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DECARBONISING SOUTH AND SOUTH EAST ASIA

Shifting energy supply in South Asia and South East Asia to non-fossil fuel-based energy systems in line with the Paris Agreement long-term temperature goal and achievement of Sustainable Development Goals

MAY 2019 **FULL REPORT**

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This document may be cited as:
Climate Analytics (2019). Decarbonising South and South East Asia: Shifting energy supply in South Asia and South East Asia to non-fossil fuel-based energy systems in line with the Paris Agreement long-term temperature goal and achievement of Sustainable Development Goals

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This report has been prepared under the project "Pilot Asia-Pacific Climate Technology Network and Finance Centre", an initiative of UN Environment and the Asian Development Bank (ADB), funded by the Global Environment Facility (GEF).

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Shifting energy supply in South Asia and South East Asia to non-fossil fuel-based energy systems in line with the Paris Agreement long-term temperature goal and achievement of Sustainable Development Goals

CONTENTS

KEY MESSAGES

South and South East Asia are among the world's most vulnerable regions with very large and increasing populations exposed to very high and often extreme climate risks. Already at 1°C warming substantial damages and risks have been observed. Limiting global warming to 1.5°C in line with the Paris Agreement's long-term temperature goal reduces impacts and risks for these regions which would otherwise threaten achievement of sustainable development goals.

South and South East Asia have vast renewable energy potential. Utilisation of solar and wind could satisfy the needs of almost all of the countries in these regions many times over, and the average costs of utilising these renewable power sources in 2016 was already often in the range of the costs of fossil fuels even if the external costs of the latter are not included.

An energy system transformation towards full decarbonisation would have multiple benefits for sustainable development for South and South East Asia through increased energy security and access to affordable modern energy for all, avoided air pollution damages and reduced or avoided water use, land contamination and environmental degradation.

To meet both sustainable development goals and the goals of the Paris Agreement, South and South East Asia need to **decarbonise their energy systems by 2050,** mainly through a rapid increase of renewable energy use, in particular in the power sector, and decarbonisation of end use sectors through electrification or direct use of renewable energy, as well as large demand reductions across all end-use sectors.

The power sector plays a critical and essential role for decarbonising the entire energy system. An analysis of available global and regional scenarios shows that for the power sector, **a benchmark of at least 50% share of decarbonised electricity generation by 2030 and 100% by 2050** needs to and can be achieved both in **South Asia and South East Asia**. A wide range of renewable energy and storage technologies, with **wind and solar** the most important technologies to be expanded at large scale, are available to meet the **increase in demand** to achieve full access to electricity and economic growth in these dynamically developing regions.

In order to align their energy plans with the Paris Agreement and SDGs, and limit the risk of stranded fossil-fuel assets, countries in South and South East Asia will need to urgently consider how to **reverse their current trend of expanding coal-fired generation capacity** and how to implement policies to enable a fast decarbonisation of the electricity mix, **phasing out coal for power generation by 2040.**

Executive Summary

South Asia[1] and South East Asia[2] are among the world's most vulnerable regions to climate change and are already experiencing severe climate impacts related to current warming level of around 1°C above pre-industrial levels. Limiting global warming to 1.5°C, in line with warming limit in the Paris Agreement's long-term temperature goal will significantly reduce future impacts and risks, which would otherwise threaten the achievement of sustainable development goals in these regions.

How these rapidly growing economies choose to meet increasing energy demand whilst meeting their sustainable development goals (SDGs) will have major implications for global efforts to tackle climate change. Policy in these regions will need to take into account both vulnerability to climate change impacts as well as the need to achieve emission reductions whilst overcoming poverty, increasing access to safe and affordable energy, and meeting key sustainable development goals.

In their efforts to bring their large populations out of poverty, countries in South and South East Asia have relied historically on large-scale fossil fuel-based industrial and power projects, and plan many more, which unmitigated will result in globally significant increases in greenhouse gas emissions.

Yet both regions have vast renewable energy potential that is still largely untapped. Utilisation of solar and wind could satisfy the needs of almost all of the countries in these regions many times over, and the average costs of utilising these renewable power sources in 2016 was already often in the same range as fossil fuels even if the external costs of these are not included.

Full decarbonisation of energy systems in countries across these regions would yield multiple benefits for sustainable development, in particular through increased energy security and access to affordable, clean and modern energy for all. In addition, the avoided air pollution damages and environmental degradation (including water use and land contamination), through switching from fossil fuel systems to renewable are substantial.

In order to be in line with the long-term temperature goal of the Paris Agreement, South and South East Asia will need to decarbonise their energy systems by 2050. This is possible with a rapid increase of renewable energy use, in particular in the power sector, and decarbonisation of end use sectors such as industry or transport, through electrification or direct use of renewable energy, as well as large demand reductions through increased efficiency and improved infrastructure across all end use sectors.

The power sector plays a central role in decarbonising the energy system as a whole. An analysis of available global and regional scenarios shows that both regions need to and can reach at least 50% share of decarbonised electricity generation by 2030 and 100% by 2050, and phase out coal for power generation by 2040. This can be achieved with a wide range of renewable energy and storage technologies, with wind and solar being the most important technologies to be expanded at large scale. Achievement of this is feasible even with the significant increase in demand required to achieve full access to affordable electricity and economic growth in these dynamically developing regions.

In order to align energy plans with the Paris Agreement and the SDGs, and to limit the risk of stranded fossil-fuel assets, countries in South and South East Asia will need to reverse the current trend of expanding coal-fired generation capacity and instead urgently implement policies to enable a fast decarbonisation of the electricity mix.

This report shows what climate impacts can be avoided by limiting warming to 1.5°C in line with the Paris Agreement, and what sustainable development benefits countries in both regions can leverage as a result. It also shows what is required to fully decarbonise the energy system at the global and

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1 South Asia comprises the following countries Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka,

2 Understood here to comprise the 10 ASEAN member countries plus East Timor, and PNG

regional level, according to the latest findings of the Intergovernmental Panel on Climate change (IPCC) Special Report on 1.5ºC (IPCC SR1.5). Finally, it assesses current and planned energy supply technologies across both regions, and outlines alternative technology and fuel options to address the shift to non-fossil fuel-based energy systems in line with implementing the Paris Agreement and its long-term temperature goal to limit warming to 1.5°C, as well as the Sustainable Development Goals.

Avoiding climate impacts and leveraging benefits for sustainable development

Limiting global warming to 1.5°C in line with the Paris Agreement long-term temperature goal is of crucial importance for both regions as climate impacts are detrimental for achieving sustainable development goals. It would reduce impacts for these regions by:

- **Supporting economic growth, with per capita gains of 10-20% GDP** compared to a global warming level of 2°C particularly for countries in the tropics, thus reducing economic damages;
- **Reducing drought and water stress**, which is crucial for achieving sustainable development goals of **zero hunger, good health and well-being, and clean water and sanitation**, and for using the hydropower potential in the region;
- Reducing the risks from flooding resulting from **extreme precipitation**;
- **Reducing the risk of extreme heat** that can otherwise reach intolerable levels for **human health and labour productivity**, causing heat-related morbidity and mortality particularly for densely populated cities in South Asia;
- **Reducing sea-level rise, storm surges, and related flooding risks**, which threatens large numbers of people in South and South East Asia living in coastal regions;
- **Reducing impacts on biodiversity and ecosystems such as coral reefs**, with direct implications for large populations of South- and South East Asian countries depending on coastal livelihoods and ecosystem services such as fisheries and tourism;
- Reducing risks in relation to more intense **tropical cyclones**.

Global energy system transformation in line with the Paris Agreement 1.5°C temperature limit: insights from the IPCC Special Report on 1.5°C

The IPCC SR1.5 provides the best available science for operationalising the long-term temperature goal of the Paris Agreement (LTTG) and the most comprehensive and up-to-date assessment of global mitigation pathways and their sustainable development implications. This report shows that a rapid and profound decarbonisation of energy supply is a key and driving characteristic of Paris Agreement consistent 1.5°C pathways, leading to a net-zero-emissions energy supply system by mid-century, and with the right policy settings large benefits for the SDGs. Energy system transformation globally is characterised by:

- Fully decarbonised primary energy supply by mid-century (including with CCS);
- Large energy demand reductions across all end-use sectors by 2030;
- Large reductions of fossil fuel use, in particular coal (minus 64% by 2030, minus 75% by 2050) and oil (minus 11% by 2030, minus 60% by 2050);
- Rapid increase in use of renewable energy;

- Bioenergy is used in many 1.5°C pathways, both with CCS (BECCS) and without, with uncertainties regarding limits to sustainable use;
- Full decarbonisation of electricity generation by 2050, mainly through increased use of renewable energy reaching shares of over 50% by 2030 and over three-quarters by 2050 globally;
- Coal use for electricity reduced dramatically by around 70% in 2030 and complete global phase out by 2050. Due to high carbon intensity, no role for coal even with CCS by 2050;
- Electrification of end-use sectors (transport, buildings, and some industry processes) and decarbonisation of final energy other than electricity, for example through the use of biofuels, hydrogen or other energy carriers (aviation, shipping, and some industry processes). While electrification leads to an increased demand in electricity, reducing energy demand to meet energy services, including through enhanced energy efficiency is an important element of all mitigation pathways.

The political, economic, social and technical feasibility of **solar energy, wind energy, and electricity storage technologies** has improved dramatically over the past few years, with costs dropping rapidly over the last few decades, and with corresponding growth trajectories much faster than expected by the energy community.

Nuclear energy and CCS in the electricity sector have not shown similar improvements, with costs of nuclear power having increased over time in some developed countries, and costs of CCS not coming down over the last decade, which - together with more limited co-benefits than renewable energy - makes these technologies increasingly unlikely to be able to compete with renewable energy and modern storage. The consequential relative change in costs between these technologies, which advantages renewable and model storage, is not yet reflected in many energy-economy models.

Energy system transformation in South Asia and South East Asia in line with the Paris Agreement 1.5°C temperature limit: key characteristics

The context in South Asia and South East Asia is one of continued high rates of economic development and increasing demand for energy. To achieve this, Paris Agreement-compatible pathways all show strong reductions in fossil-fuel consumption compared to reference scenarios:

- The most striking characteristic of the 1.5ºC pathway for both SA and SEA is the very high increase in generation from **renewable energy**, which becomes the dominant source even within the next decade in a number of countries – against the backdrop of an overall sharp increase in electricity generation;
- A large **increase in electricity demand** is due to the need to provide access to clean and affordable energy for a growing population and the essential role of **electrification to decarbonise end-use sectors,** in particular transport;
- Available global and regional scenarios show that for the power sector, **a benchmark of at least 50% share of decarbonised electricity generation by 2030 and 100% by 2050** needs to and can be achieved both **in South Asia and South East Asia**;
- Use of unabated **coal** (without CCS) is reduced dramatically by 2030 and essentially phased out by 2040;

- There is a wide range of renewable energy and storage technologies available to achieve these aims, with **wind and solar** being the most important technologies that can be deployed rapidly at large scale.

Benefits of energy system transformation towards renewable energy for sustainable development

Apart from contributing to the global effort to limit global warming to 1.5°C and avoiding major climate change risks and damages to these two regions, the energy system transformation outlined in this report would come along with the following benefits for sustainable development for South and South East Asia:

- **Increase energy security and energy independence.** With all countries in the regions not being able to rely on their own fossil fuel resources for their increasing energy demand, renewable energy resources provide security of supply and reduce the economic burden of imports;

- **Access to affordable modern energy for all**, with renewable energy providing opportunities for access to electricity both through conventional transmission grids or decentralised solutions such as microgrids or off-grid solutions;

- Access to modern technologies for cooking and lighting contributes to **reducing health damages from indoor air pollution**, which disproportionately affects women and children;

- **Reducing outdoor air pollution, environmental degradation, and improving health,** as air pollution is a growing problem that seriously endangers health and leads to high costs, in particular in many urban areas both in South Asia and South East Asia. A large part of ambient air pollution is caused by fossil fuel power generation, in particular coal, with more than 1.9 million premature deaths in South East Asia due to outdoor air pollution, and 1 million in India according to the World Health Organisation;

- **Economic prospects and employment opportunities** for a growing population, with construction and maintenance of most renewable energy technologies being more labour intensive and localised.

Implications of current planning for coal fired power generation

Several South and South East Asian economies are planning to expand their coal plant capacity rapidly, despite the need to phase out coal-fired power by 2050 globally as shown by the IPCC or even by 2040 as our analysis of a Paris Agreement consistent pathway shows for these two regions.

Together, countries in these regions account for half of the world's planned coal power expansion. India, Vietnam, and Indonesia alone account for over 30% of this planned expansion. An important share of these plans comes from emerging economies whose energy systems have not heavily depended on coal in the past. These include Bangladesh, Pakistan, Philippines, Thailand, Myanmar, Cambodia, which together account for over 13% of the planned expansion of the global fleet. Relative to the current fleet size, Bangladesh plans to increase its coal-based capacity threefold and Philippines aims to nearly double the size of its coal-based capacity.

The present plans for major new coal deployment in the region would endanger the achievement of the Paris Agreement as well as many SDGs in this region, undermining sustainable development objectives across the region.

In this report we have estimated the gap between current and planned coal power generation and Paris Agreement consistent benchmarks for India and the ASEAN region. A key finding is emissions from current and planned coal-fired capacity will exceed the Paris Agreement compatible regional benchmarks by a large margin, unless curtailed in favour of renewable and/or low carbon alternatives.

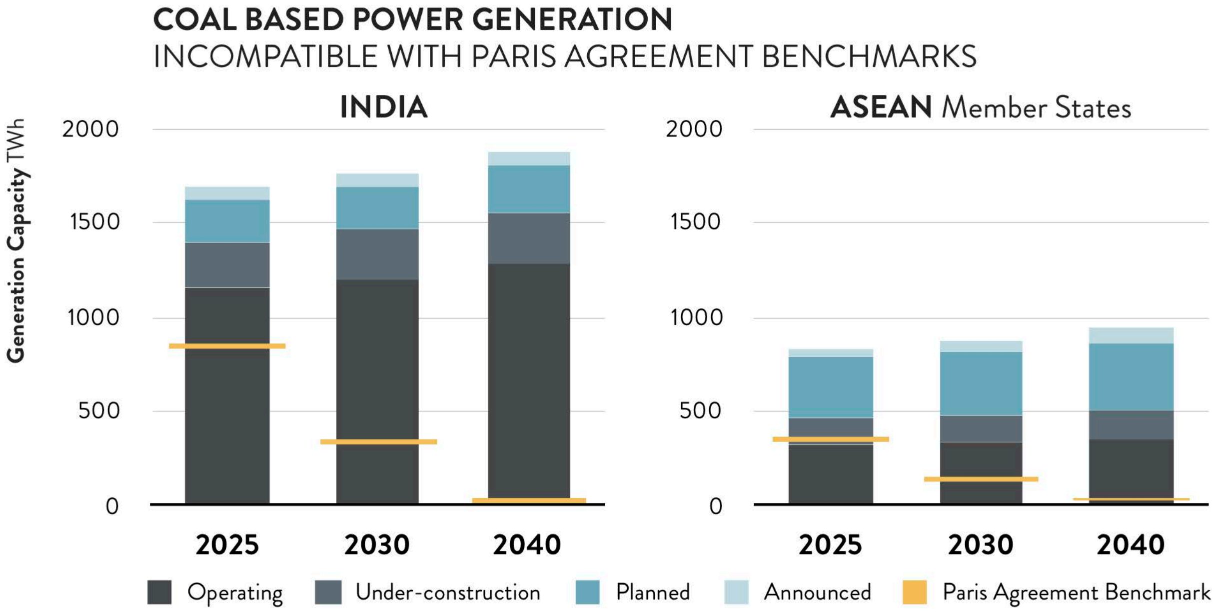

Figure 1: Coal power generation for India and ASEAN: Paris Agreement compatible benchmarks against projected generation from current and planned coal fleet

In order to achieve the Paris Agreement's long-term temperature goal, countries in South and South East Asia will need to implement early retirement of coal-fired power plants and/or to dramatically reduce their utilisation rate. Opening new plants will only widen the gap between committed emissions and benchmarks consistent with the Paris Agreement.

Countries will need to consider their options to reverse the current trend of expanding coal-fired generation capacity and instead consider how to implement policies to enable a rapid coal phase-out from the electricity mix, whilst expanding renewable energy and advanced storage systems. The economic conditions for enabling such a switch have never been more favourable, with ongoing rapid reductions in renewable technology costs, and with these costs projected to continue to decrease, the economic conditions exist to substantially speed up the deployment of low carbon and carbon neutral technologies for electricity production to phase out fossil fuel emissions from the electricity mix by around mid-century at a lower cost than fossil fuel based systems.

Redirecting resources currently planned for coal fleet expansion to renewable energy deployment can not only result in substantial emissions reductions compared to a BAU scenario, but also could reduce substantially the capital at risk of stranding, while ensuring that the growing energy needs of these regions is met, in a sustainable and affordable manner. This would not only result in substantial CO_2 emissions reductions, but also could reduce substantially the capital at risk of stranding, and also avoid a number of severe negative impacts on air quality, health, water and land-use.

Technology and fuel options to replace fossil fuels in energy supply

Countries in South and South East Asia have a number of options at their disposal to replace fossil fuels by renewable sources of energy and thereby achieve Paris Agreement contributions.

- Solar and wind could satisfy the needs of almost all of the countries of South and South Eastern Asia many times over. In addition hydropower, geothermal and bioenergy – much more unequally distributed - can contribute to grid flexibility and complement wind and solar technologies;

- Renewable technologies have the advantage of being able to provide electricity rapidly and cost-effectively in areas without a well-functioning electricity grid – a major issue in many parts of the region;

- The average costs of utilising these renewable power sources in 2016 were already often in the range of the costs of fossil fuels even if the external costs of the latter were not included. The most recent auctions have resulted in prices significantly below that range in particular for solar and wind;

- Declining costs of renewables and storage technologies such as batteries serve as a strong leverage point for not only decarbonising the power sector, but also for concurrently increasing the electrification of other sectors such as transportation, residential energy use and industrial processes;

- For thermal energy applications in industry, bioenergy is currently the most common renewable energy application in South East Asia, but solar and geothermal have large potentials as well, especially since industrial energy consumption is projected to grow significantly in the next two decades;

- Key technologies related to the use of hydrogen from renewable-energy based electricity are maturing, which leads to an option of decarbonising of processes that are difficult to decarbonise through direct electrification;

- Regional cooperation can support a higher uptake of renewable energy in the South and South-East Asian regions to use the diverse renewable energy potentials of different countries in a more effective way, and existing cooperation frameworks can be used to enhance and accelerate the utilization of this potential.

Introduction

South Asian (SA) and South East Asian (SEA) countries are striving to bring their large population out of poverty including through large scale industrial and fossil fuel-based power projects, resulting in an increase in green-house gas (GHG) emissions, hence increasing the vulnerability of these countries due to climate change. The SEA region is one of the fastest growing regions in the world and with increasing population, industrialisation and urbanisation has shown the fastest growth in carbon dioxide emissions in the world between 1990 and 2010, while India is ranked as one of the top GHG emitting countries in the world. Since the overall increase in the emissions from SA and SEA is harming not only the world but the region itself, the findings of the IPCC Special Report on Global Warming of 1.5°C (IPCC, 2018a, 2018b) along with the rapidly decreasing costs of wind and solar power generation as well as storage options underline opportunities to break the fossil fuel based GHG-intensive development path by rapidly modifying the historical model of industrial development.

In view of the strong economic growth as well as observed and projected growth in greenhouse gas emissions, while at the same time facing increasing vulnerability to climate risks, SA and SEA countries will need to take both, risks from climate impacts and emission reduction measures, into account for future development and policy making.

Article 2.1 of the Paris Agreement (PA) defines the PA Long-term temperature goal (LTTG) as "[h]olding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change".

The message of the IPCC SR1.5 (IPCC, 2018b) is very clear:

- Climate Change poses a severe threat, with risks being lower at 1.5°C than at 2°C or higher temperature increases above pre-industrial levels;
- Avoiding these severe risks is still feasible, but requires cutting global greenhouse gas emissions by about half by 2030, and, in particular swiftly decarbonising energy systems. To achieve this, every contribution counts;
- Climate change impacts as well as climate change mitigation are closely linked to sustainable development: Climate change threatens to wipe out progress made with regard to sustainable development and poverty reduction, and there is potential for synergies between achieving sustainable development objectives and climate change mitigation action.

This report assesses current and planned energy supply technologies and outlines alternative technology and fuel options to address the shift to non-fossil fuel-based energy systems in line with implementing the Paris Agreement and achieving the Paris Agreement temperature goal for SA[3] and SEA[4] regions.

The focus is on supply side technologies for power as well as for heat (e.g. in industry), considering the role of electrification in decarbonising end-use sectors. The report includes an assessment of avoided impacts, benefits, and co-benefits of Paris Agreement consistent mitigation actions in the SA and SEA regions. It identifies countries at risk to expand coal capacity in contrast to the need to phasing out coal, and provides country-based assessments of potential technologies and alternative non-fossil fuel-based options in line with the Paris Agreement. This analysis should inform stakeholders, governments, and the finance sector about the priorities for policy intervention, and changes in investment at the regional and national level.

3 SA comprises the following countries Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka,

4 Understood here to comprise the 10 ASEAN member countries plus East Timor, and PNG

Chapter 1 of this report provides an overview of climate change impacts in the SA and SEA regions that can be avoided through achieving this PA 1.5°C temperature limit and how this relates to achievement of Sustainable Development Goals (SDGs) mainly building on the IPCC SR1.5.

Chapter 2 provides a quantitative analysis of mitigation pathways consistent with the Paris Agreement LTTG and Sustainable Development Goals (SDG) based on the scenarios assessed by the IPCC 1.5°C SR and other related scenarios from the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) regarding implications for energy supply technologies (power and heat).

Chapter 3 focuses on where current policies are heading for coal power generation over the next 10 to 15 years for the SA and SEA regions, and for key individual countries of the region, and compared these Business-as-Usual (BAU) pathways with Paris Agreement benchmarks for coal power generation for the regions and assesses implications of coal use in these pathways for air pollution, water and land use.

Chapter 4 outlines the potential for technologies and fuels to replace coal and other fossil fuels for energy supply, considering current development, technical and financial viability, key facilitative actions in the countries of the regions to move to take up these technologies.

Finally, in chapter 5, individual country profiles for a selection of countries with either currently high emissions (India, Indonesia) or large expansion plans for coal fired power generation (Pakistan, Bangladesh, Thailand, Vietnam, Philippines) synthesise country-specific analysis and information from previous chapters, and map mapping technology potentials and mitigation options for energy supply against countries' current policies and plans as well as NDCs and against Paris Agreement benchmarks.

Chapter 1:

Avoiding climate impacts and leveraging benefits for sustainable development

South Asia and Southeast Asia are among the world's most climate-vulnerable regions. According to the Germanwatch Global Climate Risk Index ranking, of the top ten countries most affected by extreme weather events from 1998-2017, five are in SA (Bangladesh, Pakistan) and SEA (Myanmar, Philippines, Vietnam) with India, Cambodia and Thailand ranked in top 20 countries. The index is based on data that reflects only the direct impact, meaning direct economic losses and fatalities from extreme weather events. Due to the high incidence of poverty in the regions which increases the vulnerability of the poorest, the picture is even bleaker when indirect impacts are considered – for example food shortages as a result of drought or loss of livelihood due to a storm event.

Increase in the intensity and magnitude of extreme weather events, such as heat waves, heavy rainfall and flooding, droughts, depleting snow/ice reserves, or destructive storms, are seriously threatening the livelihoods and food security for over one billion people living in these regions. The Asian Development Bank (ADB) has concluded that climate change impacts, such as the deterioration of the Asian "water towers", extended heatwaves, sea-level rise and changes in precipitation patterns, can lead to severe disturbances and damages to livelihoods: affecting human health, migration, and increasing potential for conflicts (ADB, 2017).

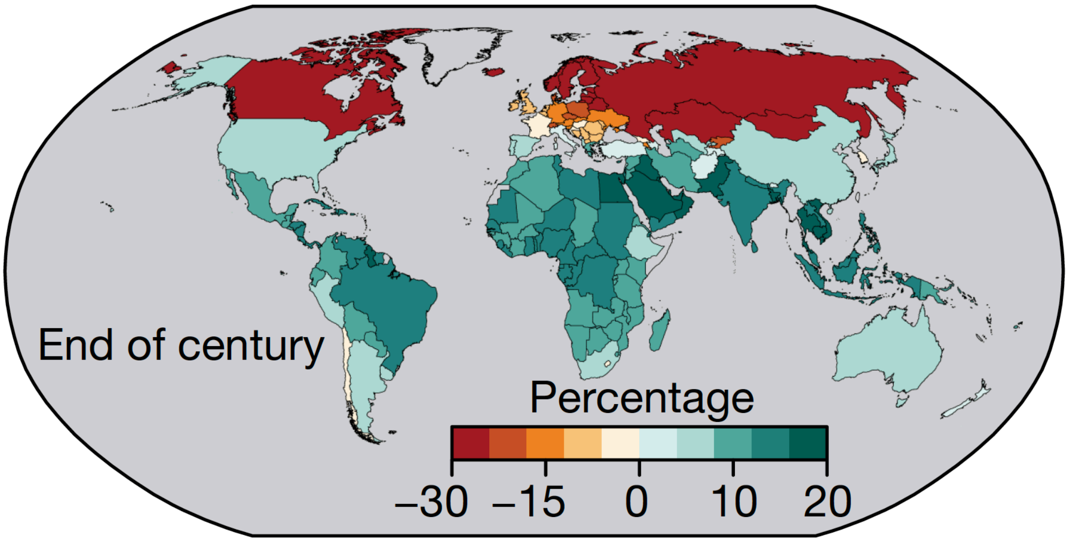

Figure 1.1: Benefits (green) of reduced climate damages under 1.5°C warming in terms of change in GDP per capita, relative to 2°C warming (Burke et al 2018)

The IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related greenhouse gas emission pathways (SR1.5), adopted and published in October 2018, outlines the current scientific understanding of climate-related risks for global warming of 1.5°C compared to 2°C. The report shows that just half a degree increase in global temperature in the recent past has resulted in more intense and frequent climate and weather extremes. The report also finds that climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but would result in lower impacts than in a 2°C warming scenario.

There is greater than 75% chance of reducing economic damages in a 1.5°C world compared with 2°C, and more than 60% chance that total global benefits will exceed $20 trillion[5], with the poorest countries benefiting the most (Burke, Davis, & Diffenbaugh, 2018). Many of the countries that are likely to experience economic benefits are located in SA and SEA, with per capita gains of 10-20% higher under a 1.5°C compared to 2°C. What is more, countries with lower GDP per capita tend to experience larger negative growth effects due to global warming (Pretis et al., 2018). The median projected GDP per capita growth at 1.5°C warming is greater than in a 2°C world for most countries. Again, countries in SEA and SA are projected to benefit most from limiting warming to 1.5°C compared with 2°C.

Limiting global warming to 1.5°C and avoiding dangerous and irreversible climate impacts supports not only economic growth but development as a whole by complementing developmental actions and making it easier for countries to achieve the SDGs. Below are the impacts for Asia, which are relevant to SA and SEA, and their relationships with SDGs, as reported by the IPCC (IPCC, 2018a) and the Asian Development Bank (ADB, 2017).

- **Drought and precipitation deficits** are higher at 2°C compared with 1.5°C of global warming in some regions of the world. It is suggested that more urban populations will be exposed to severe **drought** in different regions of the world, including Southeast Asia at 1.5°C, and the number will further escalate at 2°C. Moreover, increased temperature will likely induce changes in **river discharge and basins water amount**, leading human and livestock populations to experience **water stress,** especially over the driest parts of the world, including some regions of South Asia. Avoiding droughts and precipitation deficits is crucial for achieving **SDG2** (Zero hunger), **SDG3** (Good health and well-being) and **SDG6** (Clean water and sanitation).

- **Heavy precipitation** is projected to be higher at 2°C, which will result in higher inundated global area than at 1.5°C warming levels. Global estimates from the IPCC SR1.5 show that 31-69 million people will be exposed to coastal flooding at 1.5°C warming, compared with 32-79 million people under the 2°C scenario. Annual mean precipitation in the Asian region shows an upward trend, but the magnitude of increase is much less under a 1.5°C scenario compared with a scenario with no climate action (BAU). South Asia is a hotspot for increase in precipitation intensity. At 1.5°C warming the projected increase for the region is 7% compared with 5% globally, and 10% at 2°C compared with 7% globally (Schleussner et al., 2016). According to observational records, **precipitation and runoff** have increased from 1950-2012 in some regions of the world including South Asia. Southeast Asia displays statistically significant differences in projected changes in **heavy precipitation, run-off and high flows** at 1.5°C versus 2°C warming, and thus is also considered as a hotspot in terms of increases in heavy precipitation between these two global temperature levels. The increase in frequency and intensity of heavy rainfall is also more pronounced in SEA compared to other Asian countries, which, coupled with the recession of glaciers across High Mountain regions in Asia, could lead to higher flood risk. Avoiding flood risk is vital for preserving infrastructure and growing industries (**SDG9)** and ensuring sustainability of cities (**SDG 11)**.

- River flows in South Asia are highly dependent on the glacier melt from the Himalayas, which are sensitive to temperature increase. A 1.5 °C global increase implies a warming of 2.1 ± 0.1 °C for the glacierised areas in the High Mountains of Asia (Kraaijenbrink, Bierkens, Lutz, & Immerzeel, 2017). The melting of glaciers due to global warming will not only result in reduced water supply in future, but also in the increase of Glacial Lake Outburst Flood (GLOF) events. This will have direct implications to the availability of water **(SDG6)** as well as affordable and clean energy **(SDG7)** amid hydropower potential in the region.

5 Using 3% discount rate with 2010 as reference year.

- Keeping global warming increase to 1.5°C by 2100 would result in global mean **sea level rise** to be around 0.1 metre lower than at 2°C warming, which implies that up to 10 million fewer people would be exposed to related risks. The magnitude and scale of sea level rise depends critically on future emissions pathways and the timing of peaking emissions (Mengel, Nauels, Rogelj, & Schleussner, 2018). Both South Asia and Southeast Asia are highly vulnerable to increased **flooding** in the context of sea level rise. Risks from increased flooding rise from 1.5°C to 2°C of warming with substantial increases beyond 2°C. Half of the estimated impact of sea level rise and storm surges by the end of the century[6] fall unequally on the residents of ten Asian cities, over 40% of the impact falling on Manila, Karachi and Jakarta alone. Furthermore, 19 of the 25 cities most likely to experience sea level rise of 1 metre belong to the Asia and the Pacific region, seven of which are in the Philippines (Brecht, Dasgupta, Laplante, Murray, & Wheeler, 2012). Managing flooding risk has implications on progressing development under **SDG 11** on sustainable cities.

- Impacts on **biodiversity and ecosystems**, including species loss and extinction, are projected to be lower at 1.5°C of global warming than at 2°C. Limiting global warming to 1.5°C compared with 2°C is projected to reduce risks to marine biodiversity, fisheries and coral reefs ecosystems. Global estimates from the IPCC SR1.5 show that 70-90% of coral reefs will experience bleaching under a 1.5°C scenario, compared with 99% under a 2°C scenario. This will have direct implications for large populations of South and South East Asian countries, which are dependent on coastal livelihoods and ecosystem services. This impact is highly relevant for **SDG 14** on life below water, and related coastal livelihoods such as fisheries, and tourism corresponding to **SDG 2** on zero hunger and **SDG 8** on economic growth.

- Lower risks are projected at 1.5°C and 2°C for **heat-related morbidity and mortality**, whereas urban heat islands often amplify the impacts of heatwaves in cities. At 2°C of warming, some of the densely populated cities of South Asia (including Karachi and Kolkata) could experience annual conditions equivalent to the deadly heatwave of 2015, which resulted in thousands of deaths. The IPCC SR 1.5 estimates 3.5-4.5 billion people will be affected by heat waves in a 1.5°C world, compared with 5.4-6.7 billion people in a 2°C world. There is also a lower risk of temperature-related morbidity and smaller disease-carrying mosquito range projected for 1.5°C as compared to 2°C. Limiting warming to 1.5°C would halve the percentage of Asian lands projected to experience severe **heat extremes** compared with 2°C. Avoiding heat extremes is relevant for preventing thermal stress and heat-related illnesses corresponding to **SDG 3** on health, and **SDG 11** on sustainable cities.

- Risks in relation to more intense tropical cyclones with rising temperatures and the co-hazard of rising sea levels are likely to result in significantly lower losses under the 1.5°C compared with the BAU scenario. Avoided damages are relevant for achieving sustained economic growth corresponding to **SDG 8**.

- Climate related risks to **health, livelihoods, food and human security, water supply,** and **economic growth** are all projected to increase with global warming of 1.5°C and increase further with 2°C. Limiting warming to 1.5°C would have significant positive implications for sustainable development, and reducing poverty and inequality. Even in a 1.5°C world, moderate and high **multi-sector impacts** are still expected where vulnerable people live, predominantly in South Asia, which hosts the largest population that is exposed and vulnerable to the impacts of climate change.

6 The study included 31 developing countries totaling 393 cyclone-vulnerable coastal cities and population greater than 100,000.

- Beyond 2°C and at higher risk thresholds, the world's poorest are expected to be **disproportionately impacted**, particularly where there is high inequality in South Asia. The heavier burden on the vulnerable relates to **SDG 10** on reducing inequalities.

- Climate change is projected to have the largest impacts on **economic growth** in countries in the tropics and subtropics in the Southern Hemisphere, with large benefits of reduced damages under 1.5°C warming in terms of change in GDP per capita, relative to 2°C warming in many South and South East Asian countries (Figure 1.1). SEA is highly exposed to climatic changes and vulnerable to adverse consequences that result in economic losses far greater than the world average (Raitzer et al. 2015). Asian countries are closely linked through strong trade agreements and common ethnic groups, therefore a shock in one area or country may well reverberate across many parts of the region. Preventing economic and social impacts of climate change by limiting warming to 1.5°C will likely result in a more positive benefit of having these **strong international ties** relevant for **SDG 8** on economic growth and **SDG 17** on partnership for the goals.

- The combination of rising temperatures, reduction in water availability, and the occurrence of more severe and more frequent extreme events has already led to **human displacement** and could be aggravated by projected future climate changes. Limiting warming to 2°C already lowers the risk to moderate levels, whereas a 4°C increase could result in severe disruptions in ecosystems vital to the Asian economy, as well as humanitarian disasters, informal settlements, and unmanageable migration surges. Avoiding human displacement is relevant in achieving **SDG 11** on sustainable cities.

- **Food security** is a threat at higher levels of global warming. The IPCC estimates that a 1.5°C warming would put 32-36 million people at risk of lower crop yields, but at 2°C the projections increase about tenfold to 330-396 million people, mainly in tropical regions including SA and SEA. The biophysical impacts of climate change coupled with developmental challenges in the Asian region are likely to affect the agriculture sector and threaten food security. The region already suffers from declining soil productivity, groundwater depletion, water scarcity, and increased pest incidence and salinity. Limiting warming to 1.5°C, compared with 2°C, is projected to result in smaller net reductions in yields of maize, rice, wheat and potentially other cereal crops. In a 1.5°C world, **local yields** are projected to decrease **in tropical regions** that are world's major food producing areas, including South Asia. For Southeast Asia, a 2°C warming by 2040 indicated a one-third decline in per capita in **crop production** associated with general decreases in crop yields. However, at 1.5°C of warming, significant risks for crop yield reduction in the region can be avoided. These changes pose significant risks to poor people in both rural regions and urban areas of Southeast Asia, and are worse at 2°C of global warming compared with 1.5°C of warming. This will have direct implications for **SDG 2** on zero hunger as well as **SDG 8** relating to decent work and economic Growth.

- The IPCC shows that at 1.5°C warming only 4% more people than at present will be affected by **water scarcity**, compared with 8% under a 2°C scenario. While precipitation increase and run-off are expected within the Asian region, the Asian Development Bank (2017) foresees water scarcity in the region, mainly due to increasing demand from population and economic growth. This will affect achievement of **SDG6** on clean water and sanitation as well as **SDG8** on decent work and economic growth.

Chapter 2:

Analysis of mitigation pathways: Implications from the IPCC 1.5°C SR for mitigation pathways and energy system transformation in SA/SEA

2.1 Global mitigation pathways consistent with the Paris Agreement long-term temperature goal

The IPCC Special Report on 1.5°C (SR1.5), adopted and published in October 2018, outlines pathways for limiting global warming to 1.5°C and assesses global, regional, and sectoral transformations in the near-, mid-, and long-term, as well as synergies and trade-offs for sustainable development.

The SR1.5 provides the best available science for operationalising the long-term temperature goal of the Paris Agreement (LTTG). It provides the most comprehensive and up-to-date assessment of mitigation pathways. The SR1.5 Summary for Policymakers (SPM) establishes 1.5°C compatible mitigation pathways as those with no- or limited overshoot. These pathways limit median global warming to 1.5°C throughout the 21st century without exceeding that level ("no-overshoot"), or allow warming to drop below 1.5°C by the end of the century (around 1.3°C warming by 2100) after a brief and limited overshoot of median peak warming below 1.6°C around the 2060s ("low-overshoot"). With a peak warming of 1.6°C, these pathways meet several tests with reference to the LTTG: whereas the "hold below 2°C" pathways (used to inform the former Cancun Agreements temperature goal) peaked warming at up to 1.8°C, the 1.5°C-compatible pathways peak warming at a significantly lower level (1.5-1.6°C), hence they can be said to hold warming "well below 2°C", while warming by 2100 typically drops below 1.5°C with chance greater than 50% (see Annex I for background). In these 1.5°C mitigation pathways, total greenhouse gas emissions peak around 2020 and decrease rapidly to global zero around 2070.

In the context of defining the broad features of these pathways it is important to note that the IPCC SR1.5 identified limits based on sustainability and economic constraints on Carbon Dioxide Removal (CDR). These limits were found for bio-energy with carbon capture and storage (BECCS)[7] to be below 5 $GtCO_2$/yr globally in 2050 and for agriculture, forestry and land use (AFOLU)[8] below 3.6 $GtCO_2$/yr sequestration globally in 2050. We follow these limits in this report to define Paris Agreement long-term temperature goal compatible pathways as those that limit global warming to 1.5°C, or below, throughout the 21st century with no or limited (<0.1°C) overshoot. Hence, the pathways considered for this report are drawn from the "low overshoot" 1.5°C pathways assessed in the IPCC SR1.5, filtered to exclude those that exceed the BECCS and AFOLU sustainability limits identified in the IPCC SR1.5. In these pathways global average temperature increases above pre-industrial are limited to below 1.6°C over the 21st century and below 1.5°C by 2100 (typically 1.3°C).

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7 Bio-Energy with Carbon Capture and Storage, defined in Lower Mekong Countries: Cambodia, Laos, Thailand and Vietnam
SR1.5 glossary as: "Carbon dioxide capture and storage (CCS) technology applied to a bioenergy facility. Note that depending on the total emissions of the BECCS supply chain, carbon dioxide can be removed from the atmosphere."

8 SR1.5 refers to CDR measures in the Agriculture, Forestry and Other Land Use sector and notes such measu Fig. 2 res are mainly represented in the models as afforestation and reforestation.

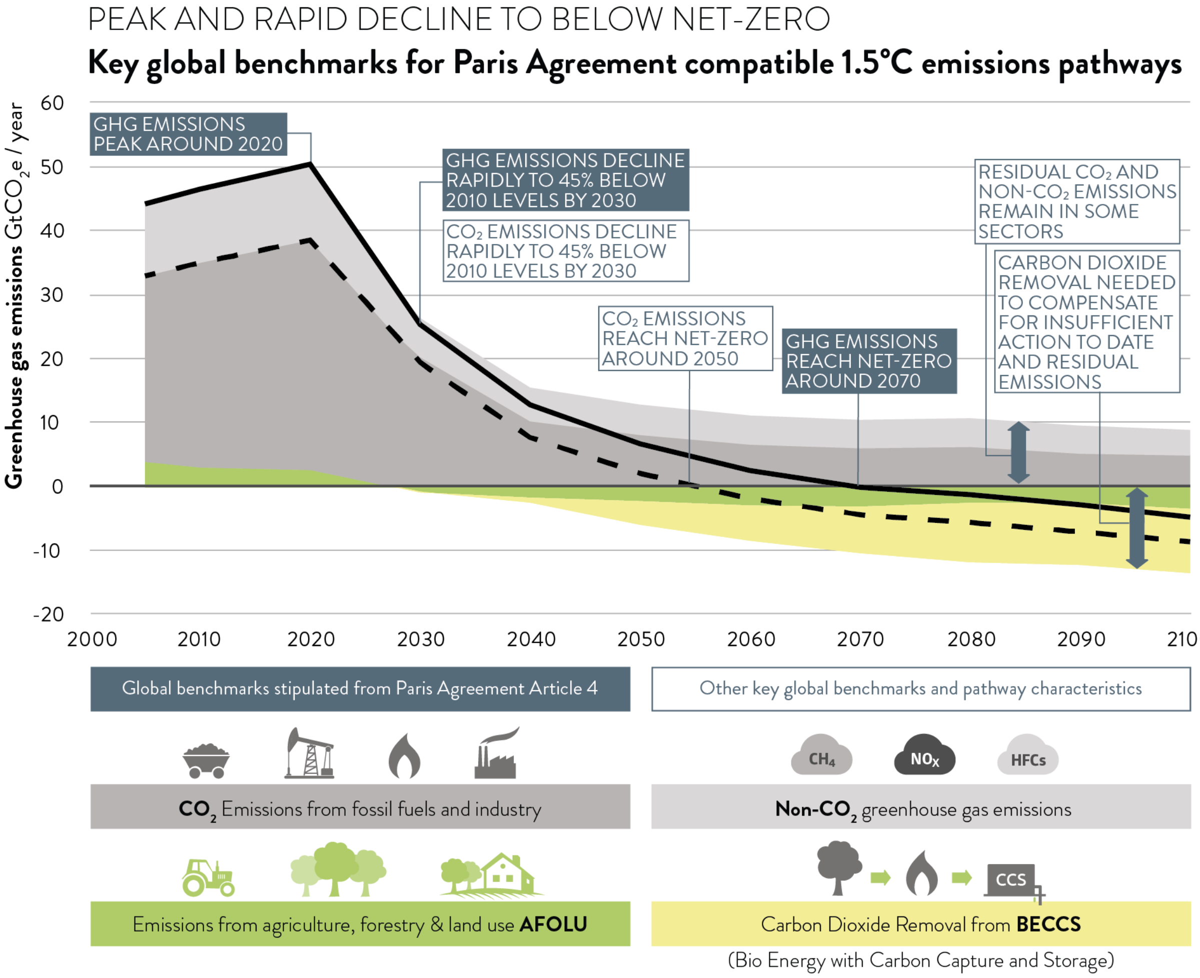


Figure 2.1. Illustration of the three benchmarks in Paris Agreement Article 4.1 for operationalisation of Article 2.1 (dark blue boxes) and global decarbonisation benchmarks (white box). This representative pathway is the median across all 1.5°C-compatible pathways from the IPCC SR1.5 that reach levels of Carbon Dioxide Removal (CDR) below the upper end of estimates for sustainable, technical and economic potential around 2050 from SR1.5 in the sector of Agriculture, Forestry and Land-Use (AFOLU), as well as via Bioenergy combined with Carbon Capture and Storage (BECCS).[9] Source: (Climate Analytics, 2019)

With these considerations the implications for operationalising the Article 4.1 global emission pathways can be outlined. Article 4.1 of the Paris Agreement is designed to operationalise the LTTG with global emission goals "in order to achieve the long-term temperature goal set out in Art. 2.1" – to peak global emissions "as soon as possible", followed by "rapid reductions thereafter", and to reach a balance between anthropogenic sources and sinks of greenhouse gases emissions in the second half of this century – are to be determined "according to best available science" so as to be consistent with the LTTG.

Figure 2.1 illustrates the Paris Agreement 1.5°C pathways and the three stages of global transformation and mitigation strategies as outlined in Art. 4.1 (peak, rapid decline and zero GHG emissions) as well as the fourth key mitigation benchmark for decarbonisation (net zero CO_2 emissions around 2050).

Taken together, key global benchmarks and characteristics can be identified based on these criteria:

9 All emissions and removals where calculated from the median emissions levels across the 46 pathways in the SR1.5 scenario database that are 1.5°C compatible and that reported data for all variables included here (Source: SR1.5 scenario database https://data.ene.iiasa.ac.at/iamc-1.5c-explorer , accessed 22 October, 2018)

- Peaking of greenhouse gas (GHG) emissions and of CO2 by around 2020
- Rapid decline of GHG and CO2 emissions of around 45% by 2030 (from 2010)
- Net zero total CO2 emissions by around 2050, negative thereafter
- Net zero total GHG emissions by around 2070, negative thereafter
- Net zero AFOLU emissions by around 2030 (between 2025 and 2040) then negative
- Bioenergy with Carbon Capture and Storage (or other negative emission technology) starting to be deployed at scale by around 2040

The IPCC SR outlines the range of mitigation strategies that can achieve the emissions reductions required to follow the pathways consistent with the PA LTTG described above.

Role of non-CO_2 Greenhouse Gases and air-pollution components

All pathways achieving the Paris Agreement LTTG require a rapid decarbonisation of energy systems, with global net anthropogenic CO_2 emissions declining by about 45% from 2010 levels by 2030 and reaching net zero around 2050. In addition, substantial reductions of emissions of non-CO_2 greenhouse gases such as methane and nitrous oxide from agriculture, industry and other sectors are needed, and as well a phase out of HFCs.

Air-pollution components, such as black carbon, are reduced as well. Some of the reductions are a result of targeted measures in industry, agriculture and waste sectors, but a large part, in particularly for methane and aerosols, results from mitigation measures in the energy and transport sectors focusing on a transition away from coal and natural gas in the energy sector and oil in transportation, which lead to associated methane emission reductions (from phasing out fossil fuel extraction) as well as reductions in black carbon from eliminating the combustion of coal and oil.

The SR1.5 shows that the mitigation pathways and benchmarks for CO_2 already account for reductions in co-emitted pollutants such as black carbon. Therefore, addressing these co-emitted pollutants has no place in an NDC or LTS, because they are already accounted for under 1.5°C-compatible benchmarks for CO_2 mitigation and provide no additional reduced warming.

In this report, we make use of two specific mitigation pathways that provide sector and regional information that is not readily available from the broader collection of mitigation pathways assessed in IPCC SR1.5. Figure 2.2 shows energy-related CO_2 emissions from the International Renewable Energy Agency Global Energy Transformation 2050 scenario (IRENA, 2018c) and the International Energy Agency Energy Technology Perspectives (ETP) Beyond 2C Scenario (B2DS) (Guay, 2014)(IEA, 2017). In addition, we will also consider the Greenpeace Advanced Energy [r]evolution scenario that presumes the potential for achieving 100% renewables in all sectors by 2050. (Greenpeace, 2015a)

The IEA ETP B2DS pathway provides a close analogue to a Paris Agreement compatible 1.5°C decarbonisation pathway. We have complemented energy-related CO2 emissions in this pathway with land-use emissions and emissions from other greenhouse gases and evaluated total emissions with the carbon cycle and climate model MAGICC. This confirms consistency between the B2DS and the PA long-term temperature goal[10]. The IPCC SR1.5 has also considered the utility of B2DS for

10 See also the Climate Action Tracker Scaling Up Climate Action for the EU Textbox 2, page 65 https://climateactiontracker.org/documents/505/CAT_2018-12-06_ScalingUp_EU_FullReport.pdf

providing information on 1.5°C consistent pathways. Chapter 2 of IPCC Special Report shows the B2DS scenario to be consistent with 1.5°C pathways in terms of emissions up to 2060 (Section 2.4.3 and Figures 2.18, 2.19 and 2.20 in IPCC SR1.5). While emissions intensity by 2050 in the power and industry sectors in the B2DS pathway are above those typical for 1.5°C pathways, B2DS emissions intensity is lower in the transport and buildings sectors. Because the B2DS also provides some specific regional data for ASEAN countries and for India (as well as for China) in the ETP 2017 report, and also reports data for the entire ASIA region in the SR1.5 database, this information will be used as the starting basis for evaluating regional energy system transformation under a PA-compatible pathway.

The IRENA Global Energy Transformation (GET) based on their REmap pathways is a scenario that aims at consistency with the former (Cancun) "stay below 2°C" temperature goal, and not with the Paris Agreement LTTG. It relies on significant increases in the rate of deployment of renewables in all sectors, as well as on enhanced energy efficiency, especially in the buildings sector. The power sector shows an increase to 85% renewable energy by 2050 in this scenario, and renewable electricity provides about 65% of final energy consumption.

The Greenpeace Advanced Energy [r]evolution scenario sets as a target 100% renewable energy in all sectors by 2050, without the use of nuclear power or CCS. It is considered here to illustrate a case for higher renewable energy integration potential.

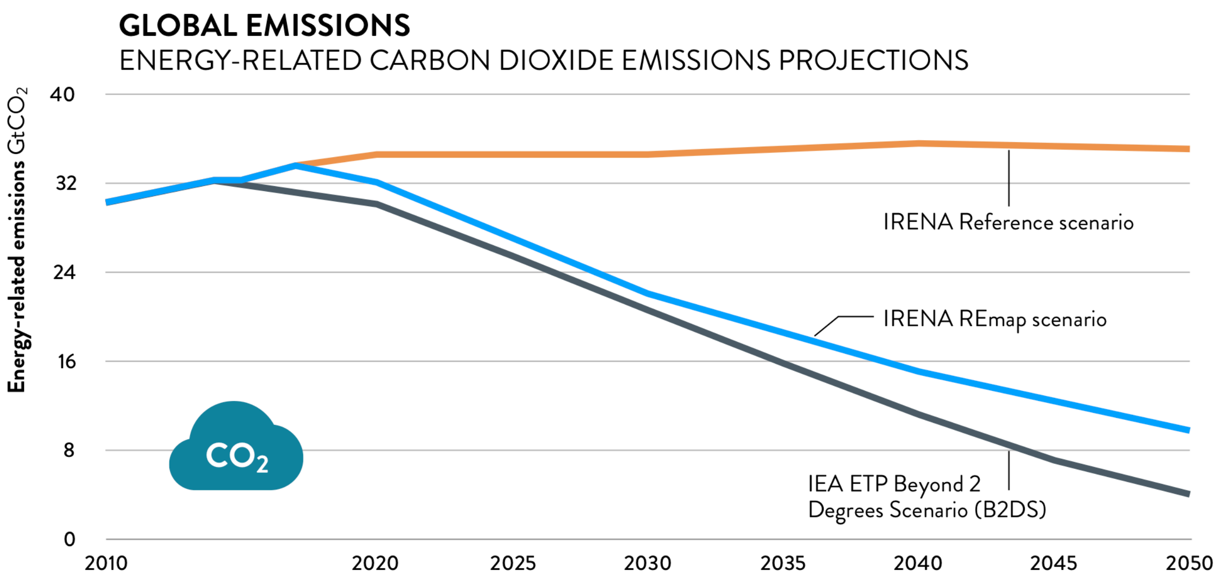


Figure 2.2 - IRENA REmap world energy-related CO2 emissions and the IEA ETP B2DS emissions pathway. The latter is a proxy for Paris Agreement compatible 1.5°C emissions.

2.2 Global energy system transformation consistent with the Paris Agreement LTTG

A rapid and profound decarbonisation of energy supply is a key and driving characteristic of 1.5°C pathways, leading to a net-zero-emissions energy supply system by mid-century. Energy system transformation is characterised by:

- Fully decarbonised primary energy supply by mid-century (including with CCS)
- Large demand reductions across all end-use sectors by 2030
- Large reductions of fossil fuel use, in particular coal (minus 64% by 2030, minus 75% by 2050) and oil (minus 11% by 2030, minus 60% by 2050)
- Rapid increase in use of renewable energy
- Bioenergy is used in many 1.5°C pathways, both with CCS (BECCS) and without, with uncertainties regarding limits to sustainable use.
- Full decarbonisation of electricity generation by 2050, mainly through increased use of renewable energy reaching shares of over 50% by 2030 and over three-quarters by 2050 globally.
- Coal use for electricity reduced dramatically by around 70% in 2030 and complete global phase out by 2050. Due to high carbon intensity, no role for coal even with CCS by 2050.
- Electrification of end-use sectors (transport, buildings, and some industry processes) and decarbonisation of final energy other than electricity, for example through the use of biofuels, hydrogen or other energy carriers (aviation, shipping, and some industry processes). While electrification leads to an increased demand in electricity, reducing energy demand to meet energy services, including through enhanced energy efficiency is an important element of all mitigation pathways.

The extent to which a decarbonised energy supply relies on fossil CCS varies between pathways. Some pathways as well as an increasing number of regional or national pathways show the possibility of decarbonising the energy supply without the use of fossil CCS by around mid-century.

Coal and oil use decrease dramatically over the next three decades in 1.5°C-compatible pathways.

Natural gas shows a more complex behaviour, with many models relying on CCS combined with natural gas in electricity generation as a low-emissions source. Most striking of all is the rapid increase in use of renewable energy sources.

Renewable energy increases substantially in all mitigation pathways, including biomass use for primary energy. **Bioenergy** use represents a key area of uncertainty in Integrated Assessment models[11] and it is important to consider assessments of limits to the sustainable potential for bioenergy use, considering sustainable development needs for food production and limiting biodiversity impacts, as well as address the need for sustainable management. It is used in all pathways (1.5°C, 2°C and higher), as it is today. In deep mitigation pathways bioenergy is combined with CCS (BECCS), but it also finds robust deployment independent of availability of CCS. Bioenergy deployment is similar in 1.5°C and 2°C consistent pathways. The IPCC refers to high agreement in the literature that the sustainable bioenergy potential in 2050 would be restricted to around 100 EJ per year, with large uncertainty and limited information on post-2050 deployment, for which technical and economic potential is found to be substantially larger. While many 1.5°C pathways constrain

11 https://climateanalytics.org/publications/2018/integrated-assessment-models-what-are-they-and-how-do-they-arrive-at-their-conclusions/

bioenergy deployment to sustainable limits, many others reach higher levels that may put significant pressure on food production and prices, and biodiversity.

Table 2.1 - changes with respect to 2015 for primary energy sources at the global level for PA-consistent Integrated Assessment Models (IAMs) and for the IEA ETP B2DS.

Major primary energy sources		2025	2030	2050
Coal	Global - IAMs	-30% (-35%, -30%)	-64% (-64%, -70%)	-75% (-75%, -79%)
	Global (B2DS)	-37%	-54%	-73%
Oil	Global - IAMs	-5% (-2%, -10%)	-18% (-12%, -28%)	-63% (-36%, -82%)
	Global (B2DS)	-13%	-22%	-55%
Natural Gas	Global - IAMs	4% (-3%, +9%)	-1% (-14%, 7%)	-2% (-31%, 0%)
	Global (B2DS)	8%	4%	-46%
Non-biomass Renewable	Global - IAMs	106% (74%, 111%)	190% (170%, 210%)	500% (400%,560%)
	Global (B2DS)	+100%	+185%	+630%

Power sector

The power sector contributes approximately 40% of global energy-related CO_2 emissions and is key to all decarbonisation strategies, also because electrification is a key strategy to decarbonise end-use sectors such as transport, buildings, and industry.

Decarbonising electricity generation at the scale and speed necessary to be consistent with the Paris Agreement LTTG implies that global **coal-fired power will be reduced dramatically to around 70% below 2010 levels by 2030, and phased out globally by 2050**. This is an area of high agreement between all energy-economy models.

Another robust finding in all mitigation pathways is that **the renewable share of electricity generation will increase significantly, to over 50% by 2030 and to over three-quarters by 2050** with fast technical and economic improvements in particular of wind and solar, as well as storage technologies.

Nuclear power plays a larger or smaller role depending on modelling assumptions made in Integrated Assessment Models (IAMs), with some pathways showing a decline in capacity and share.

While the use of **natural gas** for electricity generation, replacing more carbon intensive coal, plays a transitional role in decarbonising electricity generation, its continued use would only be consistent with the Paris Agreement temperature goal if it is used with carbon capture and storage (CCS). Even then it would only play a small role in electricity generation by 2050 at only around 8% of global electricity generation. Due to incomplete CO_2 capture rates, the use of gas with CCS would have to be balanced out with additional carbon dioxide removal (CDR).

The political, economic, social and technical feasibility of **solar energy, wind energy, and electricity storage technologies** has improved dramatically over the past few years, with costs dropping rapidly over the last few decades with corresponding growth trajectories much faster than expected (IRENA, 2018c).

These fast developments enable more stringent near-term mitigation than currently planned. For example, rooftop solar has been identified as competitive in many areas, and solar PV with batteries are cost effective in many rural and developing areas, with small-scale distributed energy projects already being implemented in many countries with potential for consumers becoming producers. Several countries and other constituencies have adopted targets of 100% renewable electricity as this meets multiple social, economic, and environmental goals apart from mitigation of climate change.

Nuclear energy and CCS in the electricity sector have not shown similar improvements, with costs of nuclear power having increased over time in some developed countries, and costs of CCS not coming down over the last decade, which - together with more limited co-benefits than renewable energy - makes these technologies increasingly unlikely to be able to compete with renewable energy, which is not yet reflected in many energy-economy models.

In the next section, system transformations for South and Southeast Asia are illustrated by the IEA ETP B2DS and IRENA REmap pathways. Globally, the REmap pathway has a more rapid growth of renewables than B2DS. By 2050, phase out of fossil fuels has progressed within the range of IPCC SR1.5 1.5°C pathways, but in the near term (2030) the transformation is a little slower, which poses a risk for the 2030-2050 in terms of failure to accelerate climate action in that period and for stranded assets.

Table 2.2 - Within the electricity sector, shares of generation from different sources and how these change over time. Shown here are data from PA-compatible IAMs and for the IEA ETP B2DS at the global level of aggregation.

Share of energy sources/technology for power generation	Region (from B2DS)	Fraction of total electricity generation			
		2015	2025	2030	2050
Coal w/o CCS	Global - IAMs	37% (36%, 38%)	20% (16%,22%)	7% (3%, 10%)	0%
	Global (B2DS)	41%	20%	11%	0%
Natural gas w/o CCS	Global - IAMs	23% (21%, 24%)	22% (21%,24%)	18% (17%,21%)	2% (1%, 4%)
	Global (B2DS)	22%	26%	24%	2%
Renewable energy (including biomass)	Global - IAMs	24% (23%, 24%)	39% (37%,42%)	52% (48%,54%)	69% (64%,75%)
	Global (B2DS)	23%	39%	47%	74%
Nuclear	Global - IAMs	13% (13%, 14%)	14% (13%,15%)	15% (14%, 16%)	9% (8%, 25%)
	Global (B2DS)	11%	13%	15%	16%

2.3 Energy system transformation in South Asia and South-East Asia

Countries in SA and SEA are building up extensive energy infrastructure to satisfy growing electricity demand with increasing income levels, economic transformation, urbanisation trends and progress in access to modern energy for a large and growing population. Electricity consumption in Southeast Asia has more than tripled between 1995 and 2015, reaching over 872 terawatt hours (International Renewable Energy Agency (IRENA), 2018).

In this period, electricity generation increased on average 7% per year, especially due to the increases in Indonesia, Malaysia, the Philippines, Singapore, Thailand and Viet Nam. In the lower-Mekong countries, electricity generation has even increased eightfold since 1995. In the region's largest economy, Indonesia, electricity generation nearly tripled since 1995, rising by over 3% every year, while in the same time period Viet Nam's power generation increased more than tenfold, growing by over 6% every year.

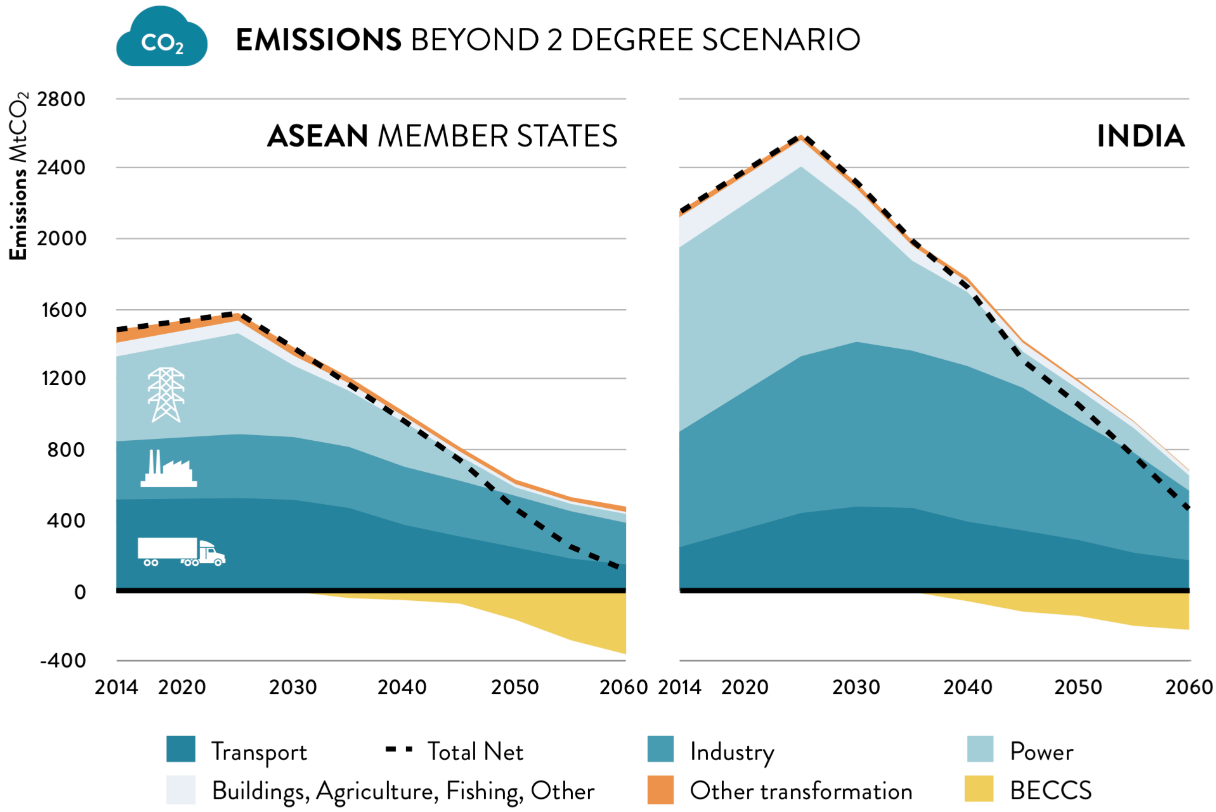


Figure. 2.3 – Energy-related emissions for all sectors in the IEA ETP B2DS for ASEAN (left) and India (right). Solid shaded areas are emissions excluding BECCS for each sector (there is no BECCS in Transportation or the Buildings, Agriculture, Fishing and Other sectors). BECCS from Industry, Power and Other Transformation[12] sectors are combined.

Fossil fuels are still the main focus in the development of energy infrastructure, which increasingly contributes to global carbon emissions and puts economies at risk of locking into carbon intensive energy infrastructure. At the same time, many Asian regions, and especially urban areas, suffer from increasing environmental pollution.

Table 2.3 summarises key benchmarks and characteristics of global mitigation pathways for the whole of Asia[13] based on the IPCC dataset[14] as well as for SEA as represented by ASEAN and for SA,

12 In the definition of IEA ETP, Other transformation includes losses by gas works, petroleum refineries, coal and gas transformation and liquefaction as well as biofuel and hydrogen production. Energy use in blast furnaces, coke ovens and petrochemical plants is not included, but accounted for in the industry sector.

with India taken as representative for the region. Figure 2.3 shows the resulting energy related CO_2 emissions for the ASEAN countries (left) and for India (right) as projected in the IEA ETP B2DS. These show a peak in the near term and rapid decline after 2025 in CO_2 emissions, with a decrease by 2060 of 90% with respect to 2014 in SEA, and of nearly 80% in India, whereas for the ASIA region as a whole (not shown), the B2DS shows a decrease of over 90%.

Table 2.3 - Primary energy sources in IAM 1.5oC compatible pathways for the ASIA region, as well as in the IEA ETP B2DS. In each column the entries represent the percentage change in primary energy source consumption with respect to 2015 (or 2014 in the case of ASEAN and India). For the range of IAMs, the values are medians with interquartile ranges given in parenthesis. The ASIA region includes all of the SA and SEA countries, as well as China, Mongolia, Taiwan, North- and South Korea.

Major primary energy sources	Region	2025	2030	2025
Coal	ASIA - IAMs	-29% (-26%, -34%)	-63% (-59%, -73%)	-78% (-65%, -80%)
	ASIA (B2DS)	-21%	-39%	-67%
	ASEAN (B2DS)	7%	-43%	-34%
	India (B2DS)	-9%	-36%	-54%
Oil	ASIA - IAMs	7% (4%,14%)	0% (-10%, +16%)	-58% (-15%, -76%)
	ASIA (B2DS)	18%	16%	-22%
	ASEAN (B2DS)	-5%	-6%	-39%
	India (B2DS)	37%	48%	16%
Natural Gas	ASIA - IAMs	43% (18%, 59%)	74% (16%, 101%)	35% (17%, 77%)
	ASIA (B2DS)	63%	78%	15%
	ASEAN (B2DS)	17%	34%	-16%
	India (B2DS)	320%	501%	243%
Non-biomass Renewable	ASIA – IAMs	+180% (15%, 200%)	310% (24%, 380%)	760% (720%, 860%)
	ASIA (B2DS)	134%	240%	700%
	ASEAN (B2DS)	148%	272%	852%
	India (B2DS)	315%	663%	2859%

This comparison shows that the key characteristics of the global transformation of energy systems as described in the previous section also hold for SA and SEA, with some important differences.

While large reductions in fossil fuel use, in particular coal, are a dominant characteristic for all 1.5°C pathways, the models expect an initial increase in the next years (by 2025) in Asia (more prominent in the IEA B2DS), and (in the case of the IEA B2DS scenario) in Southeast Asia in particular, but not in India, where coal use is expected to diminish already by 2025. For oil, global scenarios expect a substantial decrease, whereas the IEA B2DS scenario shows an increase in India and a decrease in SEA.

13 The countries included in the region ASIA in the dataset used include SA and SEA as well as China, Mongolia, Taiwan, North- and South Korea.

14 IAMC 1.5°C Scenario Explorer and Data hosted by IIASA. url: data.ene.iiasa.ac.at/iamc-1.5c-explorer

While there is a large variation of the overall globally aggregated natural gas use, a common feature of the mitigation pathways is that gas use increases until 2030 in Asia, in particular in India, but less so in SEA, with the use decreasing again by 2050.

All scenarios show a rapid increase in renewable energy that is much faster in Asia, and in particular in SEA and India than at global level – corresponding with the much higher increase in primary energy demand. In the B2DS, total primary energy for ASEAN is 50% higher in 2050 than in 2014, and in India the increase is by 90%; globally, total primary energy consumption in this scenario is nearly the same in 2050 as it is today.

Table 2.4 shows the comparison of key benchmarks for energy sources for power generation.

Table 2.4 – Benchmarks for energy sources for power generation for 1.5 compatible pathways – at regional and national level.

Share of energy sources/ technology for power generation	Region	Fraction of total electricity generation			
		2015	2025	2030	2050
Coal w/o CCS	ASIA - IAMs	58% (55%, 60%)	33% (26%, 35%)	11% (5%, 17%)	0%
	ASIA (B2DS)	57%	34%	20%	0%
	ASEAN (B2DS)	34%	26%	8%	0%
	India (B2DS)	75%	36%	11%	0%
Natural gas w/o CCS	ASIA – IAMs	11% (10%, 14%)	12% (8%, 16%)	12% (9%, 19%)	1% (0%, 1%)
	ASIA (B2DS)	13%	17%	19%	2%
	ASEAN (B2DS)	44%	38%	40%	1%
	India (B2DS)	5%	27%	36%	6%
Renewable energy (including biomass)	ASIA – IAMs	20% (17%, 22%)	40% (33%, 43%)	55% (49%, 57%)	62% (60%, 67%)
	ASIA (B2DS)	24%	39%	47%	73%
	ASEAN (B2DS)	18%	31%	43%	81%
	India (B2DS)	15%	31%	42%	75%
Nuclear	ASIA – IAMs	6% (5%, 7%)	12% (10%, 12%)	15% (13%, 16%)	13% (5%, 32%)
	ASIA (B2DS)	4%	8%	11%	16%
	ASEAN (B2DS)	0%	3%	5%	4%
	India (B2DS)	3%	5%	9%	16%
Decarbonised share of electricity generation	ASIA – IAMs	26% (24%, 29%)	52% (46%, 60%)	75% (68%, 85%)	99% (98%, 99%)
	ASIA (B2DS)	28%	48%	60%	97%
	ASEAN (B2DS)	18%	34%	51%	99%
	India (B2DS)	18%	36%	51%	93%

Key characteristics identified for the globally aggregated scenario results also hold for Asia, as well as India and SEA: A strong trend toward decarbonisation of electricity generation by 2050, mainly through increased use of renewable energy reaching shares of over 40% (global: 50%) by 2030 and over three-quarters by 2050 globally as well as in SEA and India.

Use of **unabated coal** (without CCS) is reduced dramatically by 2030 and phased out by 2040 in Asia overall (see Figure 2.4), and also specifically in SEA and India.

Natural gas is often seen as a bridging fuel for a transition to renewable energy. For natural gas without CCS, the picture is more complex than for coal, with the share initially increasing in India and then decreasing to be phased out by 2050, the share does not increase in SEA until 2030, and is also phased out by 2050. Overall and taking into account the increase in primary energy demand, the use of natural gas without CCS increases in Asia until 2030, and then declines to be phased out by mid-century (Figure 2.5) confirming there is no room for natural gas in the long term without the use of CCS. The IEA B2DS scenario shows a larger reliance on natural gas without CCS over the coming decades in ASIA than most of the IAM scenarios.

Nuclear energy increases from zero to a low share (below 5%) in SEA by 2050 and from the current low level in India to a share of 16%, comparable to the global share. However, given that costs of nuclear power have increased over time in some developed countries, it is also unlikely that nuclear energy will be able to compete with renewable energy, which is not reflected in many energy-economy models.

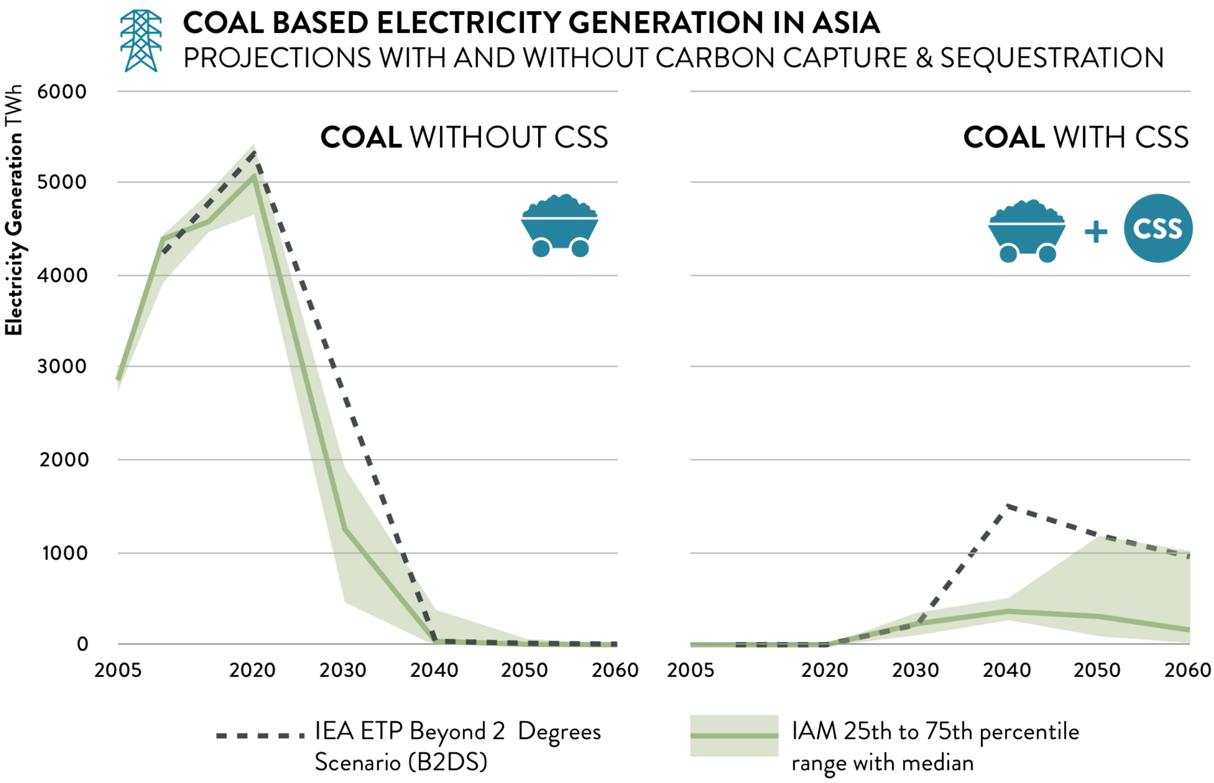


Figure 2.4 - Electricity generation from coal both with (orange) and without (blue) CCS. Shown are the median for PA-compatible IAMs, with interquartile range (dashed lines), as well as the results from the IEA ETP B2DS, both for the ASIA region.

The IEA model shows an increase in the **use of CCS** not only with gas but also with coal in Asia, in particular in SEA. However, given that in contrast with renewable energy, costs of CCS have not come down over the last decade and this technology does not provide the sustainable development benefits that renewable energy does, it is unlikely that CCS will be able to compete with renewable energy and advanced storage. This relative cost disparity is not yet reflected in many energy-economy models. To be an effective technology in a zero carbon emission energy system, nearly all emitted carbon dioxide from fossil fuel combustion must be captured. This is far from being the case in any pilot CCS projects to-date with expected capture rates in the 80-90% range.

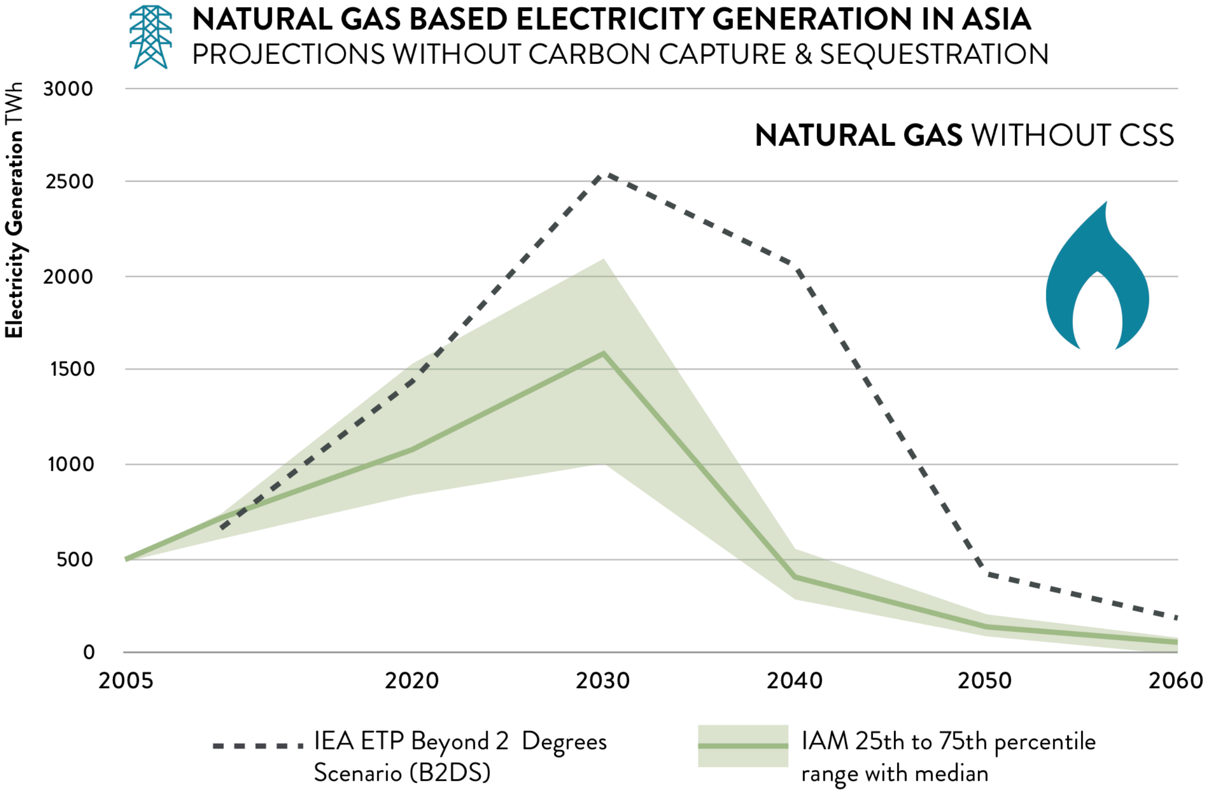


Figure 2.5 - Electricity generation from natural gas without CCS. Shown are the median for PA-compatible IAMs, with interquartile range (dashed lines), as well as the results from the IEA ETP B2DS, both for the ASIA region.

Given the long lifetime of power plant infrastructure, and, in the case of gas, related infrastructure for extraction, processing and transporting the fuel, these results show that there is a high risk of stranded assets with investment not only in coal, but also in natural gas. The role of natural gas is expected to be reduced dramatically, and could be reduced even faster given CCS will not be able to compete with renewable energy. The IEA ETP scenario shows a sharp decrease in the capacity factor of unabated coal power plants by 2030 in SEA and for natural gas power plants by 2045. This shows that newly built power stations would not be used fully throughout their planned lifetime, making an investment very risky.

Key characteristics of mitigation pathways for Southeast Asia – results of IEA ETP B2DS scenario

The role of different fuels in primary energy supply as well as in power generation in SEA needs to be seen in the context of a large increase in primary energy demand (Fig. 2.6, left) given SEA is one of the fastest growing regions in the world. The reduction in fossil fuel use is very strong compared to the reference scenario.

The most striking characteristic of the 1.5°C pathway for SEA is the very high increase in generation from **renewable energy**, which becomes the dominant source even within the next decade – against the backdrop of an overall sharp increase in electricity generation (Fig. 2.6, right). Given natural gas and coal would only have a role with CCS to be consistent with the decarbonisation needs, the share and growth of renewable energy would be expected to be even faster considering CCS is unlikely to be able to compete with renewable energy. For example, the share of decarbonised electricity generation (including nuclear and fossil fuels with CCS) adds up 34% in 2025, 51% in 2030, and 76% in 2040, and full decarbonisation by 2050 for ASEAN. These would be the share expected for renewable energy, considering neither CCS nor nuclear energy are likely to be able to compete with renewable energy.

A key feature identified already at the global level is the role of electrification to decarbonise end-use sectors, in particular transport (Fig. 2.7). This, together with the already higher increase in electricity demand due to the need to provide access to clean energy for a growing population, with a large number of people still without access to electricity in SEA, leads to an even higher increase in electricity demand than in primary energy demand.

The change to renewable sources is most dramatic in the **transport sector**, from 1% today to approximately 50% by 2050. Biofuels and electricity play important roles, with decarbonisation of the power sector and increased shares of electric vehicles leading to an increased share of renewables in transportation final energy consumption.

In the **residential sector**, total final energy increases by only about 10% by 2050 and the share of renewable energy in final energy consumption also increases modestly, from 70-75% to 80-90%, with traditional biomass giving way to electrification in a move to achieving the goal of access to clean energy for all.

The **industry sector** is expected to see an increase in final energy demand of 60% by mid-century in SEA, with a large fraction of the increase in the form of renewable energy, either modern biomass or electricity. The IEA scenario still includes a large share of natural gas in the industry sector, without including the option of replacing this with renewable energy based hydrogen (see IRENA 2018, IEA 2017). This option can lead to a faster decarbonisation of the industry sector, with hydrogen replacing fossil-fuel based feedstocks in high-emission applications.

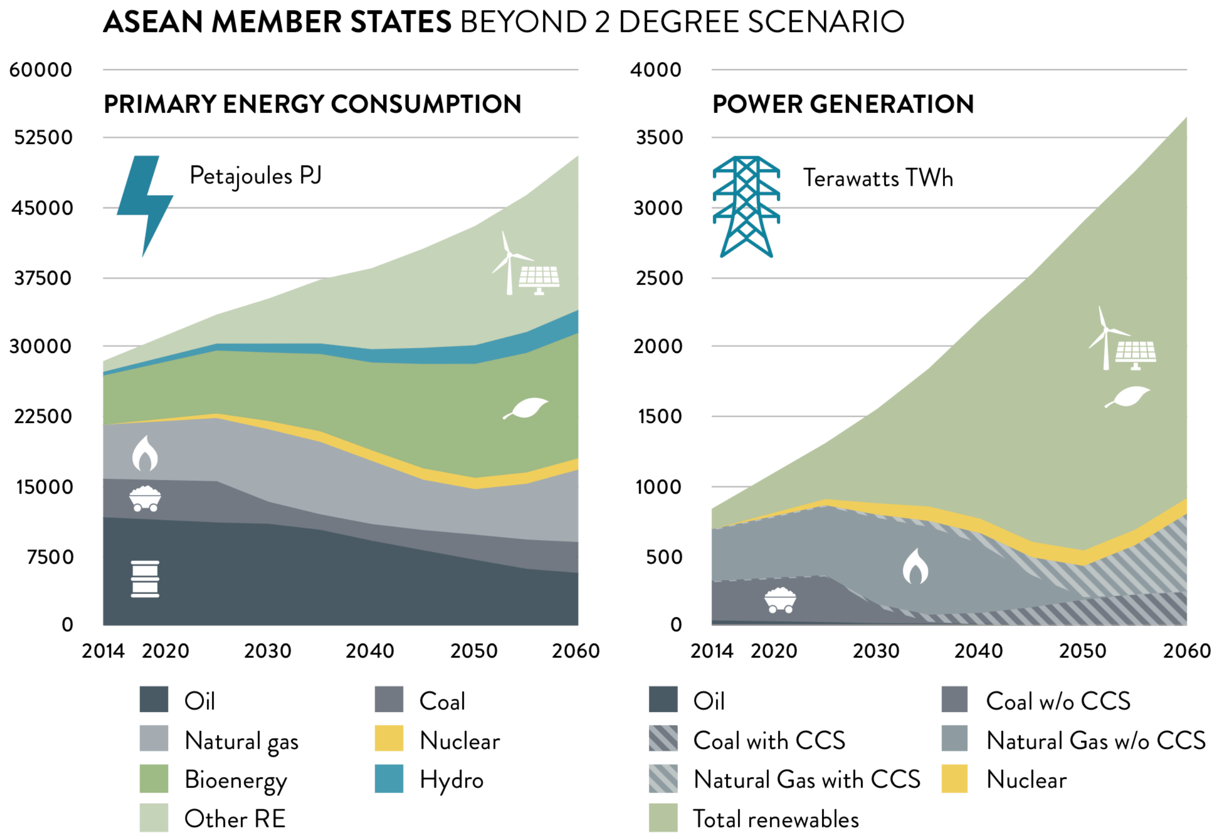


Figure 2.6 - Primary energy consumption by fuel in the ASEAN countries from the IEA ETP B2DS (left-hand side). Total power generation in ASEAN for the IEA ETP B2DS (right-hand side).

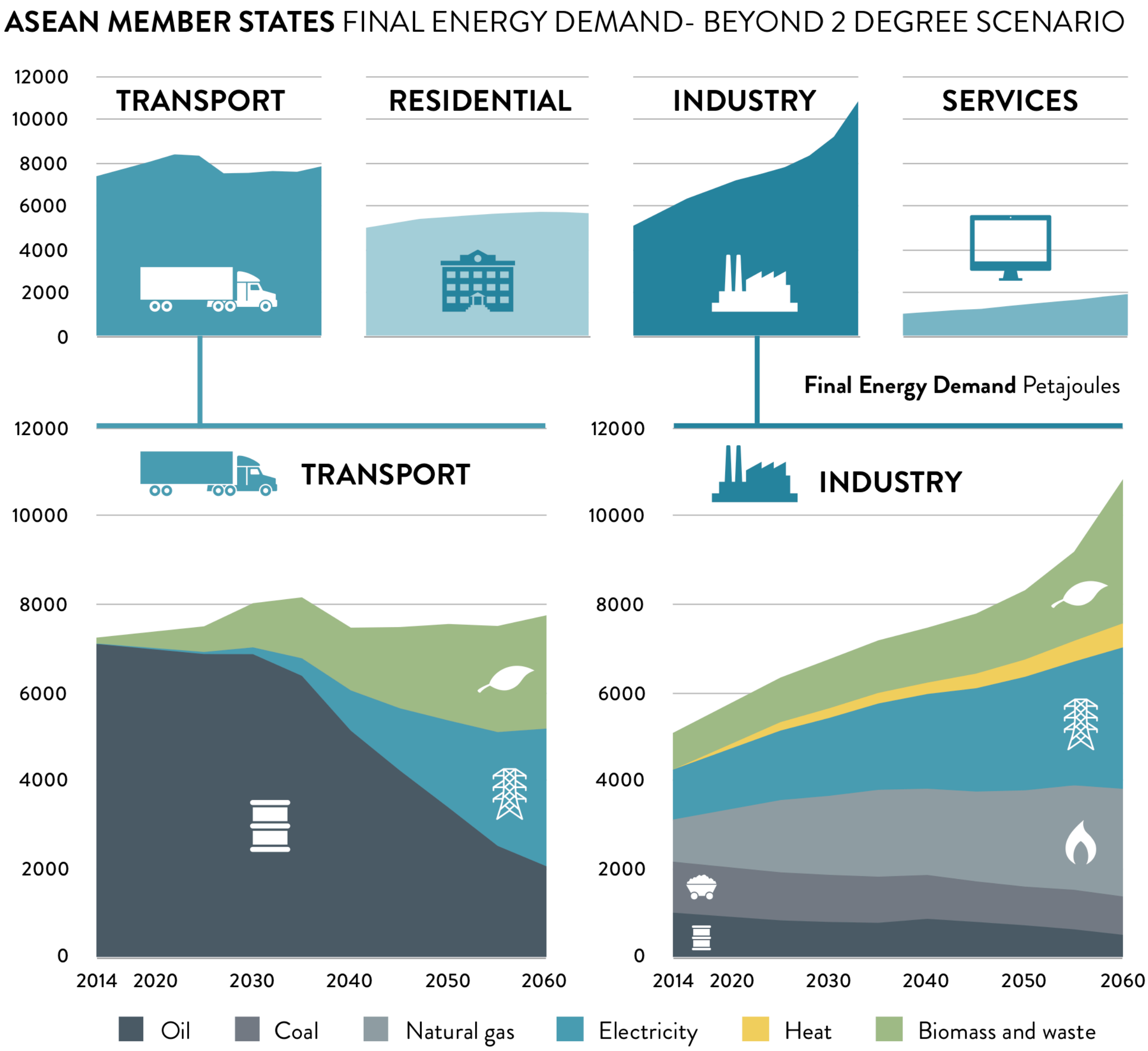


Figure 2.7 - Final energy consumption in end use sectors for ASEAN in the IEA ETP B2DS, showing the shift from petroleum to biofuels and electricity in the transport sector (left-hand side) and industry (bottom) where electrification plays an important role). As the electricity sector itself becomes increasingly renewables-based, the overall renewable energy contribution to the industry sector begins to overtake that of fossil fuels. Overall final energy use in the industry sector increases most dramatically in ASEAN (right-hand side).

The dramatic increases in renewable electricity is illustrated most strongly by results from other models that do not rely as much or not at all on CCS or nuclear energy to decarbonise the electricity generation, such as the Greenpeace Advanced Energy [r]evolution scenario and the selected IAM scenarios that explicitly meet the PA LTTG and sustainability constraints as defined previously.

Fig. 2.8 shows the share of renewables in electricity generation in a range of scenarios for the region. Although the regional aggregation differs between these scenarios, we see that the IEA B2DS is one of the more conservative in projecting growth of renewables in the power sector, given it assumes a role for both fossil fuels with CCS and nuclear energy. The IRENA REmap pathway for renewable penetration is similar to the B2DS, but for the former (Cancun) "stay below 2°C" temperature goal; we expect that a modified version of the IRENA REMAP that would be Paris Agreement consistent would lead to a higher share of renewable energy. The potential for a faster transition to renewable energy in the regions and in key countries of these regions will be explored further in Chapter 4.

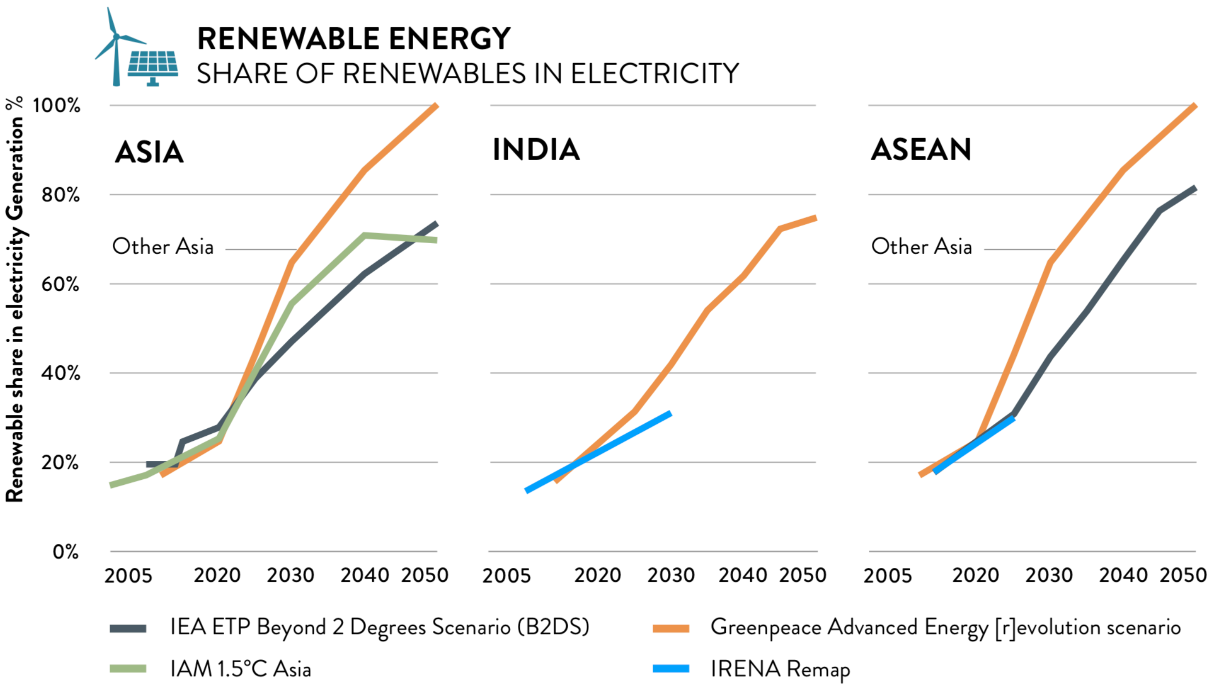


Figure 2.8 - Share of total renewable energy in electricity systems for a selection of scenarios with regional representation (ASEAN) as well as for Asia as a larger region.

Key characteristics of mitigation pathways for South Asia – results of IEA ETP B2DS scenario for India

The IEA B2DS scenario provides information about India separately, which we examine as one example of energy system transformation in the region that is consistent with the PA LTTG. At present, primary energy consumption is dominated by coal, and in the B2DS coal consumption decreases by 60% by 2060, the end of the analysis period, but quite sharply to 50% of current consumption by 2035 (Fig. 2.9). Natural gas starts from a low level currently and increases dramatically in this scenario, overtaking coal within a decade; however, both natural gas and oil peak in consumption by the mid-2030s. In the case of oil, the transportation sector begins a transition away from petroleum products toward electrification and biofuels (Fig. 2.10).

Similarly, to what is seen for SEA in the IEA ETP B2DS, electricity generation in India is projected to be dominated by renewables within a couple of decades, as shown in Figure 2.11. Although natural gas, even without CCS, is projected to play an intermediate role in the scenario, the rather rapid decline in consumption of natural gas for electricity production again raises the question of the economics of investments in generation capacity in the next decade or two that would then only have a short lifetime in operation.

At the same time, referring to Fig. 2.12, we see that there are scenarios that project the potential for a much quicker build-out of renewable energy than what is shown in either the IEA B2DS or in the range of 1.5°C compatible IAMs. Although the REmap scenario shows a very similar rate of increase to that of B2DS, as discussed above for SEA, the REmap scenario is only compatible with the former (Cancun) "stay below 2°C" goal and would therefore require a larger growth rate to achieve the PA LTTG. Once again, the Greenpeace Advanced Energy scenario shows the highest growth rate for renewables and does not include either nuclear power or CCS.

Adding up the share of decarbonised electricity generation for India in the IEA B2DS, this amounts to 51% in 2030 (renewable energy and nuclear), which is still below the share in the Greenpeace Advanced Energy Scenario (over 60%).

Just as in Southeast Asia, the change to renewable sources is most dramatic in **India's transport sector**, from 1% today to approximately 50% by 2050, with final energy demand increasing by 150% by mid-century. Both biofuels and electricity play important roles, with decarbonisation of the power sector and increased shares of electric vehicles leading to an increased share of renewables in transportation final energy consumption.

The total final energy increases by only about 10% by 2050 also in **India's residential sector**, and the share of renewable energy in final energy consumption also increases modestly, from 70-75% to 80-90%, with traditional biomass giving way to electrification in a move to achieving the goal of access to clean energy for all.

India's industry is expected to see an increase in final energy demand of 120% by mid-century, largely in the form of renewable energy, either modern biomass or electricity.

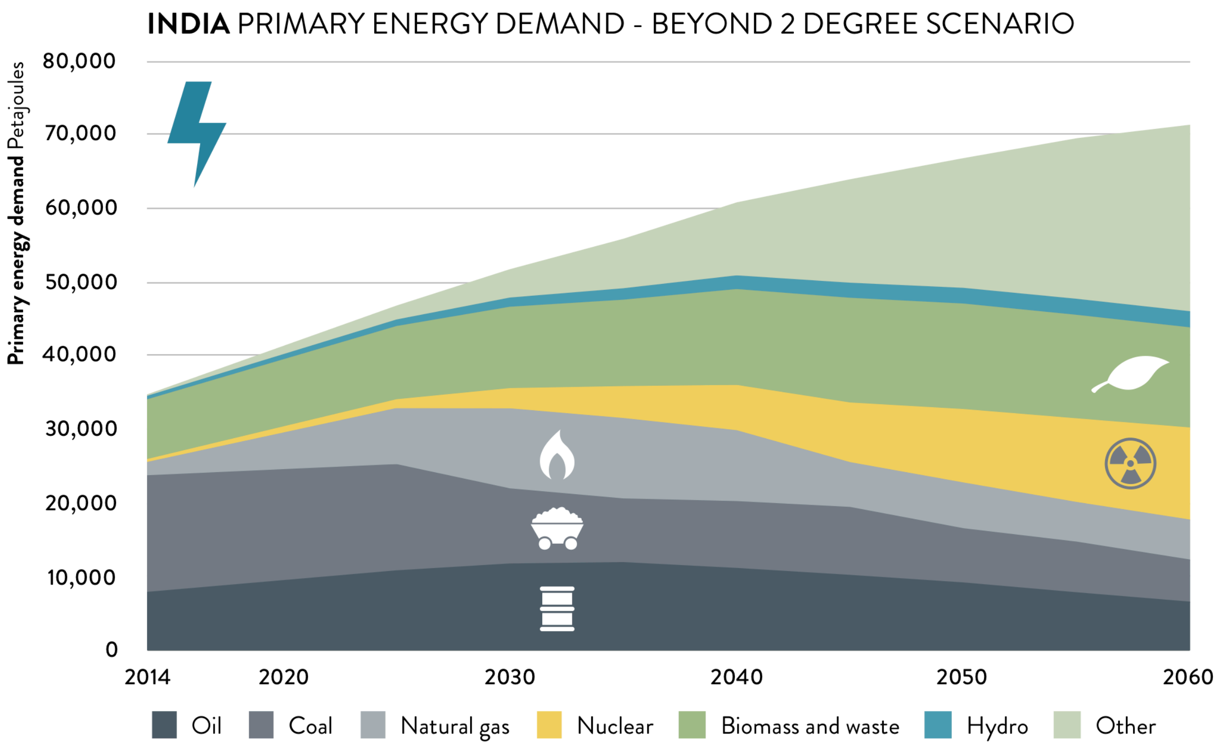


Figure 2.9: Total primary energy supply in India for the IEA ETP B2DS. Growth in renewables is rapid, but significant, although declining, amounts of fossil fuel energy are projected

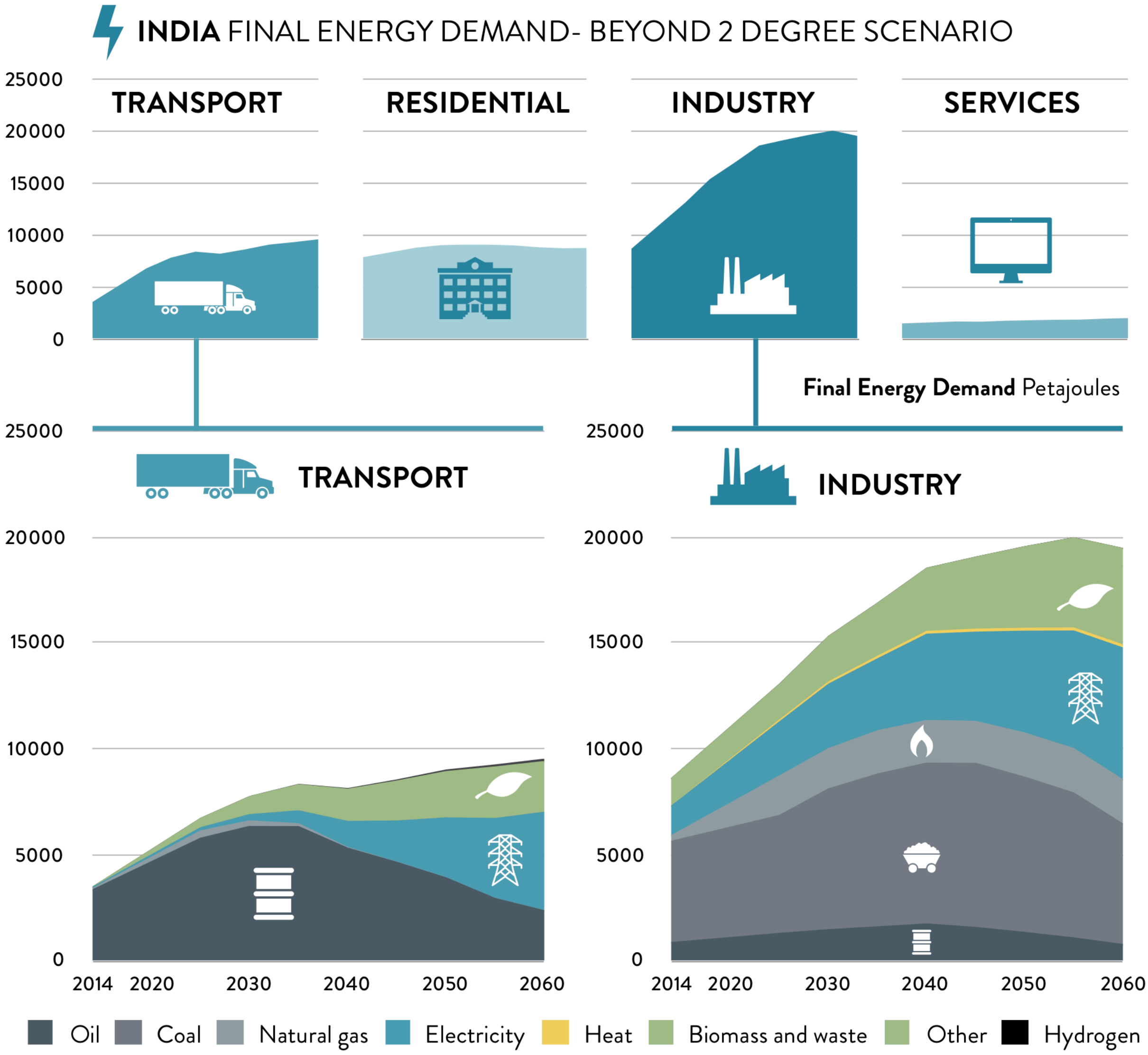


Figure 2.10 – Final energy consumption in end use sectors for India in the IEA ETP B2DS. Within two decades oil consumption in the transportation sector (bottom left-hand side) peaks and declines, with a subsequent transition toward electricity and biofuels. All fuels used in the industrial sector (bottom right-hand side) grow along with overall energy demand growth over the next two decades, after which fossil fuel use starts to decline and overall renewable energy through electricity and biomass sources.

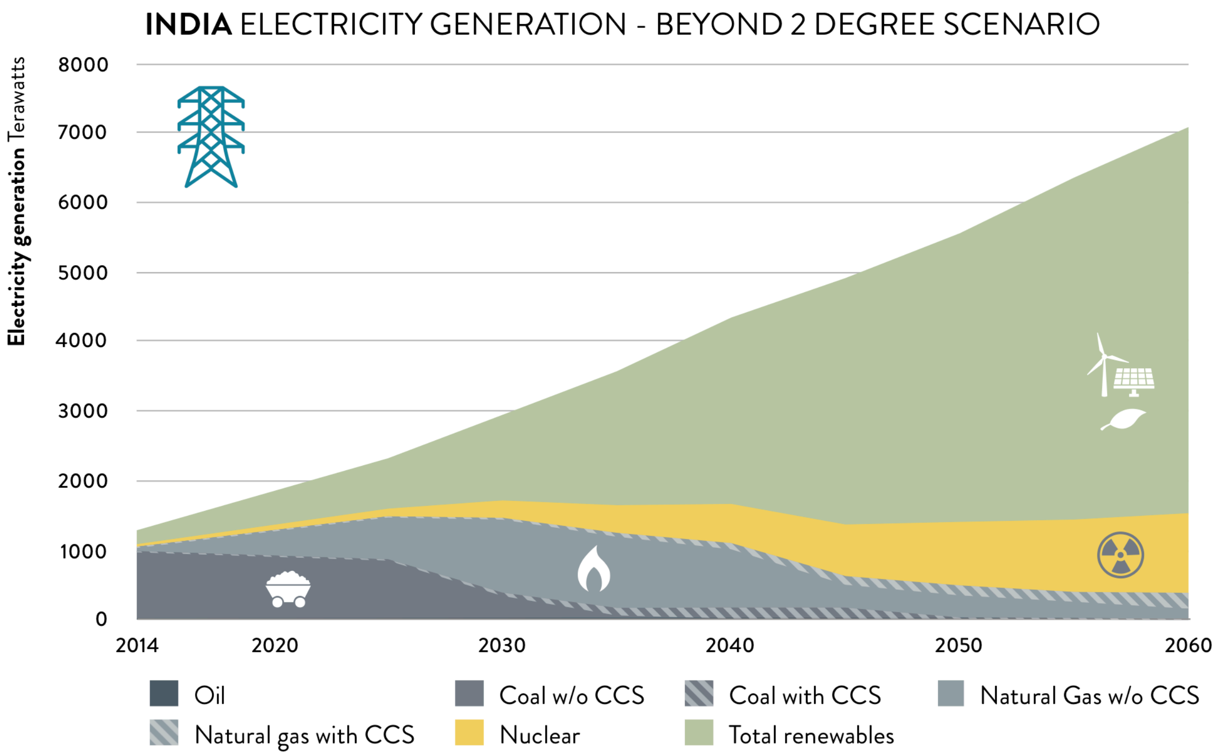


Figure 2.11 - Electricity generation in India from the IEA ETP B2DS

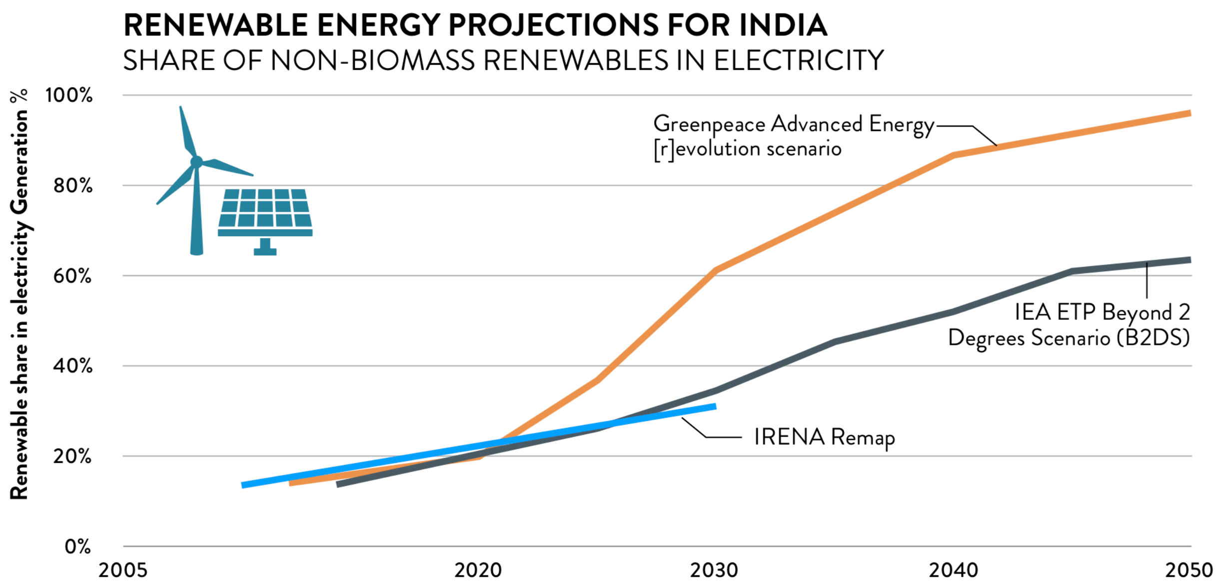


Figure 2.12 - Share of renewable energy in electricity systems for a selection of scenarios with India as a separate region, as well as for the wider ASIA region.

2.4 Benefits of climate change mitigation for sustainable development in SA and SEA

Historically, implementing climate change mitigation measures has been perceived as being in conflict with economic development objectives. However, several studies provide evidence that many options for reducing carbon emissions can yield synergies for achieving other societal objectives (Ürge-Vorsatz, Herrero, Dubash, & Lecocq, 2014). These positive side effects of climate change mitigation measures are often referred to as 'co-benefits'.

These co-benefits can be economic – employment creation, reducing expenditures on fossil fuel imports, stimulating innovation. They can relate to the environment – for example, improving air, water and soil quality, and protecting biodiversity. Benefits of climate action can also have social dimensions, including enhanced access to clean energy and reduced health impacts, as well as positive political and institutional effects, for instance improving institutional structures or enhancing cooperation between different institutions or ministries.

The impact of a policy or measure also strongly depends on the design and implementation of the measure as well as on the national context and circumstances. Potential trade-offs, such as unintended distributional impacts, can be avoided or lessened if policies are carefully designed and potentially complemented by other measures (IPCC, 2018b).

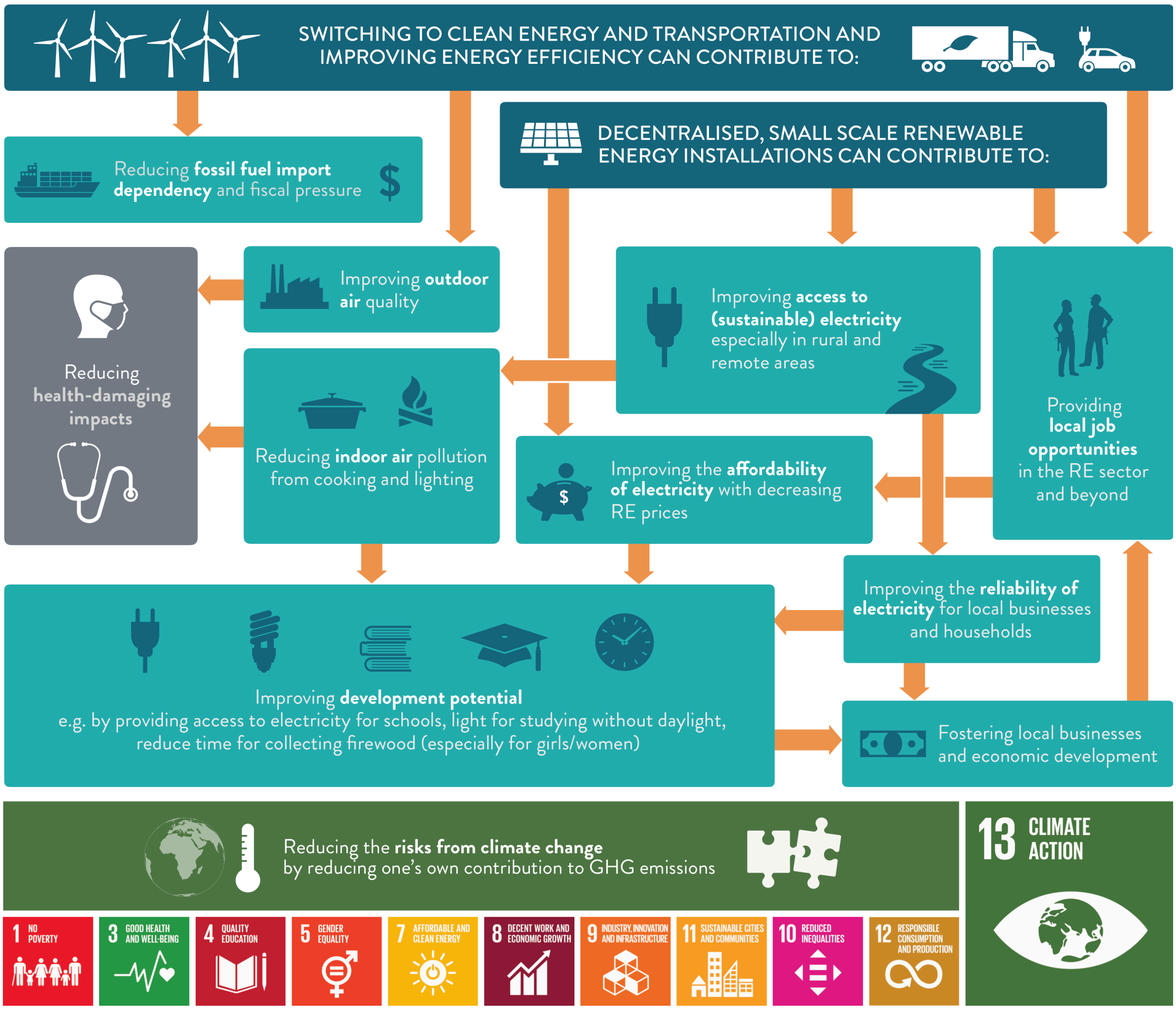


Figure 2.13: Co-benefits of energy system transformation for sustainable development

With a focus on energy supply, the Figure 2.13 illustrates the various channels through which a transformation of the energy system to sustainable renewable energy sources can create co-benefits for sustainable development.

In the following, we discuss the potential co-benefits of a timely energy system transformation for SA and SEA with regard to three key areas of interest.

Energy security and energy independence

A number of countries in the region are endowed with their own fossil fuel resources, e.g. coal or natural gas, that have allowed them a certain degree of energy independence (International Renewable Energy Agency (IRENA), 2018) for SEA. However, due to the increasing energy demand and shrinking domestic resources, this self-sufficiency is projected to diminish. Vietnam's rising energy demand exceeds domestic fuel supply, pointing to a future of rising energy imports. Historically a coal exporting country, Vietnam has already become an net importer of coal (International Renewable Energy Agency (IRENA), 2018). Also in South Asia, no country will be able to meet its energy needs domestically in long run (Kumar Singh, 2013).

Furthermore, building fossil energy infrastructure might lock these countries into imports of fossil energy carriers in the future, burdening state budgets and making them vulnerable to market price volatilities.

Energy access

Despite substantial progress in expanding modern energy access**,** almost 65 million people in Southeast Asia still lack access to electricity and about 250 million people need to rely on traditional bioenergy (International Renewable Energy Agency (IRENA), 2018). South Asia has also made progress in electrification, yet ESMAP reports nearly 400 million people without access to electricity and 1.1 billion people lacking access to clean cooking possibilities (ESMAP, 2016).

Most of the population without electricity access is located in emerging economies, such as Cambodia and Myanmar, rural areas, and countries with many islands such as Indonesia and the Philippines. Due to challenging locations, like remote islands or deep forest areas, decentralised (household- or community level) energy solutions based on Renewable Energy provide advantages over 'conventional' grid-based electricity forms.

The region has already made positive experiences with applying off-grid solutions based on available energy resources such as solar, wind, hydro and bioenergy. Examples include micro-hydro in Indonesia, Malaysia and Myanmar, solar home systems in Cambodia and solar/wind/diesel hybrid island mini-grids in Indonesia and the Philippines (International Renewable Energy Agency (IRENA), 2018). With decreasing costs and maturing technologies, these off-grid solutions provide opportunities for making progress with regard to 'clean and affordable energy for all' (SDG7) without compromising climate change mitigation targets.

Access to electricity from renewables can generate additional co-benefits further down the line. Improved lighting and cooking possibilities can have positive effects for education by allowing studying without daylight and reducing time required for collecting fire wood. As this is often the responsibility of women, it can moreover contribute to gender equality and girls' education. Clean cooking and lighting technologies moreover reduce exposure to health damaging indoor air pollution.

Air pollution, health, environmental degradation

Air pollution is a growing problem in many Asian regions and a very serious danger to health in many urban areas.

The larger part of **outdoor air pollution** stems from the power sectors, especially if coal is used, and from industry and transport, especially in urban areas (International Renewable Energy Agency (IRENA), 2018). In 2015, more than 1.9 million premature deaths in SEA have been attributed to outdoor air pollution (Lancet, 2017). India is among the countries with the highest levels of air pollution in the world. In India alone, more than 1 million premature deaths can be attributed to outdoor air pollution in 2016 according to the World Health Organisation (WHO), in Indonesia the number of people was estimated to 95 000 (World Health Organisation, 2018).

Indoor air pollution is also high in some countries where people rely largely on traditional biomass for cooking, lighting and heating, especially in rural areas. The WHO estimates that in 2016 over 100 000 premature deaths in Bangladesh can be attributed to household air pollution, over 130 000 in Indonesia, 86 000 in the Philippines, and over 1 million in India (World Health Organisation, 2018).

IRENA estimated the associated external cost of air pollution for ASEAN countries at 167 billion USD in 2014 (IRENA & ACE, 2016). It also estimates that the external costs related to air pollution stemming from the combustion of fossil fuels across the region will increase by 35%, to an average of 225 billion USD each year, by 2025 (International Renewable Energy Agency (IRENA), 2018).

Modeling estimates suggest that the benefits of reduced air pollution could outweigh climate change mitigation costs in Asia (Markandya et al., 2018). Xie et al estimate that climate change mitigation measure in line with 2°C of warming could reduce the number of premature deaths from air pollution in Asia (including China) by about 800 000 people by 2050 (Xie et al., 2018). Monetising this benefit by using a 'value of life' approach would yield savings of about 2.8 trillion USD (6% of the GDP), which largely outweighs the estimates economic costs of climate change mitigation (of about 840 billion USD, 2% of GDP). India is estimated to have the highest net benefit of 1.4 trillion USD (Xie et al., 2018).

Economic prospects and green jobs

With a continuously growing population, job creation is and will remain a major priority of governments in SA and SEA. Southeast Asia alone expects about 68 million new entrants to the labour force by 2025 (International Renewable Energy Agency (IRENA), 2018). As the construction and installation of most renewable energy technologies are more labour-intensive and need to happen locally, a transition towards RE can yield substantial local job creation opportunities. These jobs are usually higher quality jobs. IRENA estimates that in 2016, over 600 000 jobs in SEA where in the renewable energy sector (International Renewable Energy Agency (IRENA), 2018).

The synergies of different climate change mitigation options with regard to the SDGs

The choice of mitigation options, the scale and speed of their deployment and how these actions are governed can results in synergies (positive impacts) and trade-offs (negative impacts) with different Sustainable Development Goals (SDGs).

The SR1.5 clearly shows that rapidly shifting towards low carbon – in particular renewable - energy, industrial and food systems, and reducing energy demand would have the most pronounced benefits for sustainable development, provided that mitigation policies are carefully designed to shield vulnerable people and manage potential trade-offs. While the total number of possible synergies is higher than the number of potential trade-offs, it will depend on the design of mitigation policies, the local circumstances and the management of the transition whether the potential for positive synergies is exploited and the overall impact is positive. The IPCC states that particularly in the energy supply sector, the potential for synergies is larger than for trade-offs (SR 1.5).

There are many concrete examples of linkages between mitigation options and the Sustainable Development Goals (SDGs) in the energy supply sector, as assessed in the IPCC SR1.5.

Decreasing the share of coal in energy supply in line with 1.5°C-compatible scenarios reduces adverse impacts of upstream supply-chain activities, in particular air and water pollution, and coal mining accidents, and enhances health by reducing air pollution, notably in cities, showing synergies with SDG 3, SDG 11 and SDG 12.

Reducing emissions through **increasing the share of on-grid and off-grid renewable energy** directly targets access to clean energy (SDG 7) and reduces air, water and soil pollution and waste that could cause non-communicable diseases (SDG 3, SDG 6, SDG 12, SDG 14, SDG 15).

It also increases the opportunity for sustainable and inclusive economic growth that reduces reliance on limited or imported resources (e.g., oil, fuel), develops resilient and sustainable infrastructure, and paves the way for job creation (SDG 8, SDG 9, SDG 11, SDG 16).

Remote communities would have more access to electricity that, in turn, helps reduce poverty and inequality by increasing economic opportunities in remote areas (SDG 1, SDG 10). Access to electricity enables food storage that increases food availability throughout the year (SDG 2), provides the opportunity for improved educational facilities and longer studying hours (SDG 4). It may reduce women's chores (e.g., gathering wood fuel, etc.) which frees up time for more productive activities (SDG 5). It also creates the potential for more sustainable transport systems (SDG 11).

Some trade-offs with the SDGs can emerge from offshore installations such as offshore wind, particularly sustainable use of the oceans, seas and marine resources (SDG 14) in local contexts. Moreover, trade-offs between renewable energy production and affordability (SDG 7) and other environmental objectives would need to be scrutinised for potential negative social outcomes. Policy interventions through regional cooperation building (SDG 17) and institutional capacity (SDG 16) can enhance affordability (SDG 7).

The deployment of small-scale renewables, or off-grid solutions for people in remote areas has strong potential for synergies with access to energy (SDG 7) but the realisation of these potentials requires measures to overcome technology and reliability risks associated with large-scale deployment of renewables.

Bioenergy production, which may or may not be combined with CCS, also has the potential for positive and negative linkages with sustainable development, its overall effect being largely dependent on how land use is governed. A growing body of research has highlighted the potential constraints bioenergy production could place on poor and vulnerable populations, if inadequately governed.

For example, large-scale bioenergy production could increase pressure on water and nutrient resources and lead to competition with efforts to restore and protect natural ecosystems, unless good governance and sound implementation practices are put in place. There is also a risk that large-scale production would change global agricultural markets in a way that disadvantages smallholder farmers.

Conversely, increased demand for bioenergy crops could create agricultural jobs and provide farmers with more diversified income streams, and the use of marginal lands could have benefits for soil and water quality. There is a need for more research into regionally specific bioenergy production potentials and socio-economic impacts to better understand these potential synergies and trade-offs at the local level.

Carbon Dioxide Removal (CDR) options can have impacts on SDGs depending on the type of option used and the scale of deployment. If the implementation and design are flawed and do not appropriately account for local people's needs and other sustainability dimensions, CDR options such as bioenergy with carbon capture and storage (BECCS) and agriculture, forestry and other land use

(AFOLU) can lead to trade-offs (IPCC, 2018). These can include increased food prices and competition for arable land, which may disproportionately affect rural poor and indigenous populations (SDG 1). Crops for bioenergy may increase irrigation needs and exacerbate water stress with negative associated impacts on SDGs 6 and 10.

Nuclear energy can increase the risks of proliferation of nuclear weapons (SDG 16), and have negative environmental effects on water use, (SDG 6), and have mixed effects for human health when replacing fossil fuels (SDGs 7 and SDG 3).

The use of CCS with fossil fuels implies continued adverse impacts of supply chain activities in the coal, oil and natural gas sectors, and because of lower efficiency of CCS, coal power plants impacts and local air pollution are likely to be exacerbated (SDG 3). Furthermore, there is a non-negligible risk of carbon dioxide leakage from geological storage and transport infrastructure (SDG 3).

Chapter 3:

Implications of current planning for coal fired power generation in countries in South and South East Asia

3.1 Current planning for coal-fired power generation in South and South East Asia

As shown in Section 2.3, coal-fired power will need to be phased out by 2050 globally, to remain on a pathway which is consistent with the LTTG of the Paris Agreement (Climate Analytics, 2016; IPCC, 2018a) Contrary to this, several South and South East Asian economies are set to expand their coal plant capacity rapidly.

Table 3.1: Operating and Planned Coal Capacities in South and South East Asia

Country	Total coal capacity operating and under construction (MW)	Operating and under construction capacity as share of global capacity	Total planned coal capacity (MW)	Planned growth coal capacity	Planned capacity as share of global planned expansion
India	274,893	12.27%	56,773	21%	15.55%
Vietnam	23,919	1.07%	43,692	183%	11.97%
Indonesia	42,664	1.91%	26,611	62%	7.29%
Bangladesh	5,761	0.26%	18,434	320%	5.05%
Pakistan	5,025	0.22%	11,849	236%	3.25%
Philippines	12,094	0.54%	9,437	78%	2.59%
Thailand	6,331	0.28%	3,600	57%	0.99%
Cambodia	535	0.02%	2,520	471%	0.69%
Myanmar	48	0.00%	1,530	3188%	0.42%
Malaysia	13,689	0.61%	1,200	9%	0.33%
Laos	1,878	0.08%	600	32%	0.16%
Sri Lanka	900	0.04%	0	0%	0.00%

Source: Own calculations based on PLATTS WEPP & Global Coal Plant Tracker 2018A (information as of June 2018). **Note:** Countries are listed here in a descending order based on their share of global coal fleet expansion. Countries not included in the table (Afghanistan, Bhutan, Maldives, Nepal, Singapore, Brunei, and East Timor) do not have coal power plants bigger than 30 MW and are not planning new ones.

Together, countries in South Asia and South East Asia account for half of the planned expansion of the global coal power. India, Vietnam, and Indonesia alone account for over 30% of this planned expansion, but an important share of these plans comes from emerging economies whose energy systems have not depended on coal heavily in the past. These include Bangladesh, Pakistan, Philippines, Thailand, Myanmar, Cambodia, which together account for over 13% of the planned expansion of the global fleet. Relative to the current fleet size, Bangladesh plans to increase coal-based capacity threefold and Philippines aims to nearly double the size of its coal-based capacity.

As a consequence of coal power capacity additions, resulting emissions have been increasing steadily in the region in the last 30 years (Figure 3.1). Plans for major new coal deployment in the region would endanger the achievement of the Paris Agreement temperature goal, which requires fast reduction of coal emissions. It would also undermine sustainable development objectives.

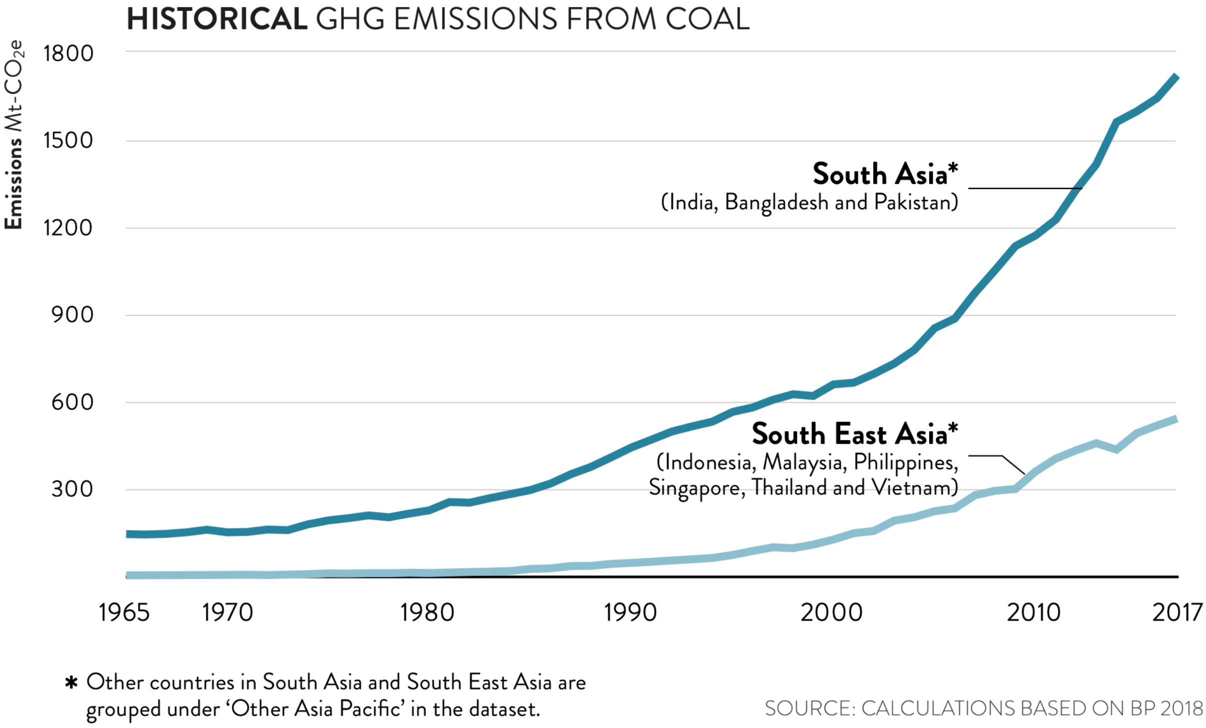


Figure 3.1: Historical GHG emissions from coal-fired power in South Asia and South East Asia. Source: Own Calculations, based on BP 2018.

Energy demand has been growing rapidly in South East Asian countries, driven by economic growth and demographic changes (ASEAN Centre for Energy ACE, 2015) (see also Section 2.3). The choice to use coal to meet this demand was largely driven by an abundance of national resources (in Indonesia and Vietnam), and the relative price advantage (IEA, 2015). The price advantage of using coal has steadily eroded, with large cost reductions observed for renewable energy technologies (ASEAN Centre for Energy, 2017c). However, these positive signals are tempered by the significant potential for lock-in of the existing, and planned coal fleet in South East Asia.

Similar trends are observed in South Asian countries as well; India, for instance, has large coal resources[15]. The IEA notes that population growth and rapid rural-urban shifts are the major drivers of growth in energy demand. Current policies that promote coal-fired power in many countries in the region to meet this growing demand would lead to increasing emissions. These trends are expected to continue in the future.

India's population is projected to increase by over 250 million people by 2040 (United Nations Population Division, 2017). Even with significant improvement in energy productivity, the accompanying growth in energy demand will need to be met by capacity additions. Going ahead with

15 Recent reserve discoveries in Pakistan and Bangladesh indicate significant unexploited resources in these countries as well, where expansion of coal mining activities is also planned.

the planned expansion of coal-fired power generation implies either failing to achieve the Paris Agreement climate mitigation objective or a large risk of stranded assets that would have to be retired before the end of their economic lifetime.

In addition, new coal capacity increases dependency on energy imports for countries with limited domestic production relative to their coal consumption. The case is even worse for countries with no coal resources. Additional investments in coal-related infrastructure (e.g. mining and transport) in countries with significant resources (e.g. Indonesia, India) also risk being stranded. In addition, this expansion of coal generation capacity is occurring against the backdrop of rapidly declining renewable costs, with new solar and wind installations already cheaper than new coal-fired capacity on an levelised cost of electricity (LCOE) basis in many countries in the region (Spencer, Pachouri, Renjith, & Vohra, 2018). Given that price signals are clearly at odds with government decisions, many governments in this region continue to divert significant funds towards subsidies, which artificially maintain the competitiveness of coal-fired power plants.

If the fast improvements in comparative cost of renewable energy observed in all the countries in the region continue as the historical rate, coal will not be cost-competitive with clean energy within the next decade on an LCOE basis, making government decisions to divert public funds to these subsidy regimes unconscionable. These cost metrics, however, exclude the cost of the externalities associated with coal, such as contribution to climate change and air pollution. If these externalities were considered, no new capacity should be built anywhere in the world considering not only the role of coal in exacerbating the impacts of climate change, but also the significant economic and social consequences associated to a coal-based electricity mix.

Figures 3.2 and 3.3 highlight the expansion plans in selected countries in South and South East Asia.

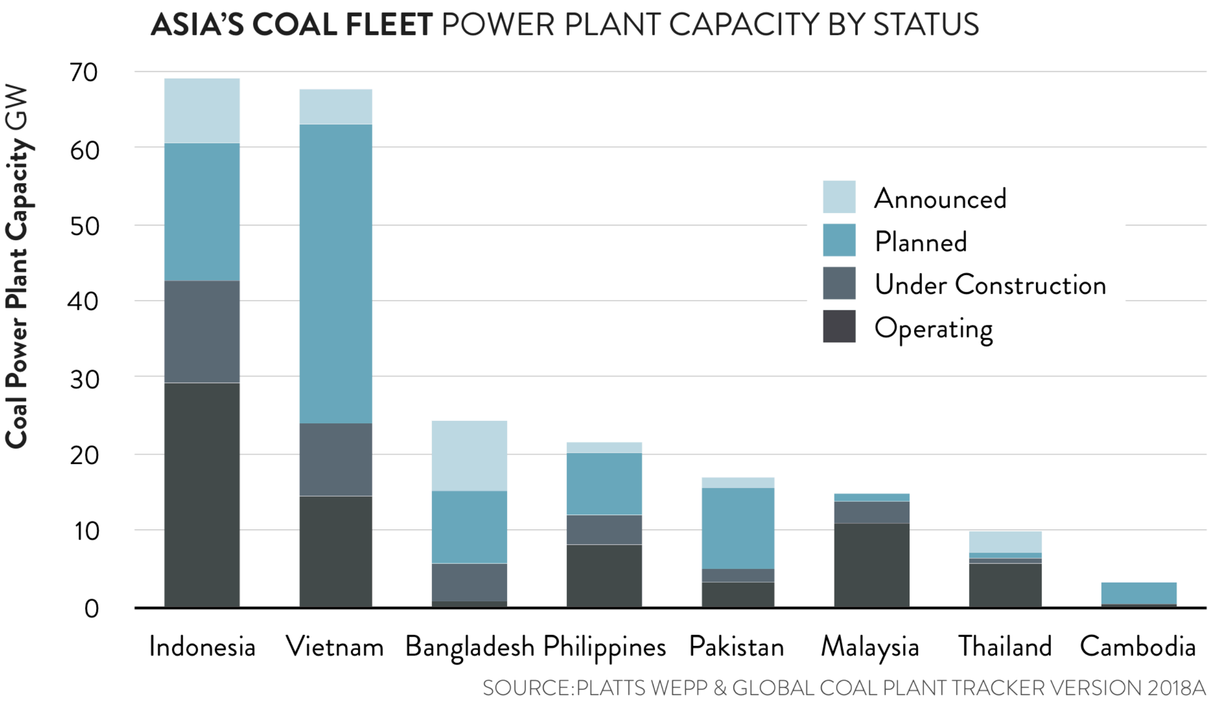


Figure 3.2: Coal Power Plant Fleet (by Country and Status) in Selected Countries in South and South East Asia. Source: PLATTS WEPP and Global Coal Plant Tracker (2018A). Only plants with a capacity of 30 MW or larger are included.

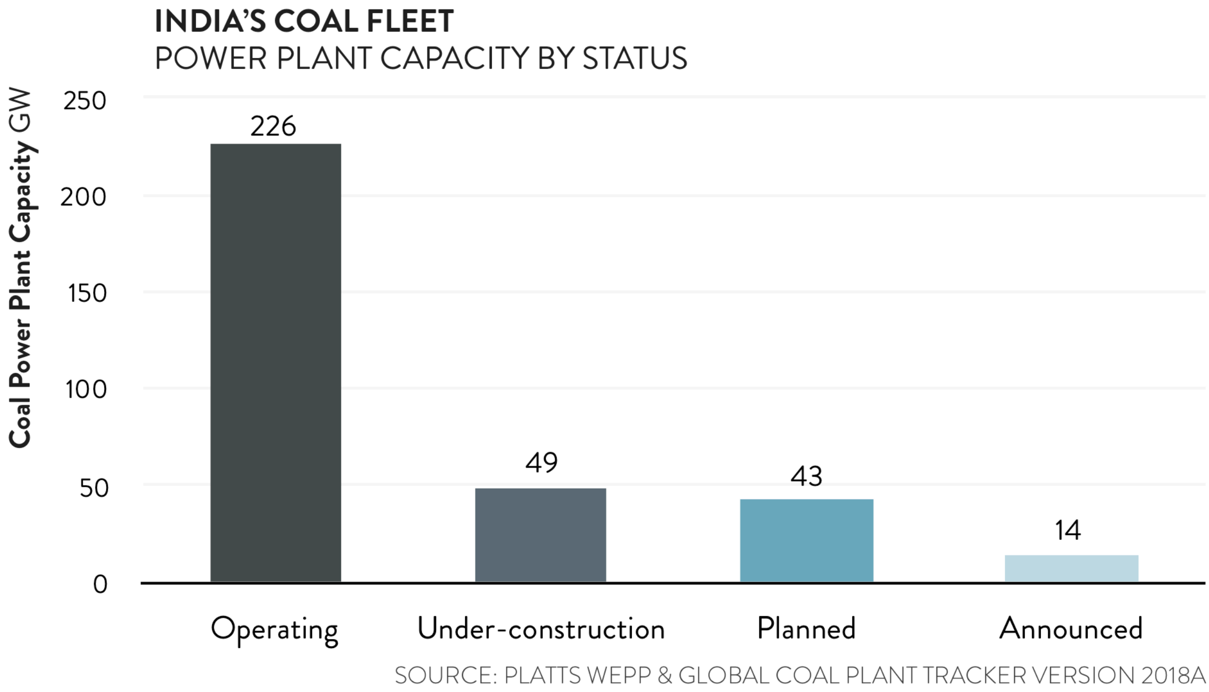


Figure 3.3: Coal Power Plant Fleet (by Status) in India. Source: PLATTS WEPP and Global Coal Plant Tracker (2018A). Only plants with a capacity of 30 MW or larger are included.

3.2 Coal expansion and the Paris Agreement

As shown in previous chapters, in scenarios compatible with the Paris Agreement, the share of coal (without CCS) in electricity generation declines rapidly to a share of 8% in 2030 in the ASEAN region and 11% in India. A similar trend would be needed for South Asia, the Paris Agreement consistent pathway showing a phase out by 2040 for the whole of Asia, and specifically for ASEAN and India. Coal use in the power sector will need to peak in the near future and decline rapidly in line with these benchmarks.

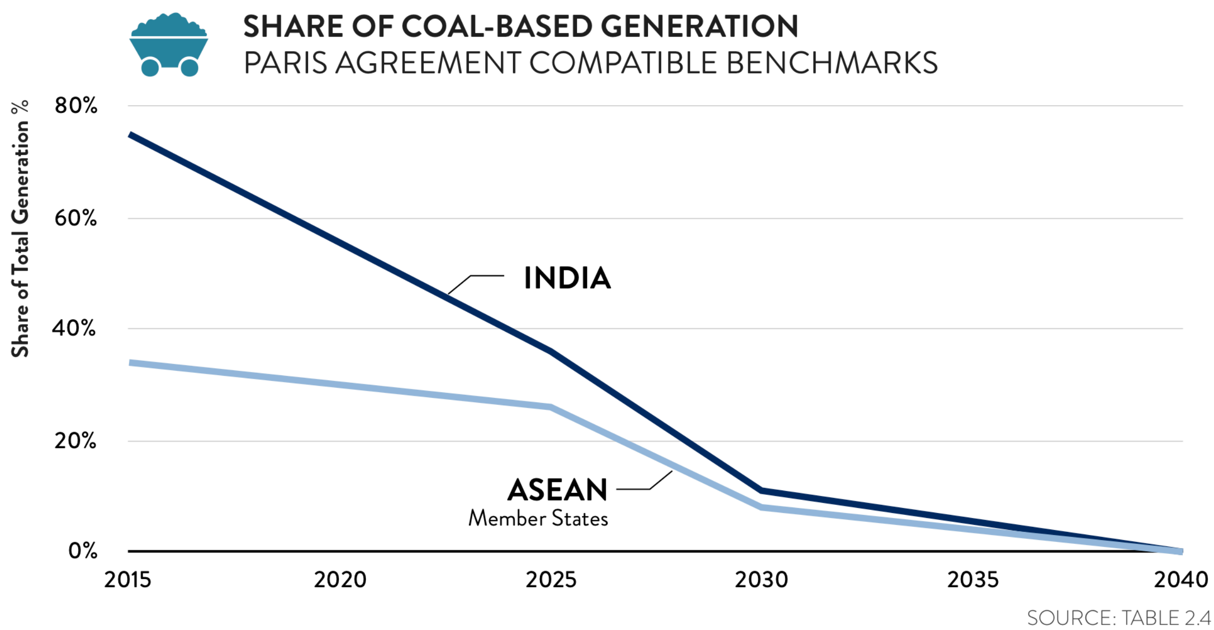


Figure 3.4: Coal power generation benchmarks for India and ASEAN. Source: Table 2.4, Chapter 2

Contrary to what is needed to achieve the Paris Agreement's long-term temperature goal, coal is expanding rapidly in SEA/SA. The 176 GW planned coal capacity expansion for the countries in both regions (see Table 3.1) will result in either a large number of stranded assets - or emissions exceeding emissions budgets consistent with Paris Agreement's goal.

Because coal plants are well-established in the electricity market in many countries, their long lifetime and low operating costs make them difficult to take them out of the energy production system (Erickson, Kartha, Lazarus, & Tempest, 2015). Globally, even if the entire planned capacity were to be cancelled (with significant implications for emerging economies), a significant portion of the existing capacity would need to be stranded to meet the goals of the Paris Agreement (Climate Analytics, 2016; Pfeiffer, Hepburn, Vogt-Schilb, & Caldecott, 2018). Regional estimates of the potential value of these stranded assets if current expansion plans materialise are pegged as high as 60 billion USD for just Indonesia, Vietnam and the Philippines (The Carbon Tracker Initiative, 2018).

For a better overview of the risk for potential lock-in and asset-stranding in South and South East Asia, we calculate the electricity generation and emissions that would result from current (operating and under construction), as well as planned coal power plants in order to estimate the gap between current and planned coal power generation, and the Paris Agreement benchmarks derived in chapter 2.

For the purpose of our analysis, we assume that all coal-fired power plants, which are announced will come online in four years after the average start operating year of plants currently under construction and those in the permit stages two years after this average (unless the database includes specific dates for operation start that differ from this assumption). While it is likely that at least some of these plans will be shelved or cancelled (a trend which we can observe in India), these estimates provide a useful frame of reference.

Based on the information provided in a coal power plant database and methodology described in detail in the Annex 1: Estimating CO2 emissions from coal plants we estimate CO_2 emissions from these coal power plants, differentiating for each power plant unit, including their fuel composition and combustion technology (Table 3.2).

Based on current and planned capacity, in 2020 and 2030 nearly 95% of the generation mix will be from hard coal, and only 5% based on lignite. A large expansion of hard coal demand would increase imports and therefore energy dependency in many countries in these regions that already rely on imports for running a large share of their power plants. The share of super-critical plants is expected to increase from 30% in 2020 to 50% in 2030 if current plans (Table 3.2) materialise. Super-critical power plants are more efficient and lead to fewer emissions per unit of output than the currently predominating subcritical coal plants. However, even the most efficient new coal power plants would add a significant amount of emissions to the future energy profile of the countries.

Table 3.2 - Current and planned coal fleet SA/SEA by combustion technology and fuel type

Country	Share of total fleet (current and planned)				
	Subcritical coal plants	Supercritical coal	Ultrasupercritical coal plants	Hard coal	Lignite plants
India	58%	35%	5%	95%	4%
Vietnam	31%	30%	3%	100%	0%
Indonesia	53%	19%	12%	97%	3%
Bangladesh	3%	11%	45%	100%	0%
Pakistan	11%	61%	0%	56%	44%
Philippines	65%	11%	13%	97%	3%
Thailand	54%	7%	10%	62%	38%
Cambodia	40%	0%	0%	100%	0%
Myanmar	100%	0%	0%	100%	0%
Malaysia	65%	0%	35%	92%	8%
Laos	76%	0%	0%	24%	76%
Sri Lanka	100%	0%	0%	100%	0%
Total SA/SEA	**51%**	**29%**	**8%**	**94%**	**5%**

Source: Own calculations based on PLATTS WEPP & Global Coal Plant Tracker 2018A (information as of June 2018).

Note: When percentages do not add to 100%, the residuals correspond to plants with unknown fuel type or combustions technology. Countries not include in the table (Afghanistan, Bhutan, Maldives, Nepal, Singapore, Brunei, and East Timor) do not have coal power plants bigger than 30 MW and are not planning new coal power plants.

We assume no further additions beyond what is currently planned. Our key assumptions to estimate generation and emissions are lifetime and utilisation rate: we have assumed units retire when they reach 40 years, which is the global average coal plant retirement age. We estimate the utilisation rate of thermal power plants in 2014 from the capacity and generation figures in the World Energy Outlook (IEA, 2018b) for historical emissions estimates. The future utilisation of coal power plants is uncertain. For this report, we also use utilisation rates derived from the World Energy Outlook projections under the Current Policies Scenario (IEA, 2018c).

To estimate the gap between current and planned coal power generation and the Paris Agreement consistent benchmarks derived in chapter 2, the following approach is adopted:

- Where available, we use benchmark generation values from the IEA B2D scenario, which is consistent with the LTTG of the Paris Agreement in the power sector, as discussed in chapter 2. The scenarios are available at regional level for India and the ASEAN countries.
- To get an indication of the gap for the rest of the South Asian countries we compare the generation from the current and planned coal fleet with the generation values from the same IEA B2D scenario for the rest of ASIA, which includes East Asian countries such as Japan and South Korea. This highlights the need to develop country-specific benchmarks based on country specific data and scenarios.

The figures below compare the benchmarks in different years for India, and the ASEAN region.

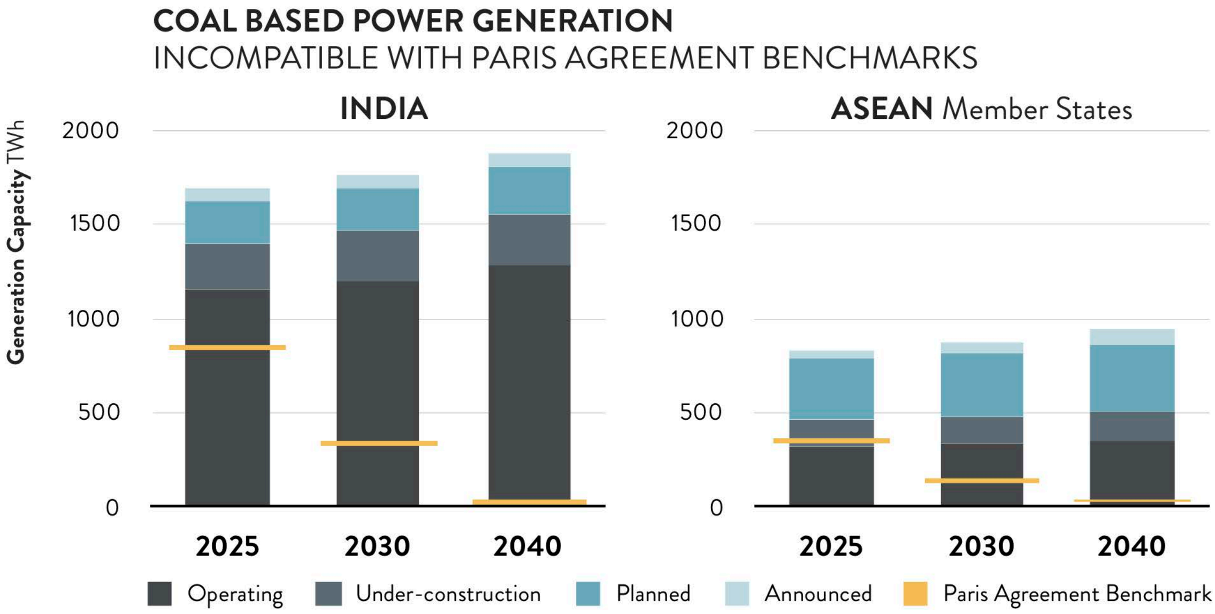


Figure 3.5: Coal power generation for India and ASEAN: Paris Agreement compatible benchmarks against projected generation from current and planned coal fleet

For the rest of South Asia (without India), the indicative benchmark derived for the rest of ASIA (“IEA B2DS (Rest of Asia)” in Figure 3.6) allows for a modest amount of coal generation build up till 2030; which is far exceeded by the generation corresponding to planned developments in South Asia (excluding India).

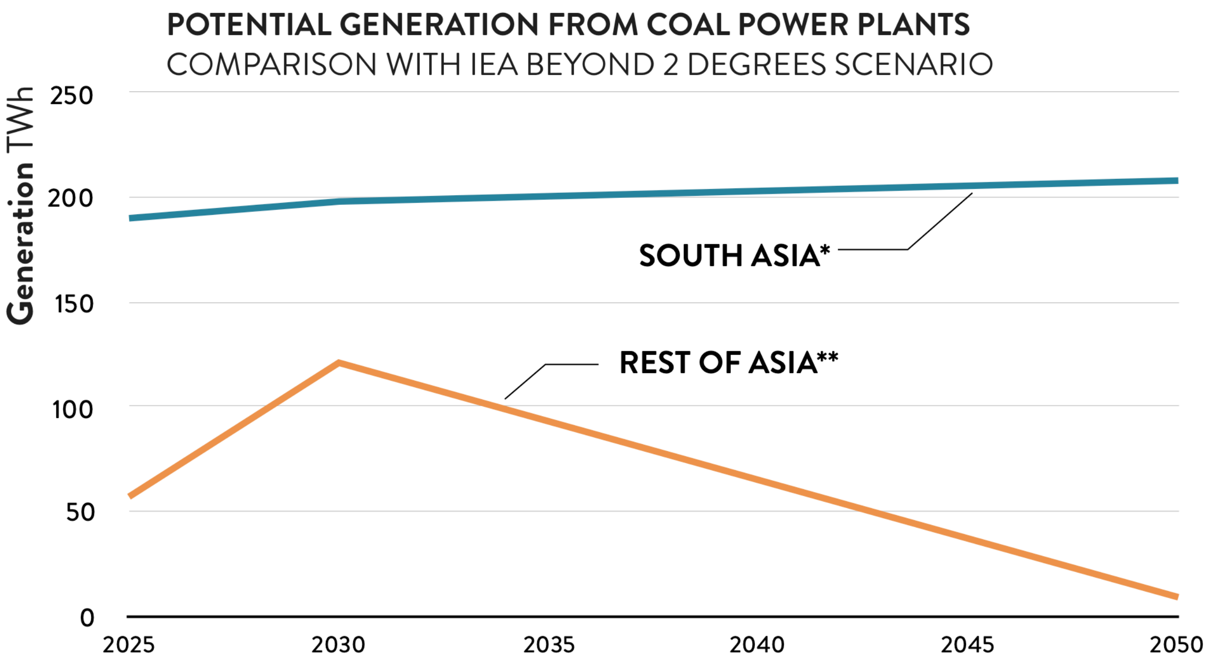


Figure 3.6: Estimated Coal power generation (in TWh) from current and planned coal fleet in South Asia. Source: IEA ETP 2017, and own calculations based on PLATTS WEPP

*South Asia in this figure includes our estimation of potential generation for all South Asian countries excluding India (that is mainly including Pakistan and Bangladesh), following the assumptions mentioned earlier in this section.

**IEA B2DS (Rest of Asia) is derived from the IEA B2DS ASIA region, by removing ASEAN, China and India, but including Central and East-Asian countries such as South Korea and Japan.

As shown in the Figures 3.5 and 3.6, electricity generation, and therefore emissions from current and planned coal-fired capacity would exceed the Paris Agreement compatible regional benchmarks by a large margin. Importantly, even if all the planned capacity were to be cancelled, the majority of the currently operating fleet in India and in the South East Asia region would already be inconsistent with the Paris Agreement compatible benchmarks by 2030, unless utilisation rates are reduced dramatically.

For other South Asian countries, we observe that the potential generation from South Asia (excluding India) alone far exceeds generation which would be consistent with the Paris Agreement for the ‘Rest of Asia’ region in the IEA B2D scenario. Given that the IEA B2D also includes other large emitters such as Japan and Korea, this illustrates the magnitude of the lock-in and asset-stranding risks for these countries.

Overall, under current plans emissions from coal power generation in South and South East Asia together would continue to increase at least until 2030, roughly double current levels in the period 2030-2050, and continue to be a part of the electricity mix until the late 2060s assuming a lifetime of 40 years (Figure 3.7). This is in stark contrast to the need to phase out coal for power generation by 2050, as required by the Paris Agreement.

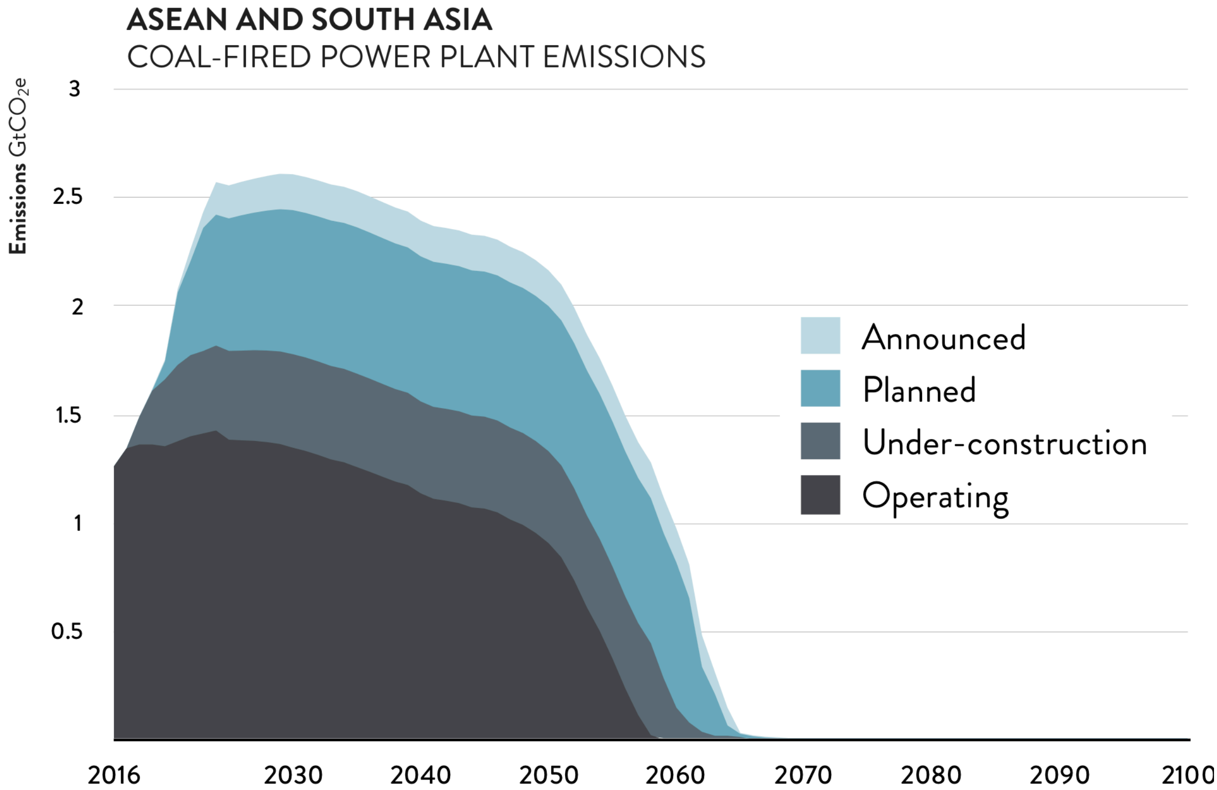


Figure 3.7: Projected CO_2 emissions from current and planned coal fleet in SA and SEA.

Source: Own calculations based on PLATTS WEPP and Global Coal Plant Tracker (2018A)

In conclusion, in order to achieve the Paris Agreement's long-term temperature goal, countries in South and South East Asia will need to implement early retirement of coal-fired power plants and/or to dramatically reduce their utilisation rate. Opening new plants will only widen the gap between committed emissions and benchmarks consistent with the Paris Agreement.

Countries will need to reverse their current trend of expanding coal-fired generation capacity and instead urgently implement policies to enable a quick coal phase-out from the electricity mix. They will also need to substantially speed up the deployment of low carbon and carbon neutral technologies for electricity production, with the aim of phasing out all fossil fuel emissions from the electricity mix by around mid-century.

Redirecting resources currently planned for coal fleet expansion to renewable energy deployment can not only result in substantial emissions reductions compared to a BAU scenario, but also could reduce substantially the capital at risk of stranding, while ensuring that the growing energy needs of these regions is met, in a sustainable and affordable manner.

3.3 Implications of coal use for air pollution, water and land use

Apart from global – and regional – risks of climate change impacts, decisions on the future of coal use in South and South East Asia also have other far reaching implications, affecting air quality, as well as water and land use in the region.

Air pollution

Throughout its life cycle - from mining, processing, and transportation to burning and coal ash handling - coal-based power generation contributes to air pollution in addition to greenhouse gas emissions (Ha-duong, Truong, Nguyen, Anh, & Nguyen, 2016). Coal combustion results in a range of air pollution emissions which are related to a wide range of health problems (Munawer, 2018).

Main air pollutants stemming from the combustion of coal are sulphur dioxide (SO_2) and nitrogen oxides (NO_x) emissions, again leading to the formation of (secondary) fine particulate matter ($PM_{2.5}$) and ozone (O_3). Fine particulate matter ($PM_{2.5}$) is considered the most harmful air pollutant in terms of world-wide human health impacts (Koplitz, Jacob, Sulprizio, Myllyvirta, & Reid, 2017). Among other impacts, $PM_{2.5}$ increases the risk of premature mortality from respiratory and cardiovascular disease. Surface ozone has also been found to be a major concern for public health and ecosystems (Koplitz et al., 2017).

Estimates suggest that particulate matter air pollution caused by coal fired power plants in India alone have been responsible for between 80 000 and 115 000 premature deaths in 2011, resulting in estimated health costs of between 3.2 and 4.6 billion USD, as well of many million cases of respiratory and cardiovascular diseases (Conservation Action Trust, Urban Emissions.info, & Greenpeace India, 2012; Guttikunda & Jawahar, 2014).

For South East Asia it is estimated that current coal-fired power plant emissions caused about 20 000 deaths per year in the region and beyond, and are expected to increase to almost 70 000 deaths by 2030 if all coal power plants are built as planned (Koplitz et al., 2017). Figure 3.8 shows the estimated deaths by country, showing that Vietnam and Indonesia are estimated to exhibit the highest coal-related fatalities in South East Asia. Another study estimates that existing coal-fired power plants in Indonesia are responsible for about 6 500 premature deaths every year (7 100 deaths including affected people outside of Indonesia) and that each new plant (1000 MW capacity) would on average result in about 600 deaths per year (Greenpeace, 2015c).

Moreover, coal-fired power plants also emit health-damaging **heavy metals** (Munawer, 2018). Coal combustion is one of the largest contemporary sources of anthropogenic mercury. Mercury is a potent neurotoxin that, among other impacts, negatively affects the central nervous system and can cause brain damage (Munawer, 2018).

It is estimated that about a quarter of all mercury emissions globally between 1850 and 2008 have been caused by coal (Streets, Lu, Levin, ter Schure, & Sunderland, 2018). Most of the mercury (about 70%) is released to the atmosphere, while the remaining 30% affect land and water (Streets et al., 2018).

In 2010, Asia was responsible for almost 70% of global mercury releases to the environment stemming from coal combustion (Streets et al., 2018). Transition away from coal (under current technologies) could avoid more mercury emissions stemming from Asia than a heavy-coal based scenario relying on technologies and stricter mercury control requirements (Giang, Stokes, Streets, Corbitt, & Selin, 2015)

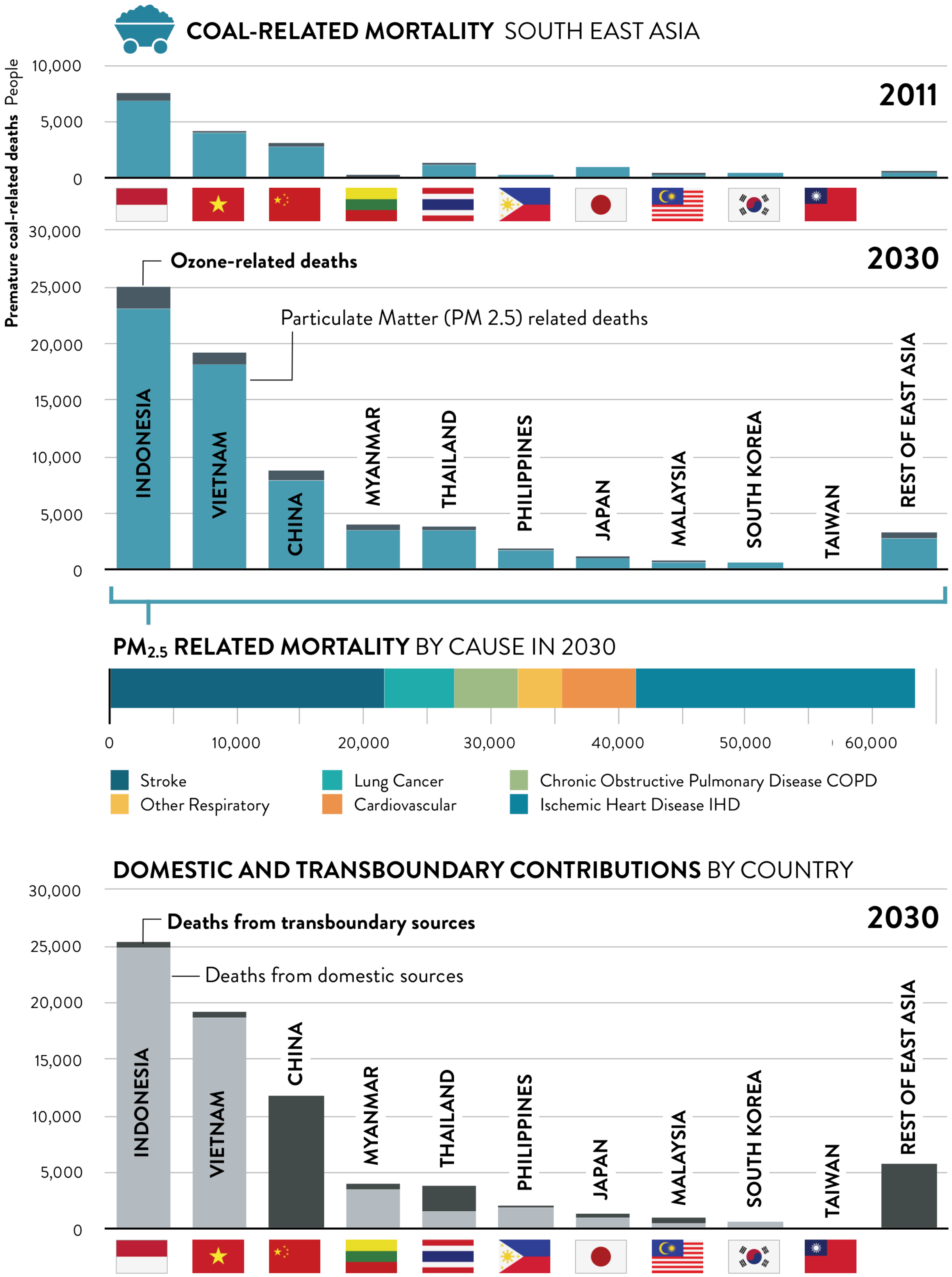


Figure 3.8: Current (2011) and projected (2030) coal-related mortality due to emissions of coal power plants located in South East Asian countries. Premature deaths due to 2011 emissions are shown in the top section, and total projected deaths due to 2030 emissions are shown in middle section. The bottom section shows the 2030 coal-related mortality broken down by contributions from domestic and transboundary sources. For China and Rest of East Asia, pollution from national power plants is not included, only impacts from transboundary pollution are shown. Source: Adapted from Koplitz et al. (2017)

Water

Coal is one of the most water-intensive forms of electricity generation, as during the lifecycle of coal it uses and pollutes vast amounts of water for coal mining, coal processing and combustion in power plants as well related to the disposal of coal ash (Greenpeace, 2015b). The water consumption of a coal power plant with 1000 MW is equivalent to the amount of water consumed by about half a million people in a whole year (Greenpeace, 2015b).

Already under current climate conditions, clean water is a scarce resource in many regions in South and South East Asia. Clean water is essential to people's livelihoods in many ways – providing drinking water, hygiene as was as an important prerequisite for agricultural production and food security. The water requirements for thermal power generation and water pollution from coal use can add to the pressure on water resources and impact water quality.

In its different lifecycle stages - from mining, processing, combustion and waste storage - coal use can have multiple **negative impacts on water quality**. These include water contamination due to acid mine drainage, due to toxic wastewater from processing, and due to disposing of ash after combustion. Water contamination caused by heavy metals (such as lead, mercury, nickel, tin, cadmium, antimony, and arsenic) contained in coal processing and post-combustion wastes also cause a range of serious diseases, such as skin and lung cancer, cardiovascular diseases, and gene mutation (Munawer, 2018).

Water pollution poses a serious health risk, causing digestive diseases as well as chronic diseases in the case of regular exposure to heavy metals. Water samples from Vietnamese power plants confirmed that the plants' activity had negative effects on groundwater, streams, rivers and sea water quality(Ha-duong et al., 2016). Sulphur and nitrogen oxides emissions from coal power plants react with rain water and lead to acid rain which can damage vegetation, buildings and also cause severe skin problems (Munawer, 2018). Acid rain again dissolves solid heavy metals thereby amplifying water and soil contamination from heavy metals (Munawer, 2018). Furthermore, thermal pollution from power plant cooling water can cause temperature shocks to ecosystems when heated water is releases to rivers and lakes (Greenpeace, 2015b; Ha-duong et al., 2016).

The need for **cooling water** in thermal power plants such as coal-fired power can contribute to **water scarcity** (see, e.g. Greenpeace, 2014). In India, for example, freshwater water consumption of the thermal power plant sector[16] has increased steadily over the last years (by over 40% between 2011 and 2016) (Luo & Krishnan, 2018)Almost 40% of India's freshwater-cooled thermal power generation capacities are located in areas that are already water-stressed, i.e. with a high level of competition over available water affecting residents, other industry as well as agriculture in the region. The competition for water is expected to increase further. 79% of India's new energy capacity is expected to be installed in areas that already suffer from water scarcity or water stress (IRENA, 2017b).

The World Resource Institute estimates that freshwater consumption from India's thermal power plants could be reduced substantially if the country achieved ambitious renewable energy targets and implemented stringent water regulations for the power sector (Luo & Krishnan, 2018). Power generation from solar PV and wind would instead result in zero carbon emissions and near-zero water consumption. In their most ambitious analysed scenario which WRI developed based on the draft of India's National Electricity Plan, freshwater consumption would stay below the 2016 level by 2027, despite a more than 60% projected increase in total electricity generation, and water withdrawals would be reduced significantly by more than 12 billion cubic meters (Luo & Krishnan, 2018). This is confirmed by another modelling study on India (Srinivasan et al., 2018), who find that investing in wind and solar power for achieving climate goals reduces consumption and withdrawal of freshwater, while relying on nuclear power for mitigation of climate change would increase both.

16 Thermal power plants are fossil fuel-based power plants (including coal) as well as biomass, nuclear, and concentrated solar.

As fresh water scarcity is also a major concern in many other countries in South and South East Asia, and population growths as well as other socio-economic trends will further aggravate this problem (Satoh et al., 2017), energy planning needs to take these considerations into account to avoid severe trade-offs. A transition towards renewable energy sources such as solar PV and wind and away from fossil fuels or other thermal power plants, can substantially contribute to reducing water demand from the power sector and therefore contribute towards achieving other sustainable development goals.

Beyond the direct impact of increased competition for water on the people's lives, water shortages have **negatively affected the reliability of electricity supply**, forcing thermal power plants to shut down causing **power outages**. In 2016 alone, India lost 14 terawatt-hours of thermal power generation due to water shortages, erasing more than 20% of growth in the country's total electricity generation compared to 2015. Fourteen of India's largest 20 thermal power utility companies have suffered from disruptions related to water shortages at least once between 2013 and 2016, resulting in large financial losses of over 1.4 billion USD in total potential revenue from electricity sales (Luo & Krishnan, 2018). not accounting for the negative impacts on industry and households affected by the outages. While water-stressed regions obviously face risks of water shortages, some of the largest water-shortage related disruptions took place in water abundant regions in India, with droughts and delayed monsoon rain posing severe risks (Luo & Krishnan, 2018).

Land-use and soil quality

Coal use can also have implications for land-use and soil quality. **Soil contamination** can be a results of different coal related processes releasing pollutants and toxic substances into air and water or directly into the soil (Munawer, 2018).

Burning coal for power generation produces combustion residual such as coal ash, including bottom ash removed from furnaces and fly ash captured in filters of power plant stacks or smaller particles release to the air. This coal ash contains various heavy metals (e.g. arsenic, cadmium, chrome, lead, mercury) as well as radioactive substances (Munawer, 2018).

Coal ash is usually transported to large disposal spaces, either in dry form or using water to transport it in pipelines. Fugitive dust of untreated dry coal ash can lead to soil contamination, while transportation in pipelines contaminates the water used for the process as well as natural water sources and soils that get in contact with the contaminated water (Greenpeace, 2015b; Munawer, 2018).

Moreover, the land under and around the disposal spaces for coal ash is contaminated and there are high risks of leakages e.g. to ground water. Food cultivated on contaminated soil can lead to health impacts to humans and animals as toxic substances enter the food chain (Ha-duong et al., 2016). Soil contamination can also result from acid rain caused by air pollutants from coal combustion leading to soil acidification and leaching processes, aggravating the contamination of food (e.g. vegetables as well as fish or livestock) with health-damaging substances such as heavy metals (Munawer, 2018). Moreover, acid rain can negatively affect agricultural yields (Munawer, 2018). Coal mining can also lead to soil contamination from coalmine dumps containing toxic substances.

Degradation of soil may not only be caused by contamination, but also by **soil erosion.** The reduction of tree coverage, as forests are cut down to make room for mines, can increase soil erosion in surrounding areas, which can result in a loss of the fertile layer reducing agricultural productivity (Ha-duong et al., 2016; Meng, Feng, Wu, & Meng, 2012). Moreover, open cast coal mining involves the removal of the fertile layer of soil, as well as a degradation of the land where the land fill is disposed (Greenpeace, 2014).

In the **direct competition for land**, coal mining as well as the construction of new coal power plants requires land to be rededicated. This can lead to increasing deforestation and decreasing cultivation of land for agriculture and food production as well as the resettlement of whole villages

(Greenpeace, 2014). It is estimated, that the area needed to dispose the amount of coal ash that would have resulted from Vietnam's original Power Development Plan VII would have been about 2800 ha, an toxic dump site the size of almost 40% of the area of Singapore (Ha-duong et al., 2016).

While also renewable energy technologies require large areas of land, which has been identified by IRENA to be one of the barriers to RE in Indonesia (IRENA, 2017a), the land around wind turbines or solar panels can in parallel be used for agriculture or livestock and is not subject to contamination by toxic substances.

3.4 Conclusion

Our analysis shows clearly that the expansion of coal-fired generation in South and South East Asia is completely incompatible with the objectives of the Paris Agreement, as it locks these countries into carbon intensive pathways for decades and creates an imminent risk of asset stranding. In order to align their energy plans with the Paris Agreement, countries in South and South East Asia will need to reverse their current trend of expanding coal-fired generation capacity and instead urgently implement policies to enable a fast phase out of coal from the electricity mix. This would not only result in substantial CO_2 emissions reductions compared to a BAU scenario, but also could reduce substantially the capital at risk of stranding, and also avoid a number of severe negative impacts on air quality, health, water and land-use.

The following chapter outlines the potential for technologies and fuels to replace coal and other fossil fuels for energy supply.

Chapter 4:

Technology and fuel options to replace fossil fuels in energy supply

Based on literature research at regional and, for a selection of countries, at the national level, this chapter outlines the potential for technologies and fuels to replace coal and other fossil fuels mainly for electricity supply but also for direct use (heat), in particular in industrial processes. The analysis looks at the status of these technologies in terms of potential, as well as technological and financial viability. This chapter further presents and assesses the results of different scenarios at the national or regional levels and assesses their feasibility. In the final part the chapter looks at the benefits, opportunities and limits of cooperation between different countries in the region.

4.1 Renewable energy technologies: potentials and cost development

The countries analysed in this section have a number of options at their disposal to replace fossil fuels with renewable energy sources. As shown in the section below, the utilisation of solar and wind could satisfy the needs of almost all South and South East Asian countries many times over. The availability of hydropower, geothermal and bioenergy is much more unequally distributed but could contribute to grid flexibility and complement wind and solar technologies. The latter also have the advantage of providing electricity in areas without a well-functioning electricity grid – a major issue in many parts of the region described in more detail at the last part of this section.

In 2016, the average costs of utilising these renewable power sources often were already in the same range as fossil fuels even if the external costs of the latter were not included (IRENA, 2018b). A number of most recent auctions resulted in prices significantly below that range, in particular for solar and wind (MERCOM, 2018; Philstar, 2018; Quartz, 2018). Declining costs of renewables and storage technologies, such as batteries serve as a strong leverage point for not only decarbonising the power sector but also for concurrently increasing the electrification of other sectors, such as transportation, residential energy use and industrial processes. Bioenergy is currently the most common renewable energy application for thermal energy application in industry in South East Asia but solar and geothermal have large potentials as well, especially since industrial energy consumption is projected to grow significantly in the next two decades (IRENA, 2018b). In addition, key technologies related to the use of hydrogen from renewable energy based electricity are maturing, creating an option for decarbonising processes that are difficult to decarbonise through direct electrification, e.g. in primary steel production (IRENA, 2018a).

Solar

South and South East Asia have high solar irradiance[17] potential of between 1300 and 2200 kWh/m^2 annually. Values around the top of this range can be measured in large portion of Afghanistan and western parts of Pakistan, with high values of direct irradiation, which also makes concentrating solar power (CSP) an attractive option. Due to seasonal cloudiness, solar irradiance is somewhat lower (1300-1700 kWh/m^2 annually) in most parts of Malaysia, Philippines and Indonesia. (The World Bank Group, 2016).

17 Measured here Global Horizontal Irradiance (GHI), the total amount of shortwave radiation, relevant for photovoltaic installations

Table 4.1. Electricity potential from solar energy in comparison to current electricity consumption and electrification rate. Own calculation based on data from the NREL. The data assumes optimally oriented PV panels situated on 1.5% of the respective country's territory and a conservative efficiency estimation of 10% (NREL, 2014). This is compared with the most recent data for electricity consumption from different sources (BP, 2018a; CIA, 2019). The electrification rates based on Tracking SDG7 (ESMAP, 2019b).

Country	Electricity consumption in 2016 (GWh)	Solar potential if 1.5% of territory used (GWh)	Electricity consumption satisfied x-times	Electrification rate in 2016
Afghanistan	5.526	1.982.758	359	84%
Bangladesh	53.650	380.054	7	76%
Bhutan	2.184	107.639	49	100%
India	1.137.000	9.877.095	9	85%
Indonesia	213.400	4.967.991	23	98%
Malaysia	162.300	874.949	5	100%
Maldives	0.37	0.79	2	100%
Nepal	4.983	466.643	94	91%
Pakistan	92.330	3.010.691	33	99%
Philippines	78.300	792.147	10	91%
Papua New Guinea	3.237	1.244.137	384	23%
Sri Lanka	12.670	189.452	15	96%
Thailand	187.700	1.557.506	8	100%
Timor-Leste	349	50.516	145	63%
Vietnam	143.200	842.394	6	100%

According to our estimates, the usage of just 1.5% of territory for solar installations in each country with 10% efficiency could satisfy the combined electricity consumption in both regions 13 times over. This factor is currently highest in Afghanistan, which could every year generate nearly 2000 TWh electricity from solar energy but in 2016 consumed only 5 TWh, three quarters of which is based on imports (see table 4.1.). Due to the low electricity consumption and electrification rate, this ratio is set to decrease as more people get access to electricity and consume more of it. This will be the case not only for Afghanistan, where the electrification rate remains below 84% but also for India (85%) and Papua New Guinea where less than the quarter of the population has access to electricity (ESMAP, 2019a). Additional factors that will increase electricity consumption in a transition to zero emissions, even with the introduction of energy efficiency measures, is an increasing role of air conditioning and, in particular, new electricity demand through electrification of the transport sector as well as parts of the industry sector processes (either directly or through fuels such as hydrogen produced with renewable energy electricity).

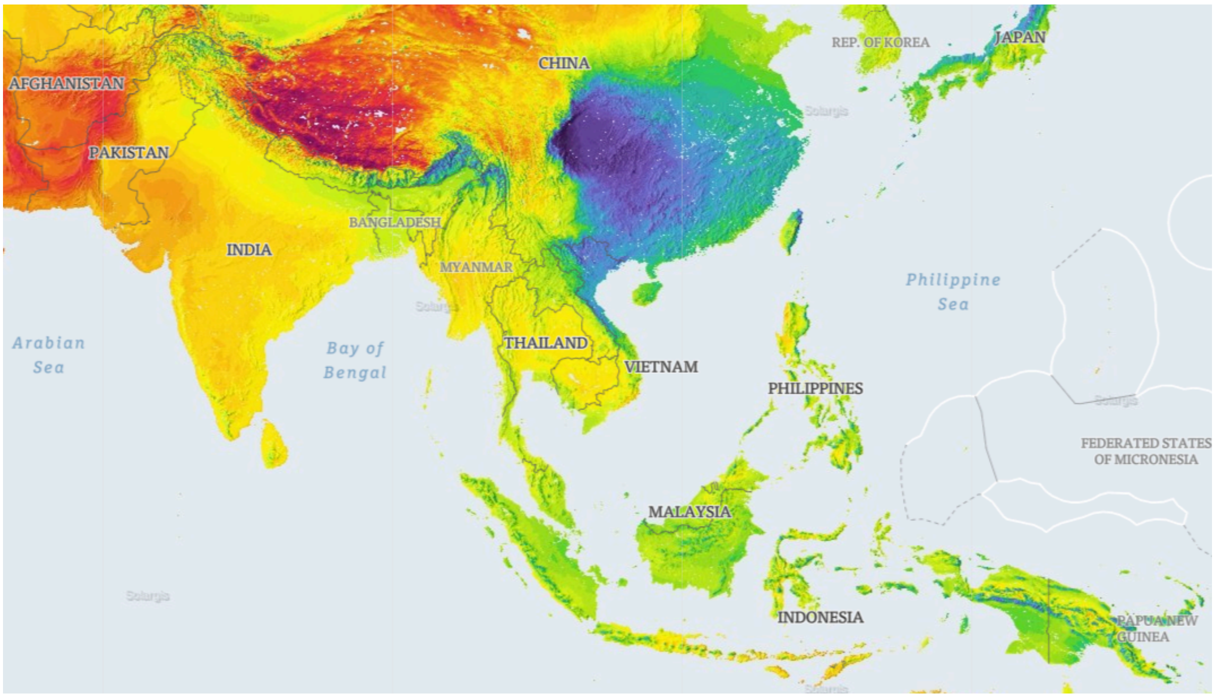


Figure 4.1. Solar resource data obtained from the Global Solar Atlas, owned by the World Bank Group and provided by Solargis.

This quantification of the resource potential raises the question as to why scenarios for energy system transformation such as those discussed in Chapter 2 do not demonstrate much higher levels of penetration of solar PV power over the next few decades. As an example, the IEA Beyond 2°C Scenario shows India with a 22% of solar PV in power generation by 2050, and ASEAN countries with only 14%.

Here we point out and emphasise the opportunities presented by the remarkably rapid decline in installation costs of solar PV and how this trend is making projections from even a few years ago appear outdated and far too conservative. Some scenarios (see Section 2.3.5) have been published that show the potential for very high penetrations of solar PV in electricity systems throughout the region.

Despite comparable levels of solar radiation, the costs of PV differ significantly between different countries in the SA and SEA regions. The Levelised Cost of Electricity (LCOE) of solar has seen a dramatic decline in India in the recent past, from an estimated 291 USD/MWh to nearly 88 USD/MWh between 2010 and 2017 (IRENA, 2018c). This is illustrated in figure 4.2.

LCOE values in the 80 USD/MWh range are also reported by Lazard and the International Energy Agency (IEA, 2018c; LAZARD, 2018). Much lower costs have been registered in auctions for solar farms in 2018 in the India's westernmost state of Gujarat: with 34 USD/MWh they belonged to the lowest ever bids in the world (PVTech, 2018). This is below the average costs of electricity of India's coal power plants, thus decreasing their profitability and putting future investments in fossil fuels in doubt (Quartz, 2018).

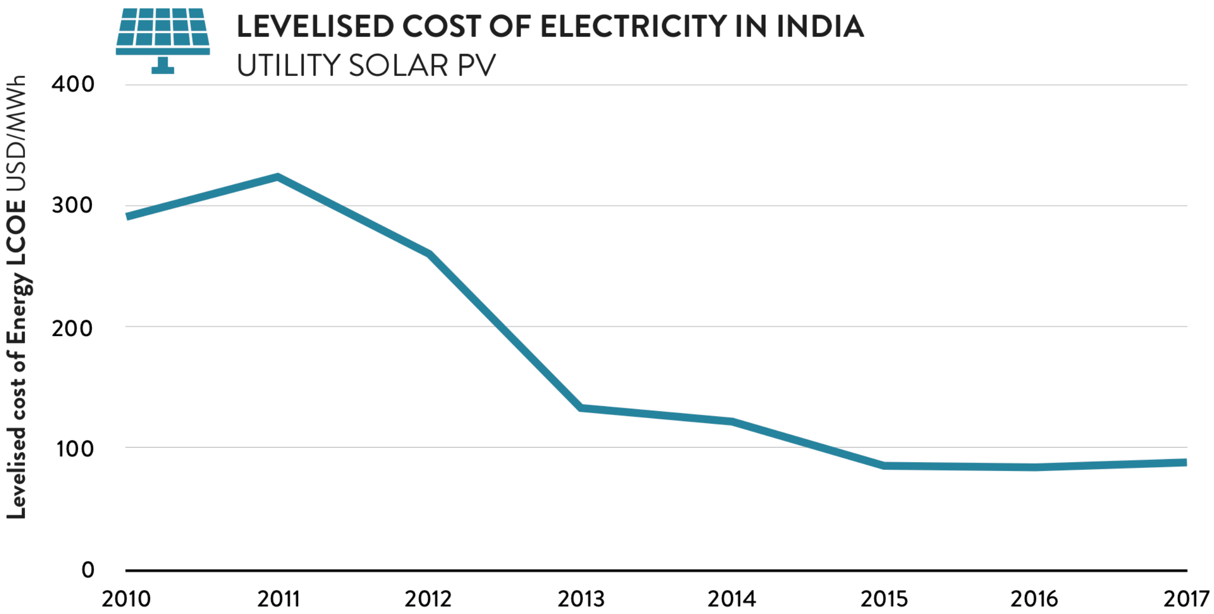


Figure 4.2 Levelised cost of electricity for utility solar PV in India. Based on (IRENA, 2018c).

At the same time, despite a 39% decrease on 2012 values, the LCOE for PV in South East Asia was one of the highest in the world, and 90% higher than in the rest of Asia - 190 USD/MWh in 2016 (IRENA, 2018b).

This points to the large potential to reduce costs and the need to address barriers through enabling deployment policies, and reducing capital costs through tax and duty exemptions, reducing "soft costs" such as licencing, permitting, grid connection and acquisition, and unlocking less-costly capital (Fuentes, Urmee, Muir, Hasnat, & Bhuyan, 2018; IRENA, 2018b).

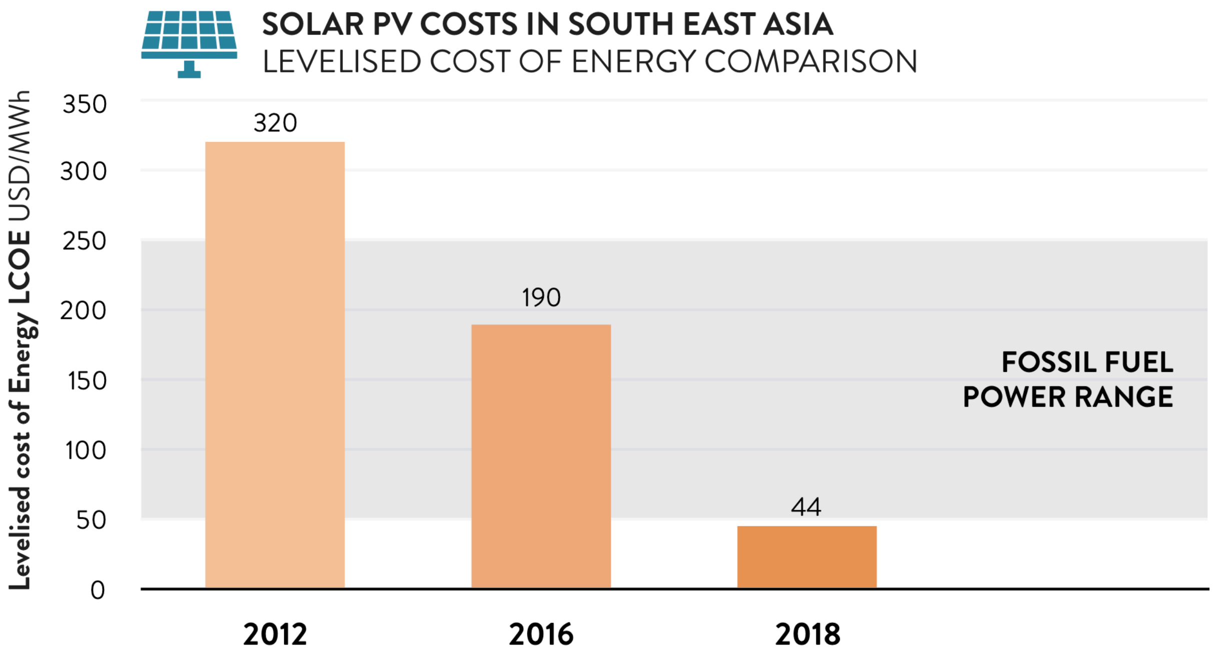


Figure 4.3. Development of costs (LCOE) for solar PV generation in SEA. Number for 2012 and 2016 represent the average LCOE for SEA from IRENA (2018b). The LCOE for 2018 comes from the auction in August 2018 in the Philippines and represents the lowest price reached in SEA regions (IRENA, 2018b; PVTech, 2018)

The situation in some South East Asian countries is improving, though, with the LCOE in some recent auctions approaching those in India. In August 2018, a tender for 50 MW was won by local producer of PV modules, Solar Philippines, which submitted a bid of 44 USD/MWh (Philstar, 2018).

Another option for some countries, especially those with strong, constant direct solar radiation, is solar thermal for low-heating and cooling and low-temperature industrial processes (IRENA 2018), as well as concentrating solar power (CSP). CSP has not been strongly utilised so far and there are nine CSP plants in India with combined capacity slightly above 500 MW and one 5 MW plant in Thailand (NREL, 2019). The reason for this lower popularity in comparison with PV solar could be the higher costs, which in the case of the projects built in India were between 150-180 USD/MWh.

Solar energy can be used beyond electricity generation. By supplying hot water and steam in a temperature range up to 400°C it can replace energy provided by fossil fuels in a number of industrial processes.

Much lower temperatures are needed in agriculture (e.g. curing, drying and pasteurisation) and textile industry (e.g. dyeing and washing). However, the low costs of fossil fuels and high up-front investment needed for solar energy – even if the investment pays off within a few years – combined with a lack of policies focusing on renewable energy beyond electricity (IRENA & ACE, 2016) are the main barriers for the broader uptake of these technologies (ETSAP&IRENA, 2015).

Wind

Compared with solar, wind resources are much more unevenly distributed not only between but also within countries. The strongest winds can be observed in western Afghanistan, especially provinces Herāt and Farāh. Average wind power density at 100m height in the windiest 10% of the country exceeds 2100 W/m^2 with the average wind speed at 12.39 m/s. Average wind speed exceeding 8 m/s can be observed in western Pakistan, but mostly in mountainous areas, which makes their utilisation difficult.

Figure 4.4. Wind strength map from the Global Wind Atlas 2.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU) in partnership with the World Bank Group, utilizing data provided by Vortex, with funding provided by the Energy Sector Management Assistance Program (ESMAP).

The average wind potential is comparably smaller in the biggest country in the region, India. The wind power density in the 10% of the windiest areas amounts to 403 W/m^2 (World Bank Group, 2018). These areas are mostly situated in the western coastal areas of the country as well as in the South of the country, especially Tamil Nadu Province, and the eastern provinces of Orissa, Jharkhand and northern parts of Chhattisgarh (NREL&USAID, 2019). Wind resources in the remaining countries in the region are comparably smaller, with the exception in some parts of the Philippines, especially near shore areas south of Southern Tagalog, where wind power density exceeds 800 W/m^2

The wind resource availability is in some cases strongly limited by the land use constraints. For example, the parts of Bangladesh with comparatively good average wind speeds also belong to the most densely populated. As a result, the technical potential for wind energy in this country, which also takes into consideration the access to the electricity grid (maximum 20 km of transmission line) was estimated at slightly above 1GW (Netherlands Enterprise Agency, 2017).

Depending on the technology and keeping in mind land limitations, the technical wind energy potential in India amounts to between 2200 and 5900 GW (Hossain, Sharma, Mishra, Ansari, & Kishore, 2016), or between 6 and 17-times the currently installed capacity in the country.

Utilisation of the good-to-excellent areas for utility scale applications would allow installation of 158 GW of wind energy in Afghanistan and 132 GW in Pakistan, assuming 5MW/km^2 (NREL, 2007). Newer, taller and more efficient wind turbines would allow increasing this potential further.

Philippines' technical potential amounts to around 76 GW (REMB, 2016), almost four times the total installed capacity in the country at the end of 2016 (Department of Energy, 2017).

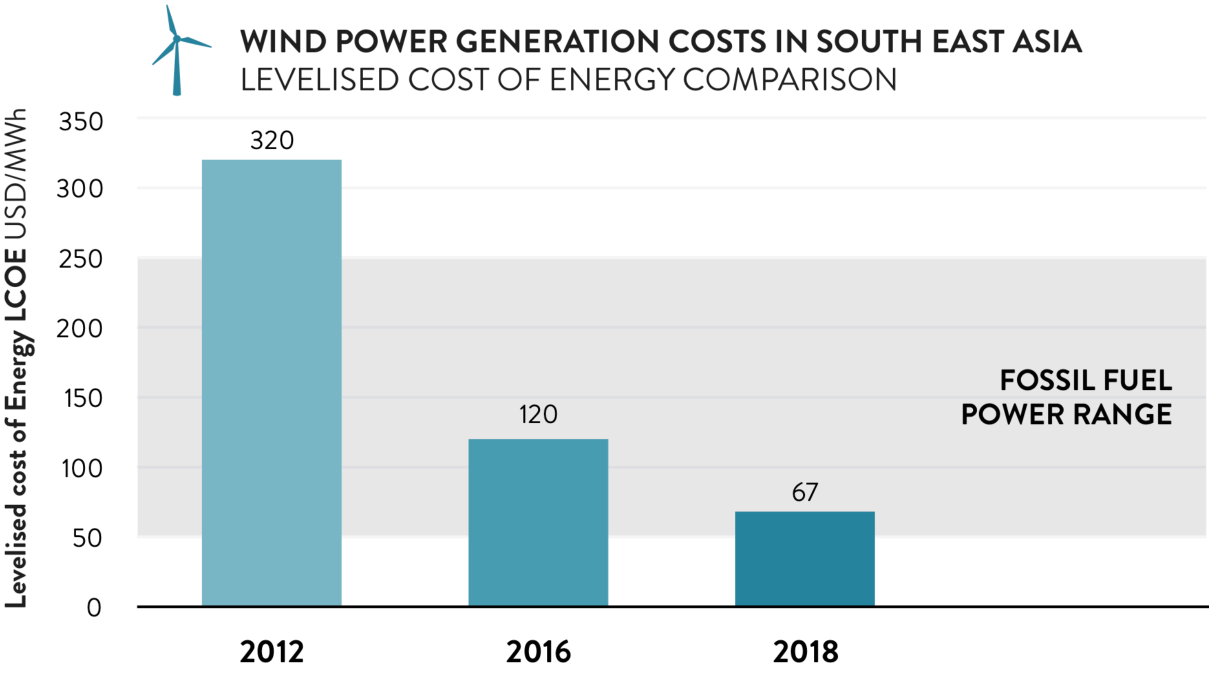


Figure 4.5. Development of costs (LCOE) for wind power generation in SEA. Numbers for 2012 and 2016 represent the average LCOE from IRENA. The cost for 2018 comes from the auction in September 2018 and represents the lowest price reached in SEA (IRENA, 2018b; Manila Standard, 2018).

Decent cost decline has been observed in onshore wind energy. Weighted average LCOE in SEA fell by 14%, from 140 USD/MWh in 2013 to 120 USD/MWh in 2016, with the LCOE in some projects falling below 100 USD/MWh, thus being cheaper than the average cost range for fossil fuel power (IRENA, 2018b). Recently, further cost reductions for wind energy have been registered, with the Island Wind Energy Corp. offering to build a 150 MW wind farm for 67 USD/MWh in the Philippines (Manila Standard, 2018). Overall, the costs of most onshore wind projects are increasingly within the estimate range of fossil fuel costs in SEA, and costs continue to fall (IRENA 2018b).

The costs in some of the more recent auctions in India resulted in even lower costs: 1.2 GW auctioned in September 2018 will be built for between 38-39 USD/MWh (MERCOM, 2018). When built, this will be below the lowest costs of fossil fuels estimated between 50-150 USD/MWh (IRENA, 2018b).

Hydropower

For decades large hydropower has been the dominant renewable source of electricity in both regions. While the share of hydropower in renewables remained at constant level of 67% in South East Asia, it decreased from 95% to 72% in South Asia. This decrease occurred despite doubling hydropower generation in the two regions due to an even faster increase in the share of bioenergy, wind and solar. This was especially the case in India where the share of wind energy increased from below 2% to over 19% of all renewables, and 2.5% of all electricity generation.[18] However, it must also be noted that electricity generation from this source of energy varies strongly between different years (IRENA, 2019b).

Three South East Asian countries are ranked in the top ten for the highest hydropower potential: Indonesia ranked 8th with 477 TWh of exploitable hydropower potential, India is ranked 9th with 387 TWh, and Papua New Guinea is ranked 10th with 355 TWh (Zhou et al., 2015). The full utilisation of this potential would allow India to generate around 26% of its current electricity demand. The estimated potential for Indonesia is almost twice its current energy consumption. Papua New Guinea could generate almost 100 times its current electricity demand from hydro energy.

Figure 4.6 Hydropower Potential (GWh/m2). Source: Hoes et al. (2017)

For many reasons, however, only a part of this potential can be used, given the serious impact on the local environment, wildlife, and communities (Cernea, 1997; Union of Concerned Scientists, 2019). In many cases, hydropower competes for water resources with irrigation activities (Zeng, Cai, Ringler, & Zhu, 2017). Especially in tropical regions large dams may also significantly contribute to climate change by flooding terrestrial organic matter and converting it into greenhouse gases: carbon

18 Own calculation based on IRENA's Trends in Renewable Energy (IRENA, 2019b)

dioxide, methane and nitrous oxide (Deemer et al., 2016). For example, the estimated potential for hydropower decreases substantially for Indonesia if national parks are excluded (Ministry of Energy and Mineral Resources, 2011).

Many of those issues do not affect small, local hydro power. According to some estimates, the discovered potential for small (up to 10 MW) hydro power plants amounts to almost 18 GW in South Asia and additional 13.6 GW in Southeast Asia. With almost 3 GW and 2.3 GW small hydro capacity installed in the respective region, there is still a large potential that can be utilised (UNIDO&ICSHP, 2016).

The distributed character of this source of energy allows for electrification of remote regions, like Northern Afghanistan, where low electrification levels coincide with high recoverable hydroelectric capacity. The major challenge in this case is, however, that the peak river flow is in summer while electricity demand peaks in winter, thus increasing the need for seasonal storage or backup capacity (The World Bank, 2018).

One of the main benefits of hydropower plants, namely the provision of flexibility to the electricity grid, can be better utilised if complemented with the development of energy sources, which need this flexibility, such as wind and solar (Hirth, 2016).

The costs of hydro energy differ significantly depending on circumstances. According to IRENA, the LCOE of hydro projects decreased slightly from 48 USD/MWh in 2011 to 46 USD/MWh in 2016 in South East Asia, and is at the bottom edge or below the fossil fuel power cost range. Even when the costs of other technologies decreased much faster, hydro energy remained the cheapest source of energy in the region (IRENA, 2018b). However, a global study of large dam projects suggests that the *actual* costs were on average 96% higher than the *estimated* costs. Large dams were also shown to take on average 8.6 years to build, with South Asian countries showing some of the poorest schedule performances (Ansar, Flyvbjerg, Budzier, & Lunn, 2014).

Geothermal

South Asia and South East Asia also have a notable potential in the geothermal sector, focused mainly in Indonesia, India, and the Philippines. Indonesia is home to roughly 40% of the global geothermal energy potential, and the country has enough resources to generate 28.6 GW of electricity (Nasruddin et al., 2016). Philippines' potential is lower and amounts to 4.34 GW of geothermal electricity generation. These two countries are expected to increase their combined geothermal capacity by 2.16 GW by 2020 (Bertani, 2016). In a cost optimal 100% renewable energy based scenario geothermal sources are predicted to supply 20% of South East Asia's entire electric grid's energy (Gulagi, Bogdanov, & Breyer, 2017).

Geothermal energy also offers a significant and largely underutilised source of renewable heat, especially for industry and agriculture, with the building sector potentially playing a smaller role in comparison to the global utilisation (IEA, 2018a). At the moment, however, it is not used beyond some applications focused on agricultural industries in Indonesia, Philippines, Thailand, and Viet Nam (IRENA, 2018b).

India has begun to realise its potential for geothermal energy estimated at 10.6 GW capacity, and has identified over 300 potential sites across seven provinces (Craig et al., 2013). Most South Asian countries, including Nepal and Pakistan, have not yet conducted any extensive research or exploration to determine the viability of potential geothermal sources (SAARC, 2011).

The cost of this energy form varies between countries and depends strongly on the respective geothermal conditions. According to IRENA, geothermal technology in the Southeast Asia region has seen an 8% rise in weighted average investment costs, from USD 2937/kW in 2014 to USD 3184/kW in 2016. This rise is assumed to be caused by increasingly sophisticated technology and infrastructure developments at the geothermal sites.

The weighted average LCOE costs of geothermal power were at 64 USD/MWh in 2016, which is a 4 USD/MWh more than in 2014 (IRENA, 2018b) but still at the lower end of the fossil fuel power cost range. However, another report from 2015 quotes the overall investments costs of a geothermal energy facility at around USD 1900/kW, thus showing a significant dependence on the individual projects taken into consideration (Huber, Roger, & Hamacher, 2015).

For some South East Asian countries geothermal is identified as being one of the cheapest electricity generation options. Also India can strongly benefit from the construction of geothermal facilities in rural areas. For example, a hypothetical 20 MWe plant in the Puga region of Jammu and Kashmir would lower the state's electricity generation costs by USD 2 million annually, as well as lead to the elimination of 28,000 tCO_2 per annum (Craig et al., 2013).

On the other hand, the location of some of the geothermal resources poses a potential hurdle. An estimated 42% of Indonesia's geothermal resources are found in protected and conservation areas (PWC, 2018). In the Philippines a large amount of the untapped geothermal resources is located in national parks or protected by the nation-state's Indigenous People's Rights Act (Reuters, 2008). Likewise, in the Jammu and Kashmir state of India, the development of geothermal facilities can pose a threat to the vulnerable ecosystems (Craig et al., 2013). Thus, the potential for sustainable use of geothermal energy needs to be estimated with great care, and also the development of projects using this resource.

Bioenergy

Over 120 million tonnes of biomass residue is generated annually in South East Asia. Indonesia, the Philippines, Viet Nam and Thailand produce over 34 million tonnes of sugarcane bagasse annually. The wood industry, which primarily operates in Indonesia and Malaysia, generates about 30 million m^3 of wood residue. In addition the countries of this region generate 19 million tonnes of rice husks and 27 million tonnes of palm oil residue (Carlos & Ba Khang, 2008a). While similar estimates for the countries of South Asia are missing, it can be assumed, that due to climatic conditions and different focus of the agriculture, the biomass waste availability is comparatively smaller but nonetheless substantial.

The use of biomass waste has many benefits, such as avoiding waste disposal and demand for land but production of bioenergy-specific crops requires large areas of land, which presents a challenge to the region. South and South East Asia already have the percentage of land not available for biomass energy production. (Hoogwijk, Faaij, Eickhout, de Vries, & Turkenburg, 2005).

Intense usage of machines for agricultural purposes can lead to soil compaction, which ultimately leads to a higher chance of erosion and weaken water retention. This can lead to a long-term decrease in yields. Excess utilisation of pesticides, herbicides and other chemicals on surface and ground water can lead to serious contamination and threaten the biodiversity of a location (Glaucia, Reynaldo, Carlos, & Luciano, 2015).

Finally, clearing of forests for palm oil plantations for bioenergy production leads to greenhouse gas emissions from the LULUCF sector which may sometimes even be higher than the emissions avoided from the utilisation of fossil fuels (Goodman & Mulik, 2015; ICCT, 2016; Jaung et al., 2018; Khatiwada, Palmén, & Silveira, 2018).

In 2016, bioenergy generated 1.2% of the overall electricity in South Asia and 3.4% in South East Asian countries, including 0.3% of biogas (IRENA, 2019a). A large share of the biomass currently used both regions is traditional biomass used for cooking. Replacing biomass by electricity from renewable sources or its more effective utilisation in modern cooking stoves would have substantial sustainable development benefits and at the same time allow for effective biomass utilisation in other sectors, especially as an alternative to fossil fuels in industry, with a low cost of around 17-42 USD/MWh (IRENA & ACE, 2016).

Bioenergy is already widely used for industry. For example, 16% of industry energy use in Indonesia (palm oil processing, sugar and wood, brick production) comes from bioenergy. In the Philippines, bioenergy is used for steam and power generation but also agriculture and other industries. In Thailand, many industries rely on bioenergy (IRENA & ACE, 2016). Bioenergy can also be used as the basis for hydrogen generation, thus replacing many areas in which natural gas is currently utilised. However the comparatively low efficiencies of this process, which depending on the kind of biomass vary between 29-33%, energy recovery techniques should be applied to maximise biomass potential (Mungkalasiri & Paengjuntuek, 2016).

The biomass projects for electricity generation commissioned between 2010 and 2016 resulted in costs range between 45-95 USD/MWh, with a weighted average of 65 USD/MWh (IRENA, 2018b). However, even more important than the cost is the biomass availability and regulatory framework. Stable streams of biomass combined with long-term power purchase agreement increase investment security and lead to lower capital costs (Carlos & Ba Khang, 2008b). The value of this source of energy could be increased by taking advantage of its dispatchable character and utilising it in combination with solar and wind energy.

Electricity grid

The utilisation of the renewable energy potential is strongly determined by the status of the grid development. In many countries the electricity grid does not reach many parts of the country, for example in Afghanistan, where in 2014 only 30% of the population was connected to the grid. The fragmentation of the transmission system divided into a number of isolated grids operating at different speeds and frequencies, further complicates the situation (The World Bank, 2018). In India concerns over inadequate transmission infrastructure led to cancelling a tender for wind energy (Clean Technica, 2018).

The countries in both regions are planning to improve the situation by facilitating transnational grid connections, for example the agreement of the ASEAN countries to develop an ASEAN Power Grid (AGP) in the framework of the ASEAN Vision 2020 (ASEAN Centre for Energy, 2017b). However, high-voltage electricity grid is not an option for large parts of the Philippines and Indonesia, which consist of numerous small islands where there is no business case for centralised power generation.

Renewable energy technologies are well suited for providing affordable access to clean modern energy through micro grid and off-grid solutions, and can avoid costly development of centralised grids. In most cases, distant regions and small islands have been powered using diesel generators, thus making electricity consumers susceptible to high electricity costs and volatile oil prices.

Decreasing costs of solar and wind energy, combined with the availability of electricity storage, opened new opportunities for electricity generation. Replacing diesel-power generators by renewables not only reduces CO_2 emissions, but also improves air quality, reduces noise pollution and therefore also attractiveness of tourist areas, and results in much lower and stable electricity prices. A number of countries in the region are already taking advantage of these opportunities. For instance, off-grid wind and solar PV play an essential role in the electrification of small islands in the Philippines, despite sizeable regulatory barriers (IEA, 2019; IEEFA, 2017).

The stability of micro grids can be increased by complementing variable renewables, such as solar and wind, with dispatchable renewables such as small biomass installations utilising local resources, or small hydropower plants. Adding smart meter technology can support the integration of large shares of variable renewables in either centralized or mini-grids allowing dynamic energy pricing and reducing peak loads and capacity needs (IRENA, 2013).

Some countries of the region are progressing fast with the deployment of smart meters with over 340 000 units installed in the Malaysian province Melaka (The Star Online, 2018) and Thailand planning to invest almost USD 300 million in 20-year smart grid project (Smart Energy International, 2017). Combined, countries in the South East Asia region are planning to invest USD 9.8 billion in smart grid infrastructure until 2027 (Power Engineering International, 2018).

4.2 Current Status and future development: targets, scenarios, and co-benefit potentials

Current Status

Between 2000 and 2016, the overall electricity generated from renewable sources South Asia and South East Asia increased by 243 TWh (140%), an annual growth rate of 5.5%, however, demand grew by 152% or 6% per year in this period. Almost 60% of the growth in renewables resulted from additional installed capacity in hydro power plants, while the rest came from additional capacity in new energy sources like wind (15% of the growth), bioenergy (16%) and solar PV (6%). The growth of solar happened almost exclusively after 2010.[19]

In 2016, almost 16% of electricity in South Asia and over 20% in South East Asia came from renewable sources. While in both regions solar PV contributed the same share of electricity (0.6%), the share of wind energy was much higher in South Asia (2.3%) than in South East Asia (0.2%) mainly due to the comparatively large contribution from the this source of energy in Afghanistan (2.9%) and India (2.6%). At the same time, while there are almost no geothermal units in South Asia, on average countries of South East Asia generate 2.6% of electricity from this source of energy, mainly due to important role geothermal plays in Indonesia (4.3%) and Philippines (12.2%).

Despite the significant growth of renewables, their share in electricity production decreased in some countries, e.g. in Bangladesh (from 4.5% in 2000 to 1.7% 2016), Indonesia (from 21% in 2000 to 16% in 2016), Vietnam (from 53% to 36%) and the Philippines (from 43% to 24%). Contribution of renewables remained stable in India (slightly above 13%), Pakistan (31-32%), and increased in Malaysia (from 11.7% in 2000 to 13.5% in 2016). A significant increase (from 6.8% in 2000 to 13.9% in 2016) was noted in Thailand mainly due to increased utilisation of biomass and to a lesser degree solar PV.[20]

Targets and how to achieve them

Most countries in the region are planning to utilise their renewables potentials further. Among the South Asian countries, Bangladesh and India have indicated their preference for increased renewables utilisation in their national electricity plans.

A key target in the Power System Master Plan of Bangladesh is to increase the cumulative installed capacity of renewable energy sources to 3.8 GW by 2041 from 0.4 GW in 2016. The plan contains a suggested optimal mix which shows the contribution of renewable energy to generation growing from 5% in 2015 to 35% in 2041. It is important to note that the plan does not classify hydropower generation as a renewable resource (Ministry of Power, 2016).

In its National Electricity Plan, India plans to increase the share of power generated from renewable sources from 13% in 2016 to 21% by 2022 and 24% by 2027, including Small Hydro Power (SHP). Among the South East Asian countries, Vietnam aims to increase the share of renewables in power generation to 43% by 2050 (Dam, 2016). For Indonesia, the most ambitious government scenarios

19 Own calculation based on data from IRENA (IRENA, 2019b). Includes electricity coming from renewable sources in the countries of South Asia (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka) and South East Asia (Indonesia, Malaysia, Thailand, Vietnam, Philippines, Timor-Leste and Papua New Guinea).

20 Own calculation based on data from IRENA, BP and CIA estimates (BP, 2018b; CIA, 2019; IRENA, 2019b).

envisage just a 26% contribution of renewables to the generation by 2050 (National Energy Council, 2017). It is significantly below the REmap scenario for 2025 this country, which sees a renewable share of 37% in the power generation mix.

In October 2015 the ASEAN Ministers of Energy agreed on an aspirational target of increasing the share of renewables in primary energy to 23% in 2025 (ASEAN Centre for Energy ACE, 2015). This would mean an increase by around 10 percentage -points compared with 13.6% in 2015. However, should all ASEAN member countries meet their national goals, the share of renewables will only reach 17.5% in 2025.

For the ASEAN region as a whole, IRENA shows that renewables could contribute at least 23% to primary energy supply by 2025, corresponding to the aspirational goal for the region. According to the IRENA REmap scenario, the share of renewables in the electricity generation would increase by 15 percentage points to 35% in 2025 (IRENA & ACE, 2016).

This is consistent with the Paris Agreement benchmark derived in Chapter 2 based on the IEA ETP B2DS Scenario for the ASEAN region (31% in 2025). Within the REmap scenario, individual countries would see different shares in their respective power mixes, with the lowest being Brunei (11%) and the highest, Laos (90%). This reflects the diversity in renewable potential among different countries in the region. Table 4.2 highlights the share of renewables in the generation mix between 2014 and 2025, in the reference and REmap cases.

In the REmap scenario, the increase in renewable shares is largely driven by solar PV additions, which account for half of all additions in renewable energy in the region, reaching a total installed capacity of 57 GW by 2025. This is much higher than the 14 GW in the reference case, which points to a significant underestimation of solar PV potential in individual national plans.

Table 4.2. Share of renewables in electricity and primary energy in Reference and Remap scenarios (IRENA & ACE, 2016).

	Share of renewables in electricity supply			Share of renewables in total Primary Energy Supply		
	2014	Reference (2025)	REmap (2025)	2014	Reference (2025)	REmap (2025)
ASEAN	20%	27%	35%	9.4%	16.9%	23%
Viet Nam	45%	27%	35%	10%	7%	15%
Thailand	13%	18%	23%	11%	18%	24%
Singapore	2%	2%	10%	1%	1%	3%
Philippines	26%	28%	33%	25%	35%	41%
Myanmar	62%	59%	71%	4%	7%	29%
Malaysia	10%	19%	32%	2%	5%	14%
Lao PDR	100%	86%	90%	46%	49%	59%
Indonesia	12%	33%	37%	9%	23%	26%
Cambodia	50%	62%	76%	19%	18%	35%
Brunei	0%	0.40%	10.90%	0%	0.2%	4%

Other scenarios for South East Asia, such as the Asian Centre of Energy (ACE) Energy Outlook and the IEA (World Energy Outlook), show even higher shares of renewable energy in power generation for pathways consistent with the ASEAN objective, with a renewable share of 42% in 2025 and 52% in 2040 for the 5th ASEAN Energy Outlook "Progressive Scenario" (ACE, 2017). The IEA "Sustainable Development Scenario" (SDS) results in a share of 36% in 2025 (slightly higher than REmap), 52% in 2030 (higher than in the ETP scenario shown in chapter 2) and 70% in 2040 (IEA, 2018c).

In the case of South Asia, the REmap project currently provides scenarios only for India, where the share of renewables in the power mix would increase to 18% by 2030 in the reference case, and 35% by 2030 in the REmap scenario. This is lower than the country's targets and lower than the Paris Agreement benchmark derived in Chapter 2 for India (42% in 2030, with a total of 51% of decarbonised power generation in 2030) based on the IEA B2DS scenario and also lower than the projection by the CAT (2018) based on current policies, with the Central Electricity Authority (CEA) projections in the National Electricity Plan (NEP) for 2022 already reaching the level reached in the Reference Case for this scenario by 2030. This highlights the potential to scale up targets including the respective NDCs, and update scenarios based on current cost estimates.

Policies to facilitate faster uptake of renewable energy

Changing the pricing of fossil fuels through carbon pricing and removal of subsidies in a way that reflects their social and environmental impact is one of the main prerequisites for reaching the goal of the Paris Agreement. At the same time, carbon pricing needs to be accompanied by transfers that will compensate for unintended distributional cross-sector and cross-national effects (IPCC, 2018a).

Furthermore, the often high upfront investment needs require the development of adequate financial instruments such as grants, interest-free loans or loan guarantees and incentives, and removal of barriers, to accelerate investments into renewable energy, even when costs are equal or lower than fossil fuels. Feed-in tariffs have already proven very effective in facilitating renewables development (REN21, 2018) but they should also allow for frequent adaptation to reflect decreasing costs of renewables (IRENA IEA&REN21, 2018), and can be followed by other approaches, such as auctioning.

An integrated and consistent strategy and policy framework across sectors is important to send strong signals to investors and maximise the benefits across the economy (Asian Development Bank, 2017b),

Co-benefit potential

Development of renewable energy is highly correlated with increasing income, job creation, industrial development, and improved livelihoods. This has been analysed by IRENA for South East Asia (IRENA 2016, IRENA 2018).

Access to decentralised renewables can substantially reduce poverty by empowering individuals and communities to gain control over their energy supply, reduce energy spending and improve livelihoods (Fuentes et al., 2018). The transition to sustainable energy creates benefits such as employment generation, market opportunities, and better health conditions.

Economic benefits include energy cost savings, improved income generation and poverty alleviation. One of the multiple benefits is the reduction of expenditure on energy imports that could be lowered by USD 40 billion by 2025 (IRENA 2016).

IRENA estimates a positive impact on employment with an accelerated renewable energy uptake corresponding with their REMAP scenario. The sector already creates 611 000 jobs across South East Asia in 2016 and a further 2.2 million jobs could be created in this sector by 2030 (IRENA 2016, IRENA 2018, Fuentes et al 2018).

IRENA estimates that achieving the regional target for ASEAN would lead to net savings, taking into account externalities, in particular from avoided outdoor air pollution outweighing costs for energy system transformation.

100% Renewables

Six South Asian countries (Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Sri Lanka) and four South East Asian countries (Papua New Guinea, Philippines, Timor-Leste and Viet Nam) are members of the Climate Vulnerable Forum (CVF) and have signed up to the goal "to meet 100% domestic renewable energy production as rapidly as possible" (CVF, 2016).

The possibility of exclusive reliance on renewables in the power sector by 2050 at the latest has already been presented in the Greenpeace energy [r]evolution scenario for ASEAN countries, published in 2013, and in the "Advanced" energy [r]evolution scenario that demonstrates 100% renewable energy across all sectors, in all regions of the world (Greenpeace, 2013, 2015a). It would allow for electricity generation to increase five-fold between 2010 and 2050, with wind (including offshore) and solar PV generating 42% and 24% of electricity, respectively in the ASEAN region. The reason for this significant increase in electricity demand is the assumed electrification of end use sectors, with electricity use for heating and cooling increasing from 1% in 2010 to 26% by 2050 (Greenpeace, 2013).

Renewable energy would reach a share of 60% of the total electricity generation mix by 2030 in this scenario. This is higher than the minimum benchmark of 51% share of decarbonised electricity generation for a Paris Agreement pathway with the IEA B2DS scenario analysed in Chapter 2, which achieves part of this with nuclear and fossil fuel use with CCS already in 2030. This, however, is highly unlikely given their higher cost and lack of benefits for sustainable development compared with renewable energy.

Other scenarios, such as that published in 2015 by Huber, et al. assume a much larger role for solar PV covering more than a third of demand of the ASEAN countries in 2050. Carbon intensity of the power sector could be decreased to below 25gCO_2/KWh either independently by each country of the region or through expanded grid-interconnection which would decrease the overall costs of almost full decarbonisation of the power sector (Huber et al., 2015).

The LUT Energy System Model has been used to develop a 100% renewable based power sector by 2050 in the whole of South East Asia connected to Australia, comparing pathways relying on use of storage technologies with other pathways relying on imported electricity through transmission of renewable energy through a High Voltage cable connection (HVDC). This integrated scenario includes desalination and industrial gas demand, with wind and solar dominating renewable electricity generation (Gulagi, Bogdanov, et al., 2017). This model has also been used to develop 100% renewables based power sector by 2050 in three countries of the region: Vietnam, Indonesia, and Papua New Guinea. In all three cases PV solar is the major source of energy providing 81% of electricity to Vietnam and 88% for Indonesia and Papua New Guinea. This increase takes place despite a significant increase in electricity consumption resulting from electrification of end use sectors (Manish Ram, Smitri Bogdanov, Arman Aghahosseini, & Ayobami Solomon Oyewo, 2017; Ram, Bogdanov, Aghahosseini, & Oyewo, 2017)

Similarly, for South Asia, a more recent modelling exercise confirms that a 100% renewable energy system is possible with regional grid interconnection at a lower total system levelised cost of electricity (LCOE), when compared to a scenario where each individual country attempts to make such a transition individually (Gulagi, Choudhary, Bogdanov, & Breyer, 2017).

As energy system modelling advances, more efforts are being made to incorporate sector coupling and full decarbonisation of all end use sectors. For example a number of studies look at Paris Agreement-compatible or 100% renewable energy scenarios that go beyond the power sector (Jacobson et al., 2017; Löffler et al., 2017; Teske, Meinshausen, & Dooley, 2019).

Part of the synergy between sectors that arises from these models is that electric vehicles and building heating systems based on heat pumps are far more efficient than current technologies, thereby opening the possibility to achieve the same energy services with a much lower input energy. At the same time, decarbonisation of the power sector means that these new applications across sectors will become increasingly low- to zero-carbon.

4.3 Opportunities for Regional Cooperation

Regional cooperation can support a higher uptake of renewable energy in the South and South East Asian regions to use the diverse renewable energy potentials of different countries in a more effective way, and existing cooperation frameworks can be used to enhance this, such as the

South Asian Association for Regional Cooperation (SAARC)[21] (SAARC, 2014) and the Association of Southeast Asian Nations (ASEAN) Plan of Action for Energy Cooperation introduced in 2015 and aiming for a creation of an ASEAN Power Grid in order to ensure regional energy security. This facilitated the development of interconnections between Singapore, Peninsula Malaysia, Thailand, Lao PDR, Cambodia and Vietnam (ASEAN Centre for Energy, 2015). While renewable energy expansion has not been the focus of this initiative in the past, recently IRENA launched the "Greening ASEAN Power Grid Initiative" to accelerate the development of utility-scale renewables-based electricity (IRENA 2018).

The South Asia Regional Initiative for Energy Integration[22] (SARI/EI) is yet another initiative that mirrors SAARC in its aims. In particular, SARI/EI hopes to create a system to facilitate the transfer of long-and-short term power surpluses of member-states throughout the region.

The potential benefits of increasing electricity trade are numerous. For instance, there are several regions in Pakistan, which face significant electricity shortages. In some of the border regions it would be more economical to import electricity from India at least until the country utilises its full renewable energy potential, which in terms of solar and wind is proportionally even higher than that of India, and starts exporting electricity. However, the interconnection between these two countries is limited (IRENA, 2016).

A renewable energy-based regional power grid would allow smaller countries like Bhutan and Nepal, which have significant renewable energy potentials, to export their surplus power and generate much-needed revenue (Kumar Singh, 2013). Simultaneously, countries with energy-intensive industries, such as Pakistan and India, can gain easier access to electricity.

The South Asia Subregional Economic Cooperation (SASEC) Power System Expansion Project provides one such example. Through financial assistance from the Asian Development Bank, Nepal aims to build over 200 kilometres of power transmission lines along the Nepal-India Himalaya corridor. The initiative has also been financed to construct several small-scale rural renewable energy projects ranging from solar mini-grids to small hydropower plants. The overall aim is to harness the clean energy potentials that Nepal has to offer, and eventually export surplus energy to India (ADB, 2019).

Cooperation on the development of electricity grid can be accompanied by an exchange of experiences in development of a decarbonised and reliable electricity sector, as is called for by Article 14 of the SAARC Framework Agreement for Energy Cooperation. An Asian emission trading scheme would also likely foster greater cooperation between the varying regions of the continent (Massetti & Tavoni, 2012).

There are significant gaps between initiatives for regional cooperation and concrete steps to put them into practice (Krampe & Swain, 2018). Associations such as SAARC and SARI/EI have largely failed to go beyond declared intentions for regional cooperation. Despite significant recent

21 SAARC comprises of Afghanistan, Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan and Sri Lanka

22 SARI/EI Members are: Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka

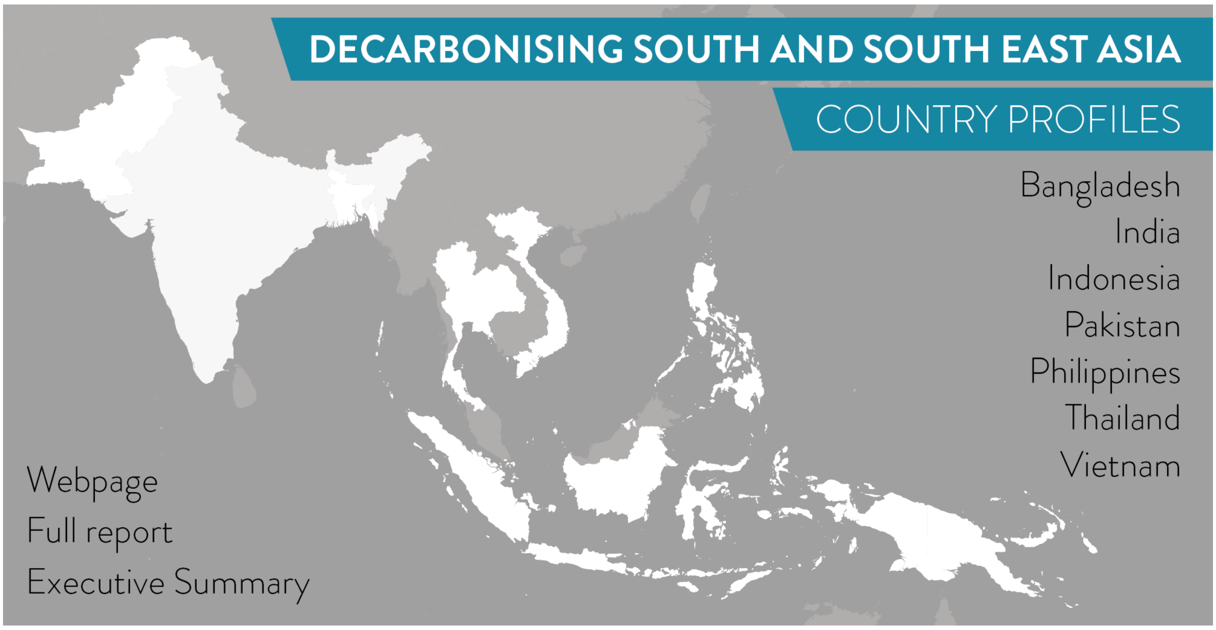
developments, such as the Indian government's policy changes that make it far easier for cross-border energy trade to take place with limited barriers, there has been an overall lack of genuine multilateral action to translate intention into policy (The Hindu, 2019).

Regional energy cooperation does not necessarily translate to the utilisation of clean energy. ASEAN's Plan of Action for Energy Cooperation has, as one of its key pillars, the aim of enhancing the image of coal through the promotion of so called clean coal technologies (ASEAN Centre for Energy, 2015). As part of the programme, countries pledged to share technical capacity to deploy low-emission coal innovations and explore the potential of CCS (Guo, 2018). Currently progress is limited, with initiatives still at the stage of concept development (ASEAN Centre for Energy, 2017a). Instead of facilitating the energy transition in the regions, in this case the regional cooperation is actively promoting the use and expansion of coal in the energy system.

The varied, and in many cases, contentious approaches to foreign policy among the countries in South Asia and South East Asia can make it difficult to expect a rapid harmonisation of policies and a shared commitment towards seizing the opportunity of renewable energies (Miner, Patankar, Gamkhar, & Eaton, 2009). However, in the face of growing energy demands the prospect of regional energy cooperation, with all its benefits, may incidentally serve to promote stronger cooperation in other areas.

Country profiles

This report also includes analysis on 7 different countries. You can find each individual profile through the links below as well as a link to the main webpage with all the most up to date content.



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Annex 1: Estimating CO2 emissions from coal plants

To estimate the CO_2 emissions from the existing and planned coal-fired capacity, we make use of the following formula:

$$Annual\ CO_2\ (in\ Mt) = capacity\ \times\ capacity\ factor\ \times\ heat\ rate\ \times\ emission\ factor\ \times\ \Phi^{23}$$

The **capacity** describes the amount of power a plant can produce and is measured in Megawatt (MW). For each plant in the database, the capacity is given, ranging from 0 to 8000MW. Information on the capacity is obtained from the Platts World Electric Power Plants database. Additional information used to classify the units include the current status of the plant ('Operating', 'Under construction', 'Planned' and 'Announced') and the combustion technology used ('Supercritical', 'Ultra supercritical', 'Subcritical').

To convert the capacity into the energy generated by the unit, we multiply the capacity with the **capacity factor** and the number of hours in the year (8760). This represents the energy generated by the unit in a year. For the purpose of our analysis, we make a distinction between the capacity factors of hard coal[24] and lignite units. For hard coal units, we use capacity factors derived from the Current Policies Scenario from the World Energy Outlook (IEA, 2018c). For lignite units, we base our capacity factor assumptions on the utilisation of lignite based coal generation in India (Central Electricity Authority, 2019).

The **heat rate** describes how efficiently a plant converts energy from coal into electricity and it is usually expressed as the amount of energy used by a power plant to generate one kilowatt hour (kWh) of electricity. This rate is derived by comparing the quantity of energy contained in coal as it enters the plant site to the quantity of energy contained in the electricity that exits the plant side into the grid. The heat rate in our analysis is expressed through Btu/kWh ant it varies from 7.528 Btu/kWh to 8.921 Btu/kWh depending on factors like the type of combustion technology, the type of coal and the size of the plant (Sargent & Lundy, 2009)

The **emissions factor** refers to the average amount of CO_2 emissions resulting of burning coal to produce a certain quantity of energy. For our analysis, we use emissions factors based on the International Energy Agency (B.D. Hong and E. R. Slatick, 1994) for the different type of coal that are used in each power plant included in the PLATTS database:

- Lignite: 216.3 pounds of carbon dioxide per million Btu
- Subbituminous coal: 211.9 pounds of carbon dioxide per million Btu
- Bituminous coal: 205.3 pounds of carbon dioxide per million Btu
- Anthracite: 227.4 pounds of carbon dioxide per million Btu

Based on the formula above we calculate the emissions on a per plant basis, which are then aggregated at a regional or country level and distinguished by their status, taking into account the plants that are either operating, retired, deactivated, under construction, planned or announced.

23 Φ represents an units conversion factor (3.97347 x 10^-9) which basically represents 8760 hours per year (to calculate the annual electricity output) divided by 2,202.31 lb/tonne (to calculate the emissions in the standard tonnes unit.

24 Hard coal includes Anthracite, Bituminous and Sub-bituminous coal.

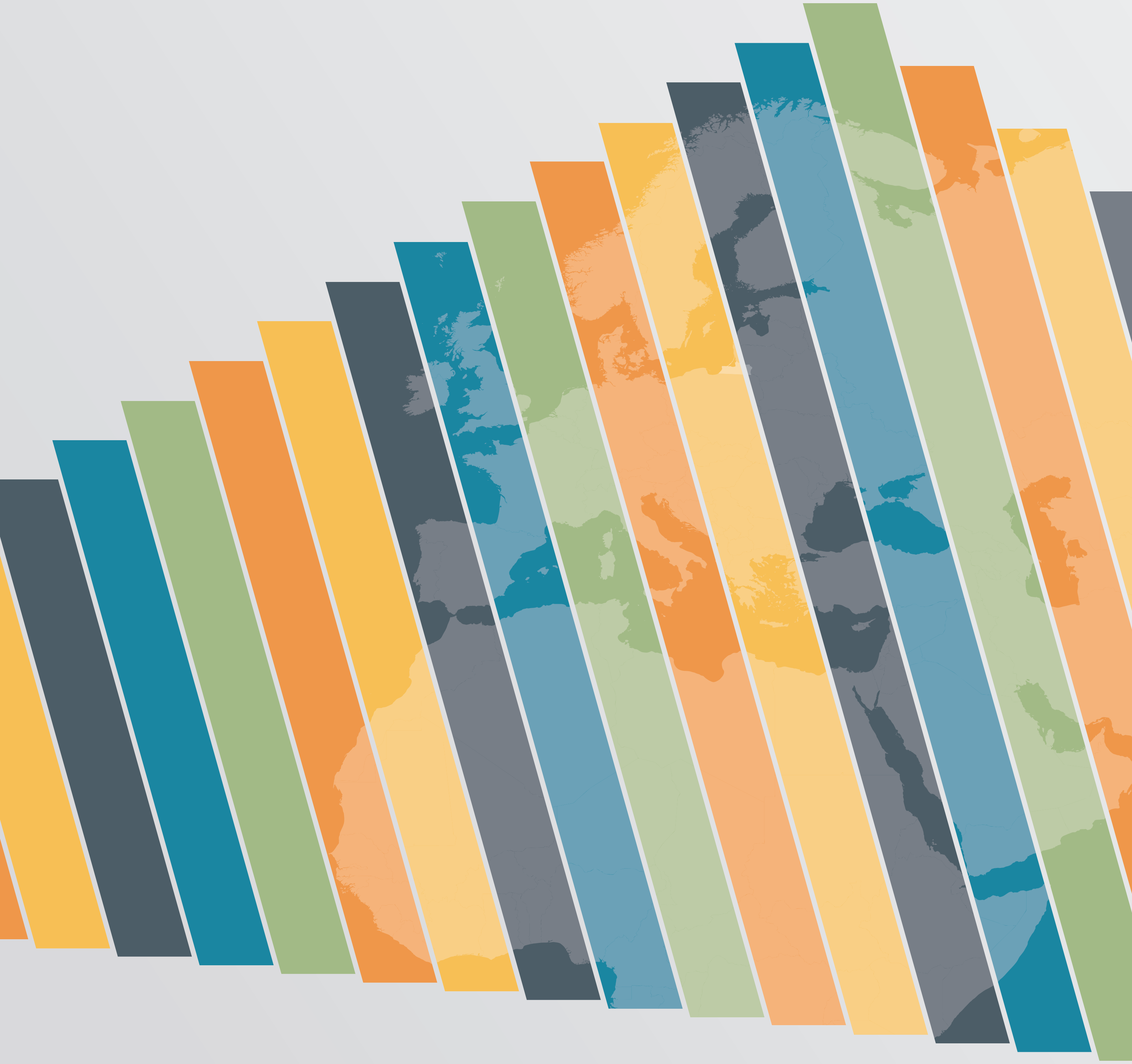
Moreover, in order to calculate the emissions for each plant, due to some missing information in the PLATTS database regarding retirement date, type of fuel, etc. for some power plants we made the following assumptions:

- Information on the type of coal burned in the power plant was missing for a considerable part of the planned coal plants (34% of total operating and under construction capacity). In order to not bias the estimates artificially assigning a too high or too low emissions factor to the plant with missing fuel information we assigned an average emissions factor to those plants, namely (211.9 $lbCO_2$/million Btu), which is the emission factor of subbituminous coal.

- For power plants that do not have a commissioning date in the database, calculate the country average opening years by status. Where this information is not available, we use the average value over the region. The following boundary conditions are imposed: for plants under construction we assume the year of commissioning is 2019; for planned power plants (including permitted, pre-permitted plants) foreseeing a 2-year time, i.e. 2021, while assuming a longer 4-year period for announced plants, i.e. 2023.

- Additionally, we assume the observed global mean average lifetime of 40 years to be the best estimate of the future observed lifetime of power plants.

- Finally, in order to build emissions pathways for the regions in the following decades, we calculated the expected retirement dates of operating power plants by adding the assumed average lifetime (40 years) to the opening year of those plants. However, consistency checks have been done afterwards. If this assumption leads to earlier retirement of currently operating power plants, we applied the following rule to adapt the estimated year of retirement: taking into account that all these power plants were supposed to be retired a while ago we assume they will be online for another 5 years but not beyond that.



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