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Greening Asia's Economic Development

Paul BURKE
(Australian National University, Australia)

Thang N. DO
(Australian National University, Australia)

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Greening Asia's Economic Development

Paul J. Burke and Thang Nam Do
Australian National University

6 March 2020

Draft – comments welcome

Asia is facing serious environmental challenges including urban air pollution and global climate change. As the largest emitter of greenhouse gases, what happens in Asia will play a crucial role in determining the extent to which the world warms over coming decades. This paper will review key environmental challenges faced by the region and the growing opportunities for a transition to a cleaner economy powered by zero-emission energy sources. Economic mechanisms – including emissions pricing, reverse auctions, and renewable portfolio standards with green certificate schemes – have the potential to underpin a much greener development model for the Asian Century.

Key words: energy, carbon pricing, market-based instruments, renewables, pollution

JEL codes: N15, Q43, Q52, Q53, Q54, Q56

Correspondence: Paul J. Burke, Arndt-Corden Department of Economics, Australian National University, Crawford Building 132, Lennox Crossing, Acton ACT 2601, Australia. Email: paul.j.burke@anu.edu.au.

1. Introduction

Asia is central to many of the world's environmental challenges. As the largest source of greenhouse gas emissions (Climate Watch, 2020) and due to its rapid economic growth, Asia is the world's most important region for efforts to stop climate change. Without a substantial reorientation of Asia's development trajectory there is a high likelihood that global warming will exceed 2^{o} Celsius. Asia itself would experience serious consequences, including a higher incidence of hot days and threats to low-lying coastal cities from rising sea levels. From Delhi's smog to Indonesia's forest fires, local and regional environmental issues also abound, bringing large costs to human health and the economy.

Fortunately, rapid improvements in clean energy technologies have opened many new possibilities. Solar and wind have become cost-competitive with conventional power generation sources in many settings (Lazard, 2019), and are now contributing the majority of new installations of electricity generation capacity globally (Blakers *et al.*, 2019). Further cost reductions are expected as the technologies continue to mature. Energy storage and grid management technologies such as lithium-ion batteries are also becoming cheaper and better. Electric vehicles have become central to car manufacturers' production plans. The chance thus exists for a transition of Asia's energy system towards one that is increasingly reliant on zero-emission technologies. Such a transition would involve sizeable economic opportunities.

Economic policy mechanisms have a key role to play in facilitating the switch to cleaner energy. Carbon pricing is being applied in a growing number of countries worldwide, although only a minority of countries in Asia. There has been some recent momentum, with for example Singapore introducing a carbon tax in 2019. Asian countries have also pursued approaches such as reverse auction mechanisms for clean energy and green certificate schemes. These approaches have the potential to be used in increasingly scaled-up ways.

A rapid transition to low-emission technologies will rely crucially on cross-border trade. Solar and wind energy generation, as well as complementary technologies such as batteries and electric vehicles, are technology- and capital-intensive and rely on sophisticated international supply chains. Openness to imports is vital for rapid adoption. Improvements in high-voltage direct current (HVDC) cables have also broadened the opportunities for cross-border electricity trade, for example sales of electricity from sunny and windy locations to demand centers on the other side of an international border. Yet trade barriers and regulatory restrictions, often motivated by a desire to boost energy self-sufficiency, are slowing the pursuit of these opportunities. There is substantial scope for improving cross-border trade opportunities in order to speed the process of regional decarbonization.

This paper will review the opportunities and challenges for a greening of Asia's economic development, with a focus on the energy sector. Section 2 will review Asia's environmental challenges, and Section 3 the improving technological opportunities to reduce emissions. Economic implications of these opportunities are discussed in section 4, and the future of fossil fuels in section 5. Key economic policy mechanisms are reviewed in section 6. Section 7 discusses the importance of openness to international trade for the region's decarbonization. The final section concludes. The paper employs the United Nations' definition of Asia, which includes East, South, Central, and Western Asia.

2. Asia's environmental challenges

Addressing climate change is a massive global challenge. The world has already warmed by 1ºC and is on track to reach about 3ºC of warming by the end of the century in the absence of ambitious new mitigation efforts (Climate Action Tracker, 2020). The climate will only (eventually) settle at a new temperature equilibrium after the world reaches net-zero anthropogenic emissions of greenhouse gases. Decarbonization is thus at the forefront of the world's, and Asia's, environmental priorities.

In 2017 Asia accounted for 57% of the world's carbon dioxide (CO_2) emissions from fuel combustion (for uses other than international aviation and shipping). This was up from only 29% in 1990 (International Energy Agency [IEA], 2019a). By far the largest emitter is China, the source of 29% of global emissions in 2017. India accounted for 7%. If currently-stated policies are implemented and continued, the IEA (2019b) foresees that India and China will together account for more than half of global growth in energy use over the period to 2040. If Asia's energy use trajectory remains emissions intensive, the world will be on track for a major disruption to the global climate.

Figure 1 uses the Kaya (1989) identity to investigate the underlying reasons for Asia's large emissions footprint. This identity specifies emissions as a multiplicative function of population size (P), gross domestic product per capita (G/P), the energy intensity of gross domestic product (E/G), and the carbon intensity of energy (C/E). The Figure expresses Asia's values for these variables as a ratio of the values for the rest of the world. As can be seen, Asia's GDP per capita remains relatively low. The reasons for Asia's large emissions *vis-à-vis* the rest of the world's are thus Asia's (a) large population, (b) highly carbon-intensive energy system, and (c) relatively energy-intense economy. Technologies and policy instruments are offering many opportunities to reduce the carbon intensity of energy use and the energy intensity of GDP in Asia and elsewhere.

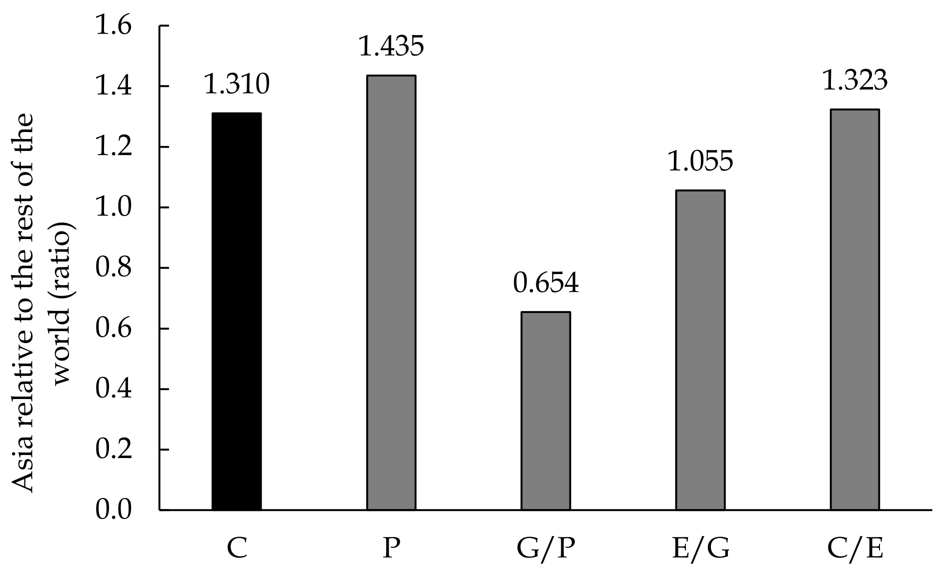

Figure 1 Kaya identity: Asia as a ratio of the rest of the world, 2017. C = CO_2 emissions from fuel combustion, P = population, G = gross domestic product, E = energy use. Energy use and emissions from international aviation and shipping are excluded, as the dataset does not allocate these emissions by country. 1.310 means that Asia's CO_2 emissions from fuel combustion were 31.0% larger than the rest of the world's. Note that 1.310 = 1.435 * 0.654 * 1.055 * 1.323, i.e. the identity balances in a multiplicative way. Source: IEA (2019a).

Asia is highly vulnerable to climate change. It has a large number of coastal cities threatened by rising sea levels, from Mumbai to Shanghai, with global sea levels currently rising at about 3 millimeters per year (NASA, 2020). Expected increases in the number of droughts and hot days will be detrimental to human health, productivity, agricultural yields, and food security. Climate change is also leading to a strengthening of storms, with significant implications for countries such as the Philippines and Vietnam. The melting of the Himalayan glaciers is threatening water supplies in India and Pakistan (Wester *et al.*, 2018), and ocean acidification and warming are affecting fish stocks and coral reefs. The economic implications of climate change for Asia are thus varied and large. The poor and near-poor are often particularly exposed given that they are less able to afford adaptation measures (Vinke *et al.*, 2017).

Local air pollution is also a serious environmental challenge. Bangladesh, Pakistan, and India are currently the world's worst-performing countries in terms of average exposure to ambient particulate matter 2.5 ($PM_{2.5}$) (AirVisual, 2019). Air pollution is also a worsening issue in rapidly-developing cities such as Hanoi and Jakarta. Fires in Indonesia contribute to major episodes of transboundary pollution. The effects of exposure to polluted air are serious: Greenstone and Fan (2018) estimate that average life expectancy would be about 4 years longer in Bangladesh and 3 years longer in China, for instance, if the World Health Organization guidelines on $PM_{2.5}$ were not exceeded.

Asia faces numerous other environmental challenges. Human activities are causing species extinctions and a contraction in animal headcounts, both on land and at sea (WWF, 2018). Deforestation has been continuing in countries such as Indonesia (Global Forest Watch, 2019). Water pollution blights many Asian rivers and inland water bodies, while oceans are being polluted by plastics and other substances. Soil pollution is compromising food supplies and human health in China and elsewhere (Rodríguez-Eugenio *et al.*, 2018). Overextraction of natural resources, from fish stocks to underground water supplies, is widespread, especially when resources are open-access in nature. In Jakarta, for instance, unpermitted groundwater extraction has contributed to parts of the city subsiding by several meters or more, exposing residents to worsening floods (Rahman *et al.*, 2018).

There are also Asian environmental success stories. Japan's urban air pollution has reduced substantially over recent decades. Beijing has also achieved a reduction in its notorious air pollution, although still experiences highly-polluted days. China and India have successfully reforested large areas of land. Indoor air pollution has reduced as a result of substantial progress toward universal access to modern energy forms such as electricity and liquefied petroleum gas (LPG). Countries such as Vietnam have implemented green growth strategies and a number of relevant policy mechanisms. Japan's CO_2 emissions from fuel combustion had fallen by 8% from their year-2013 peak by 2017 (IEA, 2019a), primarily due to reduced emissions from oil. However, the emissions of several other East-Asian high-income economies – South Korea, Taiwan, and Singapore – have continued to rise.

3. Technological opportunities

3.1 Solar and wind

A key route for achieving large-scale reductions in CO_2 emissions from the electricity sector is to reduce the carbon intensity of generation sources. In practice, this means switching from highly-emitting fuels – coal, oil, and natural gas – to low-emission options such as solar, wind, geothermal, and nuclear power. Adoption of zero-carbon energy technologies has been the main way that countries such as Sweden and Denmark have achieved large-scale emissions reductions (Burke, 2012).

Cost declines and technological improvements have meant that solar and wind are shaping up to become key pillars of the future global electricity system. Figure 2 shows the contributions of solar and wind to the electricity mixes of three large Asian countries: China, India, and Japan. The two technologies together contributed 6–8% of electricity generation in each of these countries by 2018, up from very low levels at the turn of the century. While this remains a minority contribution, the upward trends are expected to continue for years to come. Intermittent renewables have arrived as mainstream sources of electricity.

Most other Asian countries are further behind in the adoption of solar and wind. The two technologies contributed only 0.6% of Kazakhstan's electricity generation and 0.1% to Indonesia's in 2018, although geothermal and biomass contributed another 5% of Indonesia's electricity supply. There has been a recent solar photovoltaic (PV) installation boom in Vietnam, with more than 4 gigawatts (GW) of new PV capacity installed over the year to June 2019. Investments in utility-scale solar plants have also started to be seen in other lower-middle income countries such as Cambodia and Myanmar.

Globally, 7% of electricity generation was from solar and wind in 2018, up from 1% a decade earlier. Nuclear power contributed 10% to global electricity generation (BP, 2019), a share that has been declining due to safety concerns and the high cost and slow build times of nuclear power stations. In contrast, solar panels are quick and easy to install. The modular nature of solar PV also means that the technology is easily scalable; it can be installed at a micro scale or in an expansive solar array.

Global investment patterns suggest that the contribution of solar plus wind is almost certain to overtake the contribution of nuclear power in the next few years.

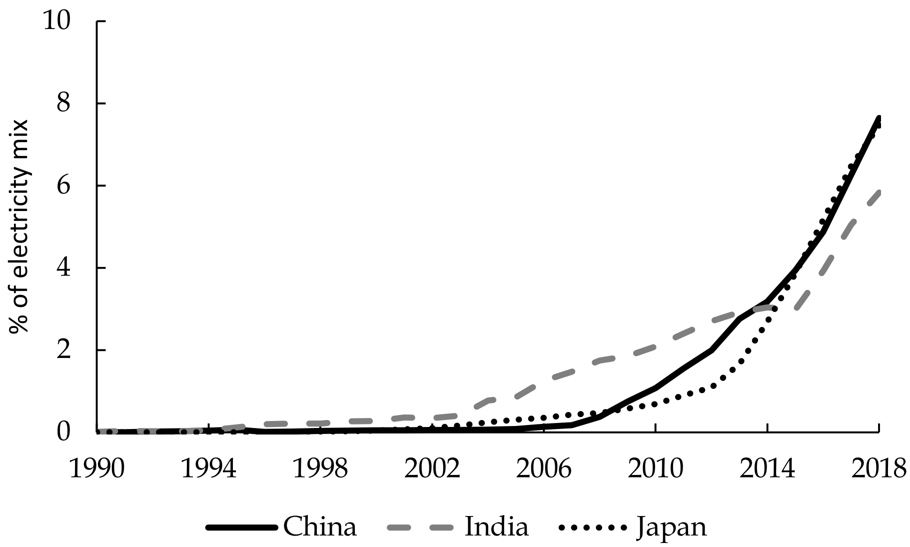

Figure 2 Solar plus wind share of the electricity mix. Source: BP (2019).

Most Asian countries have ambitious renewable energy targets. Pakistan aims to source 30% of its electricity from solar, wind, small hydro, and biomass by 2030, with another 30% from large-scale hydro. China is targeting a 35% renewable electricity share by 2030, Thailand a 25% share by 2037, and the United Arab Emirates a 50% clean energy share by 2050. India is aiming to have 450 GW of renewable generation capacity by 2030. And so on. Goals involving a fundamental pivot to renewables have thus swept the region.

All countries have solar and wind generation potential, although some are better endowed than others. China, Mongolia, and countries in Western and Central Asia have vast solar and wind resources, and Japan and South Korea have abundant opportunities in offshore wind. While northern countries experience winter lulls in solar insolation, wind speeds tend to be faster the further one travels from the equator. Equatorial countries have reasonable year-round solar conditions, although the solar potential of Indonesia is lower than it is for countries in the Mekong region, which contributes to generation costs being higher (Lee *et al.*, 2019). In addition to domestic opportunities, all Asian countries have opportunities to capitalize on offshore and international sites for renewables generation via the use of HVDC cable connections (Cheng *et al.*, 2019).

A major issue accompanying the rise of solar and wind energy is the need to manage the intermittent nature of these resources. There are important roles for energy storage and dispatchable generation. Use of batteries for storage and grid management purposes is increasing, and there are also other competing technologies. Currently the dominant form of energy storage is pumped hydro, which involves pumping water up an incline when power is cheap and then using the water to turn hydro turbines when power is scarce. Asia has many suitable off-river sites for pumped-hydro energy storage (Blakers *et al*., 2019).

There are numerous other strategies for managing the intermittency issue. Diversification between both solar and wind helps, as their generation profiles are often negatively correlated. Expanding the reach of electricity grids, both domestically and internationally, is important for enabling such diversification. Improvements in grid management are also vital for achieving high penetration rates of intermittent renewables, for example via increased use of prediction technologies. Demand-side management, using time-varying prices and other approaches, is also a useful means of introducing additional flexibility into the system.

3.2 Other emissions reduction opportunities

The primary solution to reducing fuel-based emissions outside the electricity sector is a fairly apparent one: electrification. The road transport sector, for instance, accounts for 13% of Asia's CO_2 emissions from fuel combustion (IEA, 2019a). Use of electric vehicles, if powered by low-carbon electricity from the grid or rooftop solar panels, has the potential to greatly reduce these emissions. China is currently dominating the global electric vehicle market, with 2.3 million battery and hybrid cars on the road by 2018 and annual sales reaching 1.1 million (IEA, 2019c). More broadly, electric vehicle sales are likely to take off once cost parity with internal combustion engine vehicles is reached. There is substantial scope for government policy to accelerate such a transition.

There are also emissions reduction opportunities in the manufacturing and construction sectors, the source of one-quarter of Asia's fuel-based CO_2 emissions. Electrification is an option for some processes, and researchers are currently working on other approaches to decarbonize processes such as steel refining. A possible solution involves the use of zero-carbon fuels such as green hydrogen – produced by spitting water using electrolysis, powered by zero-carbon electricity.

The governments of Japan, South Korea, and China have each expressed interest in fostering the adoption of hydrogen, with for example the Basic Hydrogen Strategy of Japan aiming for the achievement of large cost reductions for hydrogen over coming years. The strategy targets a 75-fold increase in hydrogen use in Japan by 2030 across industry, transport, and other sectors of the economy.

There are options for the decarbonization of heating and cooking, including electrification through the use of electric heat pumps and cooking appliances. Decarbonization of aviation and shipping is challenging, although zero-carbon fuels and electrification will likely be part of the mix of solutions. From an economic point of view it would be ideal for a carbon price signal to be in place to encourage research and development into the best available zero-carbon energy solutions.

Energy efficiency improvements are often the cheapest way of reducing emissions, particularly in rapidly-growing economies where additional investments in energy provision infrastructure would otherwise be needed. There are many opportunities for improving energy efficiency in Asia, for example via accelerating the adoption of light-emitting diode (LED) lighting (Zissis & Bertoldi, 2018). Because electrified processes tend to be more energy efficient, electrification also helps in improving energy efficiency (Jacobson *et al.*, 2018).

Emission reductions outside the energy sector are also needed if the world is to have a chance of restricting global warming to below 2°C, as aimed for under the Paris Agreement. Ending deforestation and improving the management of peatland are vital steps, with Indonesia being one of the world's most important countries in this regard. While reducing emissions from agriculture is often challenging, low-emission fertilizers and the rise of meat substitutes offer opportunities (Ritchie *et al.*, 2018). Difficulties in reducing greenhouse gas emissions in some settings mean that other approaches – including carbon capture, use, and storage (CCUS) – will be needed if the world is to have much chance of achieving a deep decarbonization outcome over coming decades.

4. New economic opportunities from renewables

Mitigation of anthropogenic climate change has traditionally been regarded as a costly endeavour. However improvements in solar, wind, and other technologies have opened many opportunities to switch away from fossil fuels over time while occurring zero or little in the way of additional costs. Given that power stations need to be replaced over time anyway, why not go for cost-competitive options that have zero emissions? The same logic applies to other capital equipment such as passenger vehicles. Much of the challenge is in creating an investment environment that is best able to capitalize on the many new opportunities.

The changing economics of the energy sector has opened the way for new comparative advantages throughout Asia. For instance the solar- and wind-rich Gobi Desert, shared by Mongolia and China, could become a major center for electricity generation. More generally, because the best sites for utility-scale solar and wind projects are typically outside major cities there is the potential for income and job creation potentials in areas that might otherwise have limited economic prospects. In some settings, this may help to reduce within-country regional disparities, although the extent to which local populations benefit from renewables projects depends on factors such as land ownership and the extent of community participation.

Some changes in the location of energy-intensive manufacturing activities may be expected. Minerals processing, for instance, may increasingly be located in sunny and windy locations, especially when these coincide with the location of ores. This phenomenon is not likely to affect the location of all or even most manufacturing processes, though, as other considerations such as distance-to-market and labour force availability will continue to be important. Renewable energy can also be transported in an efficient manner to manufacturing centers via HVDC cables.

One feature of solar and wind power is that, once the generation capacity is in place, electricity can be generated at a marginal cost that is equal to or near zero. Where active markets exist, the low marginal cost of generation also helps to lower general wholesale electricity prices via what is known as the merit-order effect. In key contexts, cheaper electricity will be able to power a large range of energy-intensive activities, from air-conditioner use to manufacturing.

In addition to undercutting the need for investments in fossil fuel infrastructure, the rise of solar and wind can potentially reduce the need for new on-river hydropower dams in regions such as the Mekong. This would help to avoid the sizeable environmental and social costs of these projects. While all energy-sector projects have environmental impacts, solar and wind have an advantage in terms of flexibility in siting. Ideally, new energy projects would be located in areas that have the lowest overall costs, after environmental and social costs are properly considered.

5. Prospects for fossil fuels

While renewables are making inroads, coal remains the principal source of electricity generation in key Asian economies. In 2018 coal fuelled 67% of China's electricity generation, down from a peak of 81% in 2007. Coal contributed 75% of India's electricity mix (down from 77% in 2016) and 58% of Indonesia's (BP, 2019). New coal-fired power stations continue to be built, although at a slowing rate. There is the risk that these assets will become stranded due to both increasing competition from alternative energy sources and growing concerns about the negative externalities from coal.

Fossil fuels also continue to dominate the primary energy mix more broadly. Coal contributed 42% of Asia's primary energy supply in 2017, followed by oil (27%) and natural gas (17%). The combined contribution of all other energy sources was 14% (IEA, 2019d), although the IEA's primary energy data understate the contribution of solar and wind by not counting their energy losses (Sauar, 2017). Natural gas use has increased quite quickly, with the industry being transformed by the rise of liquefied natural gas (LNG) transportation and the booms in both unconventional and offshore extraction. The Asian spot price for natural gas has crashed (International Monetary Fund, 2020), eroding the long-standing "Asian premium" for this product.

Under stated policies, the IEA (2019b) expects coal use to stagnate over the next two decades, both globally and in Asia. Use of oil and, particularly, natural gas is anticipated to grow. However it becoming highly possible that coal use – and especially thermal coal use – will instead decline quite rapidly, especially if alternative technologies continue their rapid improvements and if environmental policies are further tightened. Use of oil for road transport also faces a precarious long-term future given the rise of electric alternatives (including hydrogen fuel-cell vehicles). Indeed, the IEA (2019b) foresees declines in global coal and oil use over coming decades under the scenario in which efforts are taken to meet the Paris Agreement objective of limiting global warming to well below 2°C.

Even with further improvements in renewables, the fossil fuel industry is certainly not done with. Fossil fuel prices are capable of declining – perhaps substantially –

in response to pressure from new energy sources. Coal-fired generation also remains relatively cost competitive in locations such as Java, especially when external costs are ignored and given the existence of favorable government policies towards coal. The fossil fuel industry is a powerful incumbent in many Asian countries, with many state-owned enterprises themselves being heavily invested in fossil fuels. There is a lot of money, and many regionally-focused jobs, on the line. Renewables should thus expect vigorous competition in both economic markets and the political marketplace.

The relative decline of fossil fuels may lead to a reshaping of geopolitics. Oil and gas producers stand to lose, a process that may spur pressures for political change. However the process will likely be relatively gradual, and many oil and gas extracting countries have large accumulated savings as well as opportunities to reorientate their economic models, including towards renewables. Given its impressive lead in the manufacturing of renewable generation technologies, perhaps the biggest winner will be China. China is also rich in rare earths – vital inputs to the production of various modern energy technologies, including batteries and wind turbines.

6. Economic mechanisms

Environmental problems arise largely as a result of negative externalities from economic production. As a result, there will tend to be underinvestment in clean relative to dirty technologies. For this and other reasons, governments have a strong rationale to introduce policy approaches that help to reduce emissions. While private-sector efforts such as RE100 – under which corporations pledge to power their activities with 100% renewable electricity – are important, public policy interventions are the key means via which large-scale emissions reductions can potentially be achieved. In this section we focus on three key economic mechanisms being used in Asia and elsewhere: emissions pricing, reverse auctions, and renewable portfolio standards with green certificate schemes.

6.1 Emissions pricing

The economist's primary prescription for pollution problems is to either adequately allocate property rights or to introduce a price that acts as a proxy for the negative external costs of pollution. If an emissions price is in place, a market-based economy will have an incentive to steer itself in a greener direction. If introduced early in the development process, emissions pricing can help countries avoid the worst of the pollution problems experienced by countries such as China and India (Burke, 2014).

However pricing of greenhouse gas emissions via either an ETS or a carbon tax remains relatively nascent in Asia. Only five Asian countries had a carbon price of some form in place by 2019 (World Bank, 2020):

- Japan has a small carbon tax, set at US$3 per tonne CO_2. The cities of Tokyo and Saitama also run baseline-and-credit ETSs.
- Kazakhstan has an ETS covering the power sector, heating, and some industrial emitters. Emissions trading was first piloted in 2013.
- South Korea introduced an ETS in 2015. As of late 2019 the permit price was about US$29 per tonne CO_2.
- Singapore introduced a carbon tax in 2019, at about US$4 per tonne CO_2.
- China has run sub-national pilots and is working towards national implementation of its ETS, initially to be applied to the power sector.

A number of other Asian economies have considered the idea of pricing carbon, although implementation will be some years away. Vietnam and Taiwan have stated that they are considering introducing ETSs. In 2019 Indonesia established a new environmental fund agency under its Ministry of Finance, among the activities of which is to consider the use of green fiscal instruments. While not officially a carbon price, India imposed a small charge on coal in 2010, in part motivated by a desire to encourage cleaner energy.

From an economic point of view, a carbon tax is preferable to an ETS in many ways. A carbon tax is administratively simpler given that it does not involve permit trading. A tax is also a better fit for many countries' revenue-collection architectures, as it is suited to being collected by the national tax agency. A carbon tax avoids the price uncertainty associated with ETSs, providing a clear price signal that investors can use when weighing investment decisions.

The two key hurdles for broader application of carbon pricing are (a) technical readiness, especially in emissions measurement and monitoring, and (b) political feasibility. The first means that economy-wide carbon pricing cannot be introduced quickly in many countries, unlike some other policy mechanisms such as reverse auctions for renewable energy. However, simple schemes applied to only large emitters can be more straightforward to implement. Political feasibility varies by country, with experience showing that design features such as revenue recycling can enhance popularity. Carbon prices can be designed to ensure progressivity, and revenues can be used for productive purposes.

Emissions pricing is also useful for tackling local pollution problems. China first introduced pollution charges from the 1980s, and countries including Thailand, Philippines, and Malaysia introduced wastewater fees in the 2000s. In a 2012 reform package Vietnam introduced environmental taxes on products including plastic bags and pesticides. Environmental tax rates have tended to be quite low throughout the region, however. Compliance issues have also arisen, highlighting the importance of monitoring and implementation frameworks.

Some Asian countries do the opposite of pricing emissions, instead maintaining distortions that encourage rather than discourage fossil fuel production and consumption. There have been some reforms to fossil fuel subsidies in recent years, with Indonesia raising consumer prices for gasoline, diesel, and also electricity. India has deregulated its gasoline and diesel prices. However many fossil fuel-favoring distortions still remain, making it difficult for renewables to compete. For example Indonesia still maintains a domestic market obligation for coal producers, which depresses the local coal price and encourages the use of coal.

6.2 Reverse auctions

The primary approach for procuring new renewable energy projects has traditionally been the use of feed-in tariffs, whereby electricity from new installations can be sold at a set price over a certain period. Such an approach can certainly work well to spur renewables uptake, as seen in the case of Vietnam's sudden solar PV boom in 2019. In recent years however an alternative approach has become increasingly popular: reverse auctions for power purchase agreement (PPA) contracts. The auction winners are those projects that submit the lowest price offers, with their projects then being awarded a PPA that typically extends for about 20 years. Around 100 countries in the world have held reverse auctions for renewables to date (International Renewable Energy Agency, 2019).

India is among countries that led the way in reverse auctions for both utility-scale solar (from 2010) and wind (from 2017). The approach has helped to drive prices below the previously-applied feed-in tariffs, and to such low levels that they have begun to undercut the costs of new and even existing coal-fired power stations

(Burke *et al.*, 2019). In 2019, the lowest bid in the Solar Energy Corporation of India (SECI) national auction came in at just US$0.036 per kilowatt-hour (kWh). That is cheap. A SECI auction for solar plus storage in early 2020, for the delivery of electricity at both off-peak and peak times, also achieved low prices.

Reverse auction successes are spreading. In 2019, Cambodia recorded an auction price of only US$0.039 per kWh for a 60-megawatt solar PV installation in Kampong Chhnang province, with 26 companies submitting bids. Support from the Asian Development Bank and World Bank to cover some costs helped in the achievement of such a low price (Keating, 2019). The United Arab Emirates has achieved among the world's lowest solar auction prices, at below US$0.02 per kWh. A reverse auction in Bangladesh in 2019 saw the winning bid come in at US $0.075 per kWh, a record low for the country's solar sector (Islam, 2019). China, Malaysia, Kazakhstan, and Japan are among other Asian countries to have commenced using reverse auctions.

The advantage of reverse auctions over standard feed-in tariffs is that competitive forces in an auction can help to drive prices down. One challenge is that in some instances auction winners seek to enter ex-post negotiations to revise their feed-in price or gain other concessions. Such risks can be reduced by suitable qualification requirements and procurement rules (International Renewable Energy Agency, 2019). New auctions can also be run in the event of non- or under-delivery.

Reverse auctions work best when a supportive policy environment is in place and the investment context is de-risked as much as possible. Take-or-pay requirements and payment security mechanisms are among the tools available to reduce off-take and other risks. However the most suitable renewables procurement mechanism depends on the institutional context and the project scale. Small-scale projects such as rooftop solar are naturally more suited to feed-in tariff arrangements in order to avoid the transaction costs of participating in a reverse auction.

6.3 Renewable portfolio standards

Another key mechanism for encouraging renewables uptake is the renewable portfolio standard (RPS) – a requirement that a certain level or share of renewables be achieved in each given year. Compliance requirements are typically imposed on retail suppliers of electricity. In flexibly-designed schemes, obligations can be met using tradable renewable energy certificates (RECs), also called "green certificates". Each certificate represents a certain quantity of electricity from renewable sources. A market for green certificates then forms, with the supply side being the renewable generators and the demand side being the electricity retailers (and perhaps other entities). If a country has a goal to meet a certain renewables target, a well-managed RPS is a direct and efficient mechanism for achieving it.

RPSs and green certificates are becoming more widely used in Asia. South Korea has an RPS that required 2% of power to come from renewable and new energy in 2012, rising to 10% in 2023, with green certificates able to be used to meet compliance requirements. India has RPS and green certificate schemes, although utilities have not met all of their required obligations. China is introducing a new RPS in 2020, with requirements for each province set out for the subsequent five-year period and a market for green certificates being established. The Philippines has also recently introduced an RPS.

An RPS can help to reduce the uncertainty faced by renewables developers at both the initial investment stage and the off-take stage, as the demand for renewable energy has been shored-up by RPS compliance requirements. This helps to reduce financing costs and deliver cheaper renewables projects. However it is important to note that green certificate schemes require adequate monitoring and verification capabilities. As the case of India demonstrates, they can fail to work effectively if they do not receive strong institutional support.

Emissions pricing has an advantage over a technology-specific instrument such as an RPS in that an emissions price provides a broad signal to all relevant agents to reduce emissions when doing so is cheaper than paying the per-unit emissions price. An RPS does not incentivize emissions reductions across some key dimensions, for example by not encouraging greater use of natural gas relative to coal.

Nevertheless an RPS can often make a lot of sense, especially when a suitable emissions price is not politically viable. One advantage is that an RPS does not have the word "tax" or "price" in its name, and renewables are typically popular. It is also possible to couple an RPS with other policies in order to seek to mimic the effects of a carbon price. For example, the tightening of emissions regulations on coal-fired power stations can help to reduce the potential for coal-based emissions to rise after the introduction of an RPS.

7. The importance of internationalism

In a world without borders there would be substantially more international flows in electrons – from the sites with the best solar, wind, and hydro resources to major demand centers. There would also be sizeable international flows in technology and expertise, plus free flows in finance for new renewables projects. The result would be a cheaper and quicker transition to low-cost renewables.

In reality, there are impediments to free-flowing trade. In India, solar panel costs have been inflated by the year-2018 imposition of a two-year safeguard duty on imports from countries including China and Malaysia. These costs contributed to a 30% decline in solar installations in 2018-19 (Gupta, 2019), without much in the way of an improvement in domestic manufacturing capabilities (Saur News Bureau, 2019). Indonesia imposes local content requirements on solar projects, which leads to domestic cost inflation and inhibits the development of the installation market. Malaysia and Saudi Arabia are among other countries that favor local content in their solar procurement.

There are also barriers to cross-border trade in electricity. In 2018 Singapore did not import any electricity, despite its neighbors having ample generation opportunities and the fact that Singapore is a trade-oriented nation when it comes to most other goods and services. The country is currently pursuing opportunities to change this situation, including by making more use of its existing interconnection with Malaysia. Many other Asian countries also have zero imports of electricity, including Bangladesh and Brunei Darussalam (IEA, 2019d). Indonesia imports a small amount of electricity from Malaysia, but electricity imports are officially only permitted if they do not lead to "dependence on the procurement of electrical power from other countries" (Government Regulation No. 42/2012). The underlying reasons for low levels of electricity trade throughout much of Asia are national energy security concerns, distrust of neighbors, and protectionist sentiments.

Internationalism is vital for overcoming these barriers and ensuring a speedy transition to new zero-carbon technologies. Multilateral development banks such as the World Bank and Asian Development Bank have important roles, including in providing technical advice. Two international organizations aimed at facilitating a rapid transition to renewable energy – the International Renewable Energy Agency (IRENA) and the International Solar Alliance – are headquartered in Asia.

China has ambitious plans for an Asian Super Grid, and even a global energy interconnection. Regional groups such as the Association of Southeast Asian Nations (ASEAN) likewise have ambitious targets to establish regional power grids.

While progress on cross-border electricity trade has generally been slow, there are exceptions. Laos has emerged as a major exporter of electricity; as of 2017, Laos was the only Asian country in the world's top-10 electricity exporters (U.S. Energy Information Administration, 2020). However Laos' electricity exports have been powered by hydro dams that have brought large environmental and social costs. Solar and wind projects, together with energy storage, offer the potential for lower environmental and social footprints, especially if well-sited.

8. Conclusion

The solar and wind sectors of Asian economies have the potential to boom over coming years, with energy researchers increasingly emphasizing the potential to move towards high penetration levels of renewable electricity (e.g. Jacobson *et al.*, 2018; Blakers *et al.*, 2019). Moving in this direction makes sense given that solar and wind are now cost-competitive in many settings and given the large external costs of fossil fuel use.

Rapid adoption of zero-carbon energy in Asia would bring substantial benefits in terms of reduced local pollution and the slowing of global climate change. By helping to lower production costs, industry scale-up in Asia would also assist countries outside the region to realise their own renewable energy ambitions. However, the scale of the climate change challenge remains immense. The expectation of ongoing expansion in global energy use, driven by economic growth and population growth, makes the task of achieving large-scale emissions reductions all the more imposing.

The history of the renewables industry to date shows that well-designed policy approaches play a key role in helping to bring down renewables costs. Mechanisms such as reverse auctions have harnessed competitive pressures that have helped countries to sign up new solar and wind projects at prices that would have been seen as inconceivably low a decade ago. The rise of solar and wind has also been aided by the current low-interest rate macroeconomic environment, which favors capital- over fuel-intensive projects.

Electricity is set to make an increasing contribution to the final energy mix throughout Asia and globally. It is telling that international trade in electricity remains small in most of Asia, with numerous countries currently having *zero* trade in electricity with their neighbors. There are many potential gains from trade that are waiting to be harnessed.

Reducing emissions outside the electricity sector can be challenging, although electrification is a key part of the solution. There is some enthusiasm for the development of a green hydrogen industry, although costs remain too high for the moment. There is also the potential for trade in products that have been manufactured using zero-carbon energy, such as green steel. Strong and sustained demand-side interest will be needed if these industries are to scale up and achieve the types of cost reductions that have been achieved for solar and wind.

A key reform priority for countries in Asia is the introduction of carbon pricing so that clean energy sources are able to compete on a level playing field. Adoption of simple domestic carbon taxes is the most desirable option. The use of green certificates to help meet renewable energy targets is another approach that is gaining in popularity. It is important to note that economic instruments are also well suited to enhancing environmental and resource management outside the energy sector, for example the use of:

- Emissions pricing for local pollutants such as discharges into waterways.
- Tradable permit schemes for the extraction of resources such as water.
- Reverse auctions for the rehabilitation of land and the provision of ecosystem services.

Economic mechanisms are not the only approach to reducing environmental pollution. Regulations on emissions levels and technologies can also play a key role in steering economies in a lower-emission direction, to provide one example.

The rise of solar and wind power is not without challenges, including the need to manage resource intermittency. Cheap solar power will exacerbate some resource management issues, for example where solar water pumps are used to extract groundwater (as in India). Solar and wind farms are exposed to natural disasters such as cyclones, and it will be important for industry and governments to develop a focus on end-of-life recycling and waste management for products such as solar panels and batteries. Nevertheless, solar and wind energy are providing Asian countries with a major new opportunity to pivot their economies in a much greener development direction than has been followed to date.

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