THE ROLE OF CARBON CAPTURE AND STORAGE IN NET ZERO EMISSION ELECTRICITY SYSTEMS

Effective climate change mitigation is the defining challenge of the 21st century. To limit global temperature rise to 'well below 2°C' as mandated by the 2015 Paris Agreement, net zero greenhouse gas emissions (NZE) need to be achieved by 2050–2070, with additional removal of CO_2 from the atmosphere required thereafter.

Investment in clean technologies, particularly sources of variable renewable energy (VRE), notably wind and solar power, has significantly increased, while the use of unabated fossil fuels for power generation in developed countries is generally expected to decline. However, the greater challenge for meeting the climate change mitigation target lies in developing countries in the Asia-Pacific region as they are anticipated to experience a considerable increase in energy demand and consumption on both a per capita and absolute basis. Thus, additional deployment of coal- and gas-based power generation may be expected. As a result, it is unlikely they will be able to meet NZE targets without carbon capture and storage (CCS). Importantly, the political economy and technological supply chains associated with various clean energy technologies differ substantially between the European Union (EU) and the Asia-Pacific region, and this should be considered carefully when evaluating plausible transition pathways for these regions. Therefore, this study quantifies the value of CCS technology applied to coal- and gas-fired capacity in Europe (specifically Germany and Poland) and the Asia Pacific (Indonesia, Vietnam, and South Korea).

For each discrete power system, a business as usual (BAU) scenario is developed as a reference, where each country seeks to meet its power demand on a least-cost basis within its current policy paradigm. The costs and implications for the security of supply of trying to meet a NZE goal by 2050 by following three approaches are evaluated. There is a technology agnostic 'AllTech' scenario, a 'No CCS' option which prohibits CCS but is agnostic to all other technologies, and finally, a 'ReStor' scenario where only renewable energy and energy storage technologies are permitted.

A technology agnostic approach is key to achieving NZE, in terms of both economics and ensuring energy security. In this approach, NZE can be achieved with a negligible additional system cost that is mainly for more deployment of VRE and abatement of fossil fuel technologies. In contrast, policy decisions to ban individual technologies, such as those implemented in Germany (nuclear and coal), Poland (onshore wind), and South Korea (nuclear) incur a significant economic penalty, leading to power generation costs increasing by 14–180%, depending on the national context; exclusive reliance on renewables and storage was consistently observed to be the most expensive strategy. Without flexibility provided by CCS-equipped power plants, the system cost significantly increases in all case studies due to increased requirements for deployment of VRE that lead to high curtailment of VRE and reduced capacity nuclear power capacity.

Owing to the rapid fall in the cost of renewables, future carbon intensities will reduce significantly under BAU scenarios, particularly in Germany, Poland, and South Korea. Policy drivers in these countries, such as carbon taxes, and the technical experience required to deploy clean technologies are already advanced. Reducing carbon intensity in Indonesia and Vietnam under the BAU scenario follows the same trend, but in an attenuated fashion. This is due to the rapid growth in electricity demand that is likely to result from both the increasing availability of energy services to a growing population and an increasing total energy demand from a growing economy. This requires a reliable and affordable energy system, which incorporates firm power generation capacity. Under a BAU scenario this is anticipated to be met mainly by unabated fossil fuel power plants. Consequently, annual CO_2 emissions are likely to increase considerably in Indonesia and Vietnam.

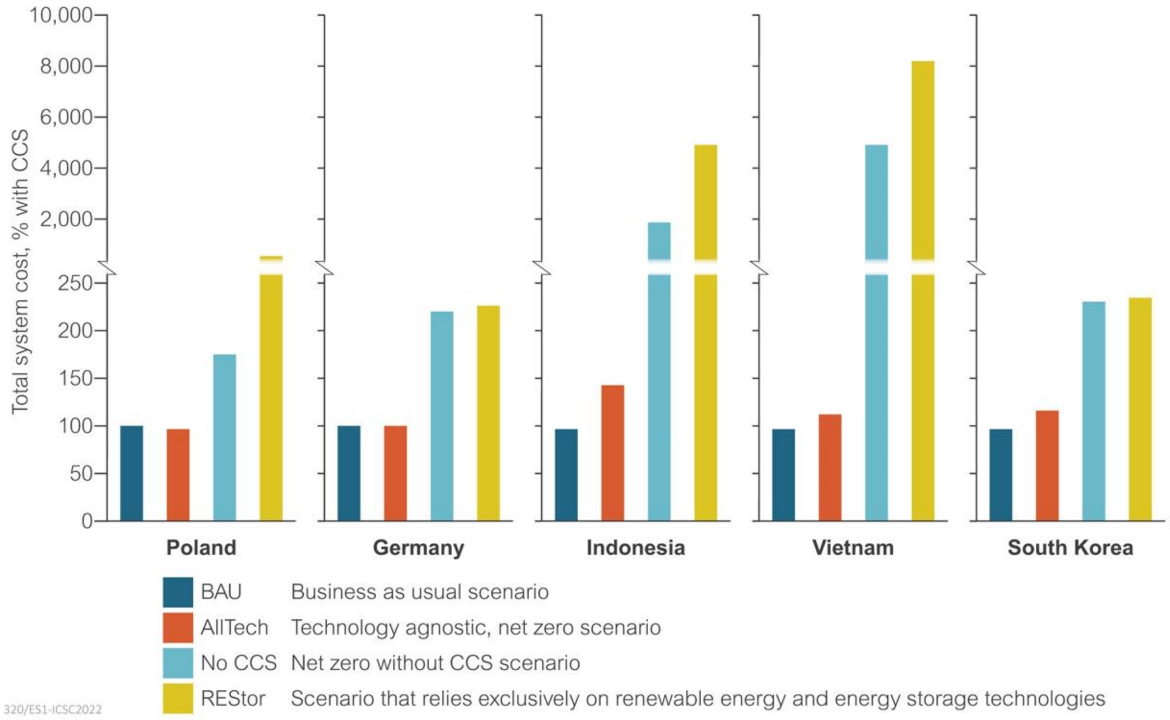

Figure ES1 Total system costs comparison for all scenarios and countries

In addition to increased costs, strategies that rely exclusively on renewable energy tend to result in unmet demand. This is particularly the case for countries with limited experience in deploying and operating VRE technologies, with a short timeline for achieving NZE. In developing countries, this strategy may suppress demand. Suppressed demand is the amount of electricity required by customers which is systematically and continuously unable to be met by the system; it hinders economic activity and growth. Although other dispatchable technologies, such as nuclear and energy storage, are allowed, CCS proves to be essential for electricity system decarbonisation. Without CCS, costs increase by 76–4812%, depending on the system's characteristics and demand growth that affect its ability to meet the demand and the costs associated with suppressed demand. For countries with high demand growth, such as Indonesia and Vietnam, up to 42% of power demand is not met (*see* Figure ES1). These results are based on a maximum build rate of renewable and storage technologies, which is doubled every five years, in all cases and scenarios, as has occurred in Germany over recent decades. Germany's sustained level of policy support for renewable energy and its advanced economy means that it is assumed to represent the maximum plausible rate of deployment.

In addition to the techno-economic challenges, relying exclusively on VRE may require significant areas of land, particularly for countries with limited interconnection such as South Korea. Onshore wind deployment in South Korea could require as much as 13–67% of the country's land area (*see* Figure ES2). Around 13–18% of the land area is required for solar photovoltaic (PV).

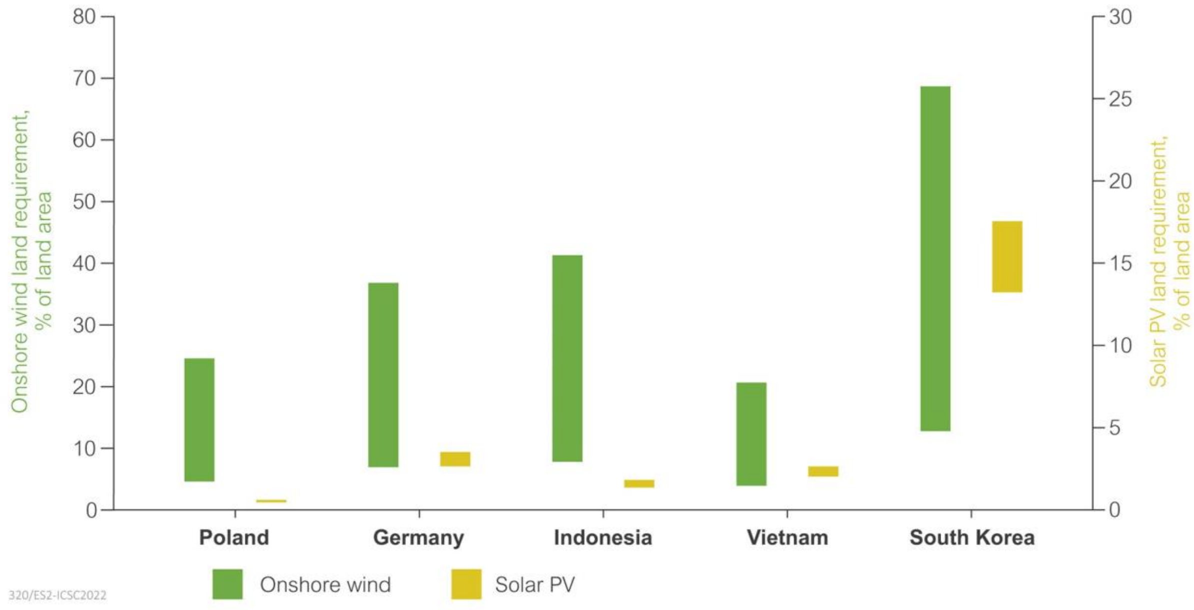

Figure ES2 Land requirements for onshore wind and solar PV in REStor scenario

CCS capacity is consistently observed to be exceptionally valuable in the context of any deep decarbonisation scenario. Depending on the national context, reducing carbon intensity below 100–300 kgCO_2/MWh becomes exponentially more expensive without CCS. As the timeline for meeting the NZE target is tight, global efforts to accelerate the commercial deployment of both coal- and gas-CCS technology are critical.

To achieve this outcome, an increased carbon price is required to privilege CCS against unabated fossil plants. However, as the deployment of negative emissions technologies is required, a carbon tax alone will be insufficient to deliver the NZE target. A unique combination of a carbon tax and negative emissions credit in different regions, hedged against local economic conditions, varying fossil energy prices and availability of wind and solar energy, is important to achieve NZE. Moreover, owing to the unequal distribution of biomass resources, international trade in negative emissions will be key.

Coal-CCS has an important role in countries with a rapid growth rate and limited clean baseload capacity alternatives, such as Poland, Indonesia, and Vietnam. Although the growth rate of South Korea is also significant, the existing nuclear capacity can provide an alternative to coal-CCS. Compared to gas-CCS, coal-CCS with the same capture rate requires more CO_2 removal to offset the residual CO_2 emissions. Thus, access to low-cost biomass for bioenergy with CCS (BECCS) is critical in countries where a considerable capacity of coal-CCS is to be deployed. Higher CO_2 capture rates of 95% and 98% capture, and high thermal efficiencies are critical to mitigate this effect.

Each executive summary is based on a detailed study which is available separately from: www.sustainable-carbon.org. This is a summary of the report: The role of carbon capture and storage in net zero emission electricity systems by Yoga Wienda Pratama and Niall Mac Dowell, ICSC/320, ISBN 978-2-9029-643-0, 76 pp, May 2022.