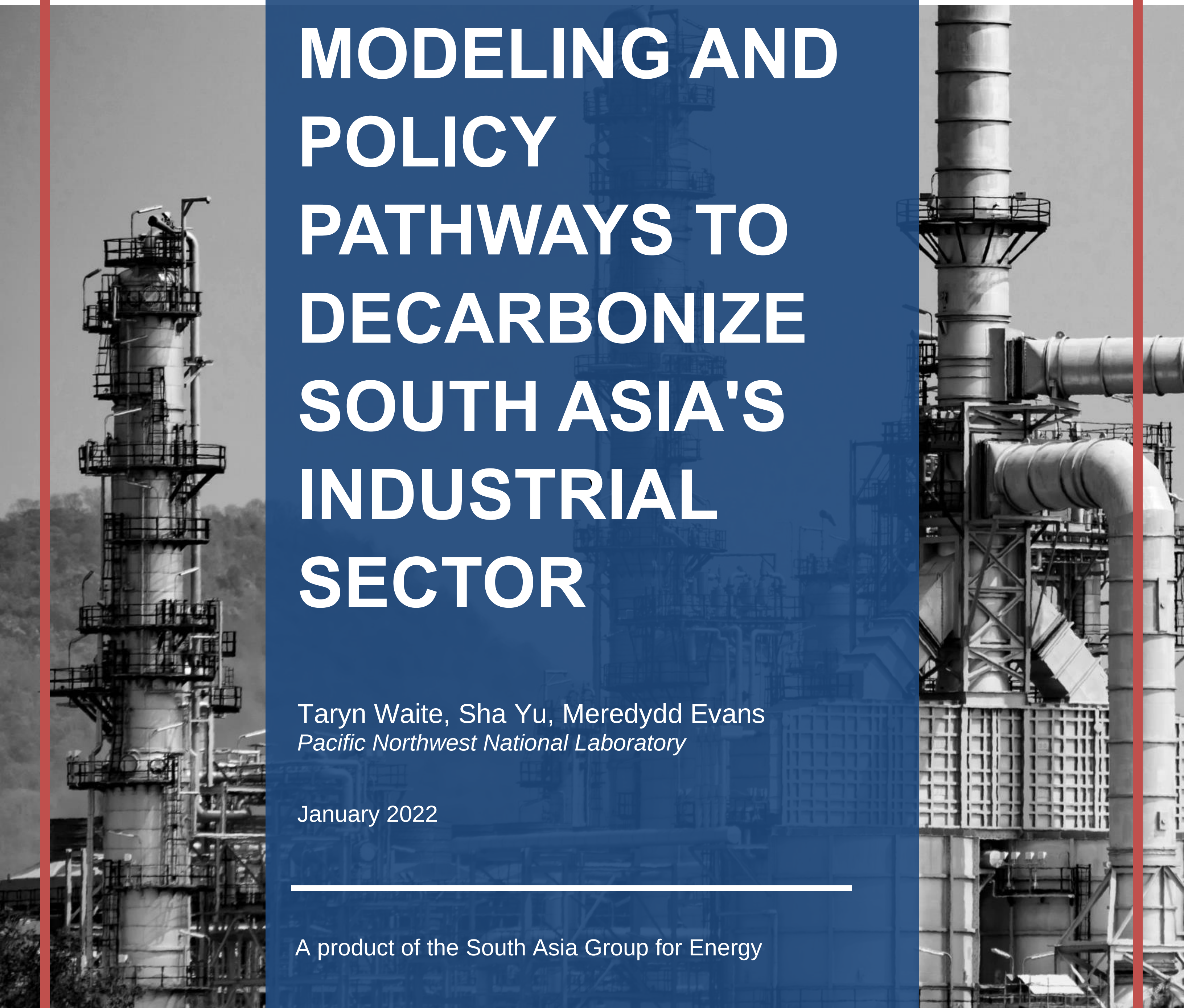

MODELING AND POLICY PATHWAYS TO DECARBONIZE SOUTH ASIA'S INDUSTRIAL SECTOR

Taryn Waite, Sha Yu, Meredydd Evans
Pacific Northwest National Laboratory

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Acronyms and Abbreviations

CCUS	carbon capture, use, and storage
EE&C	Energy Efficiency and Conservation
GCAM	Global Change Analysis Model
GDP	gross domestic product
LEED	Leadership in Energy and Environmental Design
PAT	Perform, Achieve, Trade program
RMG	ready-made garment
TERI	The Energy and Resources Institute

Contents

Figures

1.0 Introduction

The industrial sector is responsible for one-third of global greenhouse gas emissions, and industrial decarbonization will be an essential component of limiting emissions and mitigating climate change (Rissman et al., 2020). This holds true for South Asian countries as they work toward their stated commitments to reducing emissions in the coming years. India has pledged to reduce the emissions intensity of its gross domestic product (GDP) by 33–35% by 2030 (Government of India, 2016) and announced at COP26 a target of reaching net-zero CO_2 emissions by 2070, a goal that will require rapid decarbonization of energy-intensive industries (WEF, 2021). Bangladesh's Nationally Determined Contributions include a commitment to reducing greenhouse gas emissions by 6.73% to 15.12% by 2030 (Ministry of Environment, Forest and Climate Change, 2021). While these Nationally Determined Contributions do not explicitly target emissions reductions in industry, Bangladesh's Energy Efficiency and Conservation (EE&C) Master Plan highlights industry as an important sector for EE&C (Sustainable and Renewable Energy Development Authority, 2015). Sri Lanka has pledged carbon neutrality by 2050, including a reduction in industrial greenhouse gas emissions (Ministry of Environment, 2021). Nepal's commitment to net-zero greenhouse gas emissions by 2050 includes plans to establish guidelines and technology transitions facilitating industrial decarbonization (Government of Nepal, 2020).

While industrial decarbonization will be essential to achieving greenhouse gas mitigation goals in South Asia, the region faces several challenges to achieving emissions reductions in this sector. Compared to other sectors, industry is particularly difficult to decarbonize due to the sector's heterogeneity and reliance on processes with high emissions intensity. Other challenges include the long lifetime of existing industrial facilities, the high capital costs of mitigation strategies, and the lack of sufficient technology and infrastructure development needed to decarbonize (Fischedick et al., 2014). Additionally, knowledge and planning for decarbonization in industry lags behind that of other industries (Loftus et al., 2015). Thus, more research is required to determine the efficacy and feasibility of industrial decarbonization in South Asia.

South Asian countries' industrial sectors are heterogeneous and rapidly evolving. India is a major producer of iron and steel. Bangladesh's major industries include textiles, ready-made garments (RMGs), and non-metallic mineral products (Moazzem & Halim, 2019). Industry in Sri Lanka is dominated by domestic-oriented food processing, while textiles and RMGs make up the largest export-oriented industry (Subramaniam, 2019). Although there are no leading industries in Nepal yet, the country expects rapid industrial growth in coming decades (Khanal & Pandey, 2019). Industrialization is a major component of economic growth for South Asia. In 2019, industry accounted for 30% of India's GDP (IEA, 2021a) and 27.4% of Sri Lanka's GDP (Dissanayaka et al., 2021).

Industrial energy consumption has been growing rapidly in South Asia in the past three decades. India has seen a more than fourfold increase in final industrial energy consumption since 1990. In 2019, industry accounted for 38.5% of India's total final energy consumption, more than any other sector. Bangladesh's industrial sector exhibited massive growth, consuming over 11 times more energy in 2019 than in 1990. Nepal has similarly seen a tenfold increase in industrial energy consumption since 1990 (IEA, 2021b). As countries continue their economic growth and industrialization, industrial energy demand and emissions are expected to continue rising.

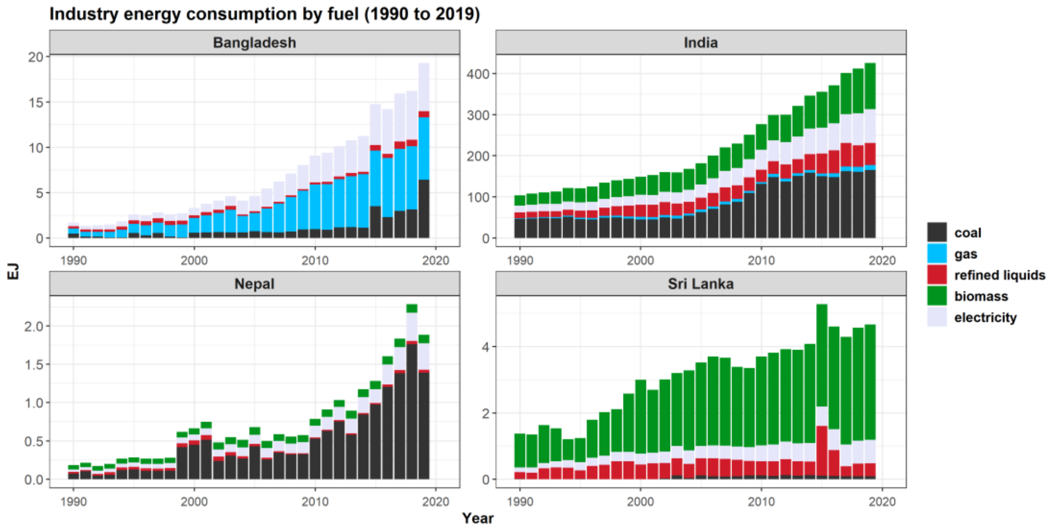

Figure 1. Industry energy consumption in South Asian countries. Data exhibited here are derived from the 2019 IEA Energy Balances, which do not include industrial energy data for Bhutan and Maldives. Source: IEA, 2021a.

South Asian countries vary in their shares of fuel types used in the industrial sector (Figure 1). India's primary fuel sources for industry are coal—which accounts for 39% of industrial energy use—and biofuels and waste, which accounts for 26%. In Bangladesh, coal, natural gas, and electricity meet a majority of industrial fuel demand. Nepal is dependent on coal for industrial energy, while Sri Lanka relies on biofuels and waste (IEA, 2021b). The countries with the highest shares of coal in industrial energy consumption also exhibit the highest carbon intensity of industrial energy consumption. In 2019, Nepal emitted 71.2 gCO_2 per MJ of energy consumed in the industrial sector, while Sri Lanka only emitted 7.8 gCO_2/MJ. India and Bangladesh emitted 56.4 gCO_2/MJ and 54.1 gCO_2/MJ, respectively (IEA, 2020).

2.0 Future Trajectories of Industrial Growth and Transition

The increasing trend in industrial energy consumption is expected to persist in South Asia throughout the coming decades as industry continues to grow. Without policy changes, India's industrial energy consumption will double by 2040, reaching a 41% share of total energy consumption. Industry will also overtake power generation as the primary driver of coal demand growth and account for the majority of CO_2 emissions by 2040 (IEA, 2021). In Bangladesh, industry will be the fastest-growing sector in terms of energy consumption through 2050, advancing the transition of the country's energy consumption profile from household dominated to industry dominated (Sieed et al., 2020a; Sieed et al., 2020b).

One challenge for South Asian countries is maintaining growth and industrialization while decarbonizing the sector per emission reduction commitments. Modeling approaches can be used to establish and assess pathways to industrial decarbonization. Pacific Northwest National Laboratory's Global Change Analysis Model (GCAM) uses an integrated quantitative approach to represent interactions between climate, water, energy, land, and socioeconomic systems globally. GCAM can be used to assess the projected impacts of development trajectories, policies, and technologies across sectors. The model contains a detailed representation of the industrial sector, accounting for a range of technologies and energy inputs used within various industries. This disaggregated approach allows GCAM to capture the complexities of a range of industrial processes and analyze specific industrial emissions mitigation pathways in line with national and global decarbonization goals (Box 1).

Box 1. Pathways to decarbonize the iron and steel sector in India

India is the world's second largest steel producer, although it accounted for only 5% of global steel production in 2020, given the scale of Chinese production (WSA, 2021). With the country's rapid urbanization and infrastructure development, steel demand is expected to continue rising. The Government of India has set targets of increasing the country's steel production capacity to 300 Mt by 2030–31 (Ministry of Steel, 2017). Studies estimate that India's steel production will increase from 94 Mt in 2020 to around 540 Mt in 2050 if no further material efficiency measures are taken (Hall et al., 2020a; Henbest et al., 2021; Yu et al., 2021). Rapid demand growth has significant implications for steel sector emissions. Without policy changes, CO_2 emissions from India's steel sector are expected to triple in the next three decades, from 240 $MtCO_2$ in 2020 to 840 $MtCO_2$ by 2050 (Hall et al., 2020a; Yu et al., 2021).

The Government of India has not yet set a specific target for reducing steel sector emissions; however, recent policy targets and private sector commitments establish momentum to decarbonize the steel sector. At COP26, India announced a target of reaching net-zero CO_2 emissions by 2070, which requires mitigation actions from all sectors. India also endorsed the Glasgow Breakthrough on Steel, signaling an interest in transitioning toward near-zero-emissions steel. Meanwhile, two major steel companies, Tata Steel and JSW Steel, have adopted internal carbon pricing and set emissions reduction targets (Sharma et al., 2021).

Understanding plausible pathways for decarbonizing the steel sector would help achieve these pledges and put India into a leading position in the global steel sector transition. It is important to examine these pathways in an integrated framework because this steel sector transition would have implications for upstream and downstream sectors, such as power generation and hydrogen production. GCAM is thus a well-placed tool for assessing steel decarbonization pathways because it provides an integrated approach. Using GCAM, Pacific Northwest National Laboratory researchers find that in a future with 1.5 °C warming, India's steel sector emissions must fall by 45% by 2030 and 90% by 2050 compared to the reference scenario (Yu et al., 2021). Much of this reduction will come from improving energy and material efficiency as well as shifting toward production processes that involve high scrap use. Additionally, fuel consumption in the steel sector will move from conventional coal to cleaner fuels, such as electricity, hydrogen, and coal with carbon capture, utilization, and sequestration (Figure 2). This will also require changes upstream, particularly through increasing demand for green hydrogen and clean electricity.

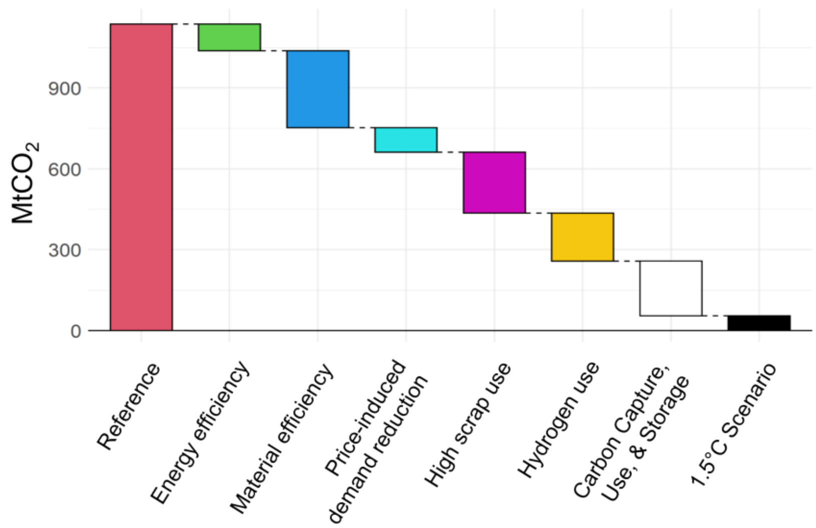

Figure 2. Contributions of different mitigation measures to steel emissions reduction in India. Source: Yu et al., 2021.

Material efficiency, the largest contributor to emissions mitigation in this scenario, encompasses both demand and supply-side measures. Steel demand can be reduced through lifetime extension, design optimization, and post-use recycling in buildings. Demand in the transportation sector can also be reduced by lightweighting vehicles. In all end-use sectors, the use of high-strength steel will increase the lifetime of end products and further reduce demand. Supply-side material efficiency will encompass measures to increase manufacturing yields. Implementing the necessary aggressive material efficiency measures will present challenges for India because the demand-side components require collaboration beyond the steel supply chain.

3.0 Policy Recommendations for Industry Decarbonization

South Asian countries' industrial sectors are heterogeneous and require sector- and country-specific decarbonization strategies. There have been few studies on industrial decarbonization in South Asia, and most of these address specific industrial sub-sectors without looking at the sector more holistically. See Box 1 for an example of sub-sector-specific analysis. The industrial sector will play an important role in meeting national decarbonization goals, but a better understanding of specific pathways is needed. Road maps for individual sectors will incorporate a range of mitigation strategies, including energy and material efficiency, electrification, alternative fuels, and carbon capture.

Energy efficiency measures vary between industries and may include updating existing equipment as well as installing new equipment such as waste heat recovery systems (Box 2). If energy efficiency improvements are to be economically feasible, policy support is critical. In India, the Perform, Achieve, Trade (PAT) program has reduced industrial energy consumption through a market-based approach to incentivize efficiency. Energy-intensive industries are given mandated targets for energy consumption reduction and receive Energy Savings Certificates (ESCerts) for excess energy savings, which they can then sell to underperforming industries. From 2012 to 2015, PAT resulted in energy savings of 5.3% across the industrial sector and a 31-million-ton CO_2 reduction in emissions (Damm et al., 2018). Along with these market-based approaches, other policies may be needed to incentivize energy efficiency transitions, including carbon prices and CO_2 emissions caps.

Box 2. Energy efficiency in Bangladesh's textile industry

The textile and RMG industry is an integral part of Bangladesh's economy, accounting for 84% of the country's exports and employing 4.4 million workers (Rasel et al., 2020). The world's second-highest exporter of RMGs, Bangladesh is a significant contributor to the global textile market (Bhogal & Govind, 2021). However, the textile industry is energy intensive, accounting for 27.8% of the country's energy consumption (Sustainable and Renewable Energy Development Authority, 2015) and thus contributing substantially to CO_2 emissions. Energy efficiency measures will be an important component of decarbonizing Bangladesh's textile and RMG industry. Bangladesh's 2018 EE&C Master Plan highlights the potential for these measures. Proposed EE&C strategies, which include adoption of high-efficiency sewing and weaving machines and stenters, expansion of LED lighting, and use of waste heat recovery, could reduce energy use in the textile and RMG industry by 31% (Sustainable and Renewable Energy Development Authority, 2015).

The Partnership for Cleaner Textile program, led by the International Finance Corporation, works with Bangladeshi textile factories to support the adoption of water- and energy-efficient technologies. To date, the partnership works with 338 factories and is estimated to save a combined 558,391 tons of carbon emissions (Partnership for Cleaner Textile, 2021). Another growing initiative for Bangladeshi textile factories is participation in the Leadership in Energy and Environmental Design (LEED) rating system. As of 2018, about 67 factories were LEED certified and implementing varying levels of renewable energy use, energy and water efficiency, and other environmental considerations, while 280 were in the process of gaining certification (Selim, 2018). However, this engagement only accounts for a small fraction of Bangladesh's textile industry, which is estimated to include up to 7,000 factories. According to a survey of textile mill managers, current barriers to more widespread energy efficiency implementation include inadequate financial resources and limited access to research, development, and technical experts (Hasan et al., 2019).

Technology highlight: Waste heat recovery

Several technologies are available to generate energy from waste heat, including generator, boiler, and oven exhaust as well as heated wastewater (Rakib et al., 2017). Waste heat recovery from generators alone is feasible for over 1,500 Bangladeshi textile factories and could save a combined 10,320 TJ of energy and 710,920 TCO_2e of greenhouse gas emissions annually (USAID, 2020). One factory that implemented waste heat recovery in 2014 was able to cut their emissions by 14% while achieving initial investment payback in only 10 months due to decreased energy costs (Partnership for Cleaner Textile, 2019).

Material efficiency and scrap use will be another essential component of industrial decarbonization, especially in hard-to-abate sectors such as steel. Material intensity has declined considerably over the past four decades in India and Bangladesh (by 57.4% and 41.7%, respectively); however, industry in these countries is still much more material intensive than in countries with more established industrial sectors such as China, Japan, and the United states (Shah et al., 2020; Pappas & Chalvatzis, 2017). Circular economy approaches in industry, including recycling and reusing materials as well as reducing material demand through innovation, are key to economically feasible decarbonization (Energy Transitions Commission, 2018). Additionally, the use of alternative materials and processes in place of more energy- and carbon-intensive traditional methods can reduce CO_2 emissions in some industries. For example, Limestone Calcined Clay Cement, which emits 40% less CO_2 in production than traditional cement and yields comparable performance, has been produced in Indian cement plants without modification of current production technology (Emmanuel et al., 2016).

A direct way to decarbonize industries is to cease the use of fossil fuels through electrification coupled with renewable energy generation. Challenges to widespread electrification include high operating and capital costs, lack of supporting policy, lack of technology and engineering knowledge, heterogeneity of industrial sectors, and intermittency of renewable energy sources (Wei et al., 2019). However, there is high potential for electrification of certain Micro, Small and Medium Enterprises in India (Pal & Hall, 2021). Capacity for electrification will vary regionally depending on available renewable energy resources. In Nepal, rural electrification via micro-hydro mini-grids has contributed to growth in the manufacturing sector and broader socioeconomic development (Meeks et al., 2021).

For industries in which direct electrification is infeasible, green hydrogen may be an effective low-carbon fuel alternative. Green hydrogen, produced using renewable electricity and electrolysis, could meet a majority of India's growing hydrogen demand and outcompete fossil fuels in the steel, ammonium, and refineries sectors by 2050 as long as there is adequate policy support for technology development (Hall et al., 2020b). In South Asian countries with high hydropower potential, including Nepal, excess energy generated from hydropower during the wet season could be converted to hydrogen as a strategy for energy storage as well as end-use sector decarbonization (Zhou et al., 2020; Mali et al., 2021). This potential could provide a promising low-carbon fuel source as industrial energy consumption continues to grow.

Carbon capture, use, and storage (CCUS) has been identified as an essential component in industry decarbonization globally, particularly for energy-intensive and hard-to-abate industries. India is still in the initial stage of developing this technology but may have large potential for economically feasible CCUS in the industrial sector. For instance, carbon capture in the fertilizer industry is possible with only a 3-4% increase in selling price (Vishal et al., 2021). There is also significant potential for carbon capture use as an input in some industries, including methanol

(Vishal et al., 2021). Research and development of CCUS in other South Asian countries is needed as their industrial sectors grow. For example, carbon capture from cement production and subsequent use in urea manufacturing could be a low-carbon and economically feasible way for Nepal to establish their domestic fertilizer industry (Devkota et al., 2021).

Feasible decarbonization pathways for individual countries and industries will depend on political, socioeconomic, and technological factors. Adequate policy support for the emissions reduction strategies described above will be crucial to their economic feasibility and long-term success. Global market dynamics and technology availability will also need to be considered, and stakeholders must acknowledge the upstream and downstream implications of possible pathways. For example, shifting technologies will affect demand for different fuel sources and prices of end products. Additionally, as South Asian countries continue to experience rapid industrial growth, decarbonization must incorporate policies for a just transition. These policies may include maintaining employment growth, protecting the wellbeing of workers, and supporting communities affected by industrial activities (Rosemberg, n.d.). Integrated modeling approaches will be key to understanding and assessing the holistic impacts of country- and sector-specific industrial decarbonization strategies.

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