No room for new gas in South Korea

November, 2022

Authors

Neil Grant, Lara Welder, Victor Maxwell, Claire Fyson, Bill Hare

We would like to thank the producers and maintainers of the IPCC AR6 database (Byers et al 2022), hosted by IIASA, who made available the underlying data from global least cost pathways used in this analysis.

In collaboration with

SFO°C
Solutions for Our Climate

Citation

This document may be cited as:
Climate Analytics (2022). No room for new gas in South Korea

Cover image: Linh Ha

CLIMATE ANALYTICS

Supporting science based policy to prevent dangerous climate change enabling sustainable development

www.climateanalytics.org

Executive summary

The South Korean power sector policy is a rapidly evolving space. The relative role of fossil fuels, nuclear and renewables in the future electricity system has changed noticeably over recent years in response to technological and geopolitical developments. However, throughout these changes, there has been a consistent vision that fossil gas will play a key role in the future power sector.

In August 2022, the South Korean government released its draft 10th Basic Plan for Electricity Supply and Demand. This envisages that fossil gas capacity will grow 40% by 2030 and that fossil gas will provide 21% of power generation. This represents an increase in gas consumption compared to South Korea's Nationally Determined Contribution (NDC), submitted in the latter half of 2021.

And, while the draft plan also sees a growth in renewables, the share of renewable electricity generation envisaged by 2030 is substantially lower (at 22%) than the 30% anticipated under the government's NDC plan.

It is essential to understand whether South Korea's current policy proposals the power sector are aligned with the Paris Agreement's 1.5°C temperature limit. This report compares the current policy context with technically feasible and cost-effective pathways for the South Korean power sector which are aligned with 1.5°C.

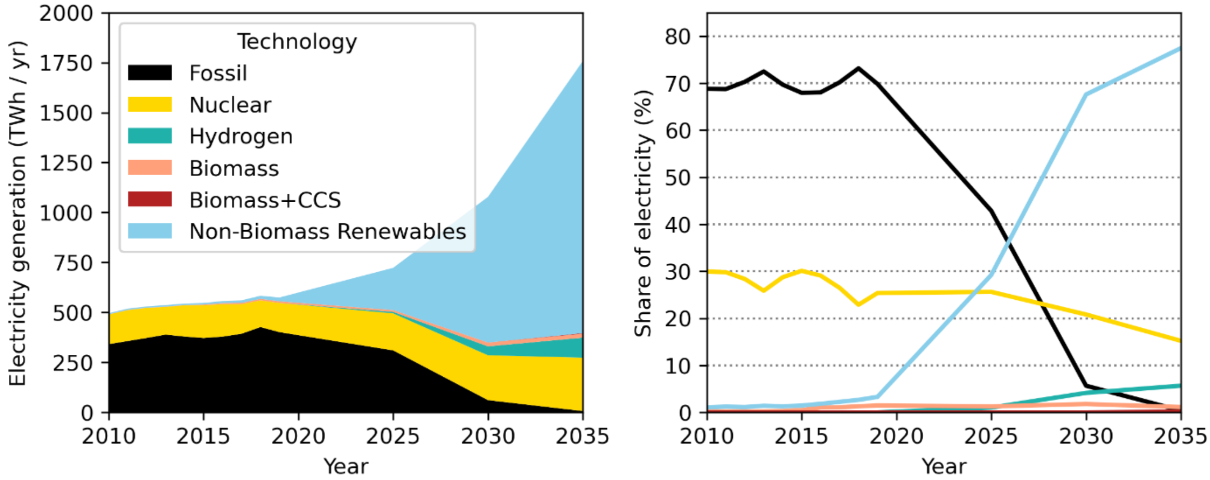
We find that if South Korea follows an approach of relying on fossil gas, it will jeopardise its climate goals, increase air pollution and exacerbate import dependency.

In the phase-out schedule determined in this report, South Korean power sector emissions fall to zero prior to 2035. Coal is phased out by 2029, and gas-fired power generation is rapidly reduced to zero prior to 2035.

This phase out is driven by three key factors:

1. A rapid reduction in coal and fossil gas generation
2. Large-scale deployment of wind and solar
3. The use of green hydrogen to provide long-duration energy storage

1.5°C compatible power sector transition in South Korea
Illustrative pathway



Some pathways achieve almost total decarbonisation by 2030. An accelerated decarbonisation of the power sector in the 2020s could reduce the need for net-negative emissions in later decades, and help South Korea align with the principles of equity and fairness, which are at the heart of the Paris Agreement.

The pathways we assess show a slight increase in gas-fired power generation between 2022 and 2025. But we see that this demand can very likely be met by existing power plant capacity, meaning that **there is virtually no scope for expanding the existing gas-fired fleet**.

Expanding fossil gas generation capacity for the next two years before embarking on a rapid phase-out would lead to high levels of stranded assets and ultimately a more disruptive and costly energy transition.

Looking ahead to 2050, the South Korean government's commitment to net zero emissions will require a complete phase out of unabated fossil gas across all sectors. The power sector will need to go first, with other sectors following.

While some have posed fossil gas as a bridging fuel on the path to a zero-emissions power sector, the evidence is clear: gas is fuelling the climate crisis and needs to be phased out prior to 2035 in South Korea.

Contents

Figures

Introduction

Clean electricity is a critical milestone on the road to net zero. Decarbonising the power sector, and then expanding the availability of clean electricity to decarbonise the buildings, industry, and transport sectors, is crucial for a successful energy transition.

South Korea's power sector is heavily dependent on fossil fuels. Coal provided 35% of electricity generation in 2021, and fossil gas a further 30%[1]. Previous work has highlighted the need for, and strong economic benefits of, phasing out coal in South Korea's power sector by 2029 at the latest[2,3]. However, South Korea also needs to phase out unabated gas generation to achieve a decarbonised power sector.

This report focuses on the question: when should South Korea aim to phase out unabated gas from the power sector, in order to align with 1.5°C?

We use a diverse set of 1.5°C compatible pathways for the South Korean power sector, produced by downscaling global pathways from the IPCC's latest assessment report[4]. By calculating a 1.5°C compatible emissions envelope for the power sector, we infer the resultant phase-out schedule for fossil gas on this basis. We then use one illustrative pathway to explore South Korea's electricity transition in greater depth.

Our results show that to align with 1.5°C, South Korea would need to phase out unabated fossil gas from the power sector before 2035. The phasedown of fossil gas generation would need to start from 2025, and the scope to increase gas consumption in the next two years is very limited. This contrasts starkly with the South Korean government's current plans, which involve significantly increasing the level of fossil gas generation in the power sector via new fossil gas plants and substantial coal-to-gas plant conversions[5].

South Korea has a crucial opportunity to align its power sector transition with the Paris Agreement and set the foundations to achieve net zero by 2050, which it is legally bound to achieve[6]. However, this will require a change of tack from recent policy proposals. South Korea can either continue its current approach of relying on fossil fuels, which will jeopardize its climate goals, increase air pollution and exacerbate import dependency. Or it can shift to a power sector driven by zero-carbon electricity, phasing out coal prior to 2030 and fossil gas prior to 2035. It remains to be seen whether South Korea will seize this opportunity.

Policy context

South Korean climate and energy policy regarding future fossil gas use reveals an ever-changing picture. The relative role of fossil gas, nuclear and renewables in the future power sector has changed noticeably over recent years in response to technological and geopolitical developments. The government's gas supply and demand plans are outlined in regularly updated framework policies.

The 3rd Energy Master Plan was adopted in June 2019 and covers the period up to 2040[7]. The Plan does not set specific targets for the role of gas in the energy mix, instead stating that gas will play a "greater role in generation and transportation." This is coupled with a target of 30-35% renewable power generation by 2040.

The 9th Basic Plan for Electricity Supply and Demand, adopted in December 2020, covers the period 2020 to 2034[8]. Under the Plan, 24 of 60 Korea's coal-fired power stations would be converted to run on liquefied natural gas (LNG). This would boost fossil gas-fired power capacity by 12.7 GW, a 30% increase on 2022 levels[9]. In relative terms, gas capacity would remain around 32% of total capacity over the 2020 to 2030 period. While the 9th Basic Plan has fossil fuels accounting for 52% of generation in 2030, renewables generation share would increase threefold from 2020 levels, reaching a 20.8% share in 2030.

The International Energy Agency forecasts that under the 9th Basic Plan, carbon emissions from the power sector would drop to just under 200 $MtCO_2$/yr in 2034[10]. While this would be a reduction from 2020 levels (around 255 $MtCO_2$/yr), it would not be in line with either Korea's 2030 NDC or their long-term decarbonisation objective[a].

The 14th Long-term Natural Gas Supply and Demand Plan, adopted in April 2021, covers the period 2021 to 2034[11]. Unlike the above two policy documents, the Gas Plan provides more details about gas's historical and future role in Korea's energy system.

It shows that demand for gas in the power sector has grown at an average annual rate of 8% between 2000 and 2020, reaching 20.38 million tonnes in the latter year. Demand is expected to increase slightly to 20.88 million tonnes by 2034. Growth in fossil gas demand for power generation was particularly fast between 2009 and 2013, driven largely by economic growth. However, from 2013 to 2015, gas demand fell just as quickly, due to the relative price competitiveness of coal-fired generation and the return of nuclear power after safety-related shut-downs in 2012[12].

[a] South Korea officially submitted their updated NDC to the UNFCCC in December 2021. The NDC targets a 40% reduction in GHG emissions from 2018 levels by 2030, including emissions reductions from LULUCF and international credits. The updated NDC also includes the previously announced long-term target of carbon neutrality by 2050.

Following the announcement of Korea's updated NDC in October 2021[13], the Ministry of Trade, Industry and Energy (MOTIE) announced new 2030 targets for the power sector[14]. Generation from coal and gas in 2030 was forecast lower than under the 9th Electricity Plan, while that from renewables was forecast higher.

Specifically, while the 9th Plan forecasted 136.6 TWh gas-powered generation (23.3% of total 585.8 TWh) in 2030, the NDC plan revised this down to 119.5 TWh (19.5% of total 612.4 TWh). Renewable generation was forecast to increase from 121.7 TWh (20.8% of total) under the 9th Plan to 185.2 TWh (30.2% of total) under the NDC plan. The NDC plan also introduced what it termed "carbon-free fuel co-firing" into the power mix, with ammonia co-fired with coal forecast to generate 22.1 TWh in 2030.

The government's plans regarding ammonia and hydrogen were detailed in the 1st Basic Plan for Hydrogen Economy Implementation released in November 2021[15]. The plan envisages the consumption of ammonia and hydrogen ramping up, particularly after 2030. But according to the plan, half of total hydrogen demand by 2030 would be grey and blue hydrogen, which are not carbon-free.

In December 2021, the Korean government announced that fossil gas power plants that produce emissions below 340 gCO_2/kWh would be temporarily classified as "green" investments, ostensibly to facilitate a move away from coal-fired generation on the net-zero transition[16]. This followed the October 2021 publication of two draft pathways to net zero emissions in 2050[17]. One of the pathways phases out fossil gas in the power sector by 2050, while the other allows for a limited amount compensated by CCUS.

Following the presidential election in March 2022, the new government indicated a different energy policy stance from the previous administration[18]. This includes a bigger role for LNG and nuclear in Korea's power sector than indicated in previous energy-related plans. The government is seeking to increase storage capacity and imports volumes, albeit with a focus on diversifying LNG sources.

In August 2022, the government released a draft 10th Basic Plan for Electricity Supply and Demand[19]. The draft plan foresees a 2030 gas capacity of 57.8 GW, accounting for 43% of (effective) capacity.

In 2030, gas-powered plants are expected to produce 128.2 TWh (20.9% of total 615 TWh) under this plan. This is an increase from that forecast under the NDC plan (119.5 TWh). The draft plan also sees a significant switch from renewables to nuclear compared to the generation forecast under the NDC plan: renewable share in generation decreases from 30.2% to 21.5%, while the share of nuclear increases from 23.9% to 32.8%.

The latest policy developments in South Korea see fossil gas playing a key role in 2030. At the same time, there is an implicit understanding that reaching net zero emissions by 2050 will require a complete phase-out of unabated fossil gas.

At the global level, energy pathways consistent with the Paris Agreement show a rapid decline in fossil gas use in the power sector, reaching an effective phase-out by 2035 in OECD countries[20]. This means fossil gas cannot play the role of a bridging fuel.

Governments are not yet collectively on track to transform their economies at the pace necessary to limit warming to 1.5°C, but the plummeting costs of renewables and storage options have made the economic case for doing so increasingly attractive.

Added to this, the ongoing energy crisis driven by soaring fossil fuel prices and geopolitical instability provides further impetus to the need to transition to a fossil free economy. The question then remains – is the envisaged role of fossil gas in South Korea compatible with the Paris Agreement, and how soon must a fossil gas phase-out be achieved?

Methods

Selection of scenarios

This research uses a diverse set of 21 1.5°C compatible pathways to explore 1.5°C compatible fossil gas phase-outs in the South Korean power sector. These pathways are produced by integrated assessment models (IAMs) and are selected from the most recent assessment report of the IPCC (AR6), which synthesises the latest evidence on what is required to limit warming to 1.5°C[4].

These 21 pathways are selected based on the following four criteria.

1. 1.5°C compatibility

First, we filter to select only pathways compatible with limiting warming to 1.5°C with no or low overshoot. This means that they:

- Limit warming to 1.5°C in 2100 with a likelihood of greater than 50%
- Exceed warming of 1.5°C during the 21st century with a likelihood of 67% or less.

In other words, 1.5°C compatible pathways are not *likely* to exceed 1.5°C over the 21st century. Such pathways exhibit a limited overshoot of about 0.1°C or less (median estimate) or no overshoot at all, with warming returned to 1.3°C by 2100.

These pathways are given the **C1 category** in the AR6 database. C1 pathways are compatible with the long-term temperature goal of the Paris Agreement set out in Article 2.1, which commits signatories to hold warming to "well below" 2°C and pursue efforts to limit warming to 1.5°C. There are 97 such pathways in the AR6 database.

2. Sustainable levels of CDR

Many pathways produced by IAMs rely on levels of carbon dioxide removal (CDR), which could be incompatible with broader sustainability concerns. Therefore, we further filter the ensemble of pathways to only consider those limiting CDR deployment to sustainable levels[21]. This means that globally, they deploy less than 5 $GtCO_2$/yr of bioenergy with carbon capture and storage (BECCS) in 2050, and under 3.6 $GtCO_2$/yr of afforestation and reforestation in the second half of the century. This provides a set of 33 pathways for analysis.

3. Compatibility with Article 4.1 of the Paris Agreement

In order to achieve the long-term temperature goal, set out in Article 2 of the Paris Agreement, Article 4.1 operationalises the aim to achieve global net-zero GHG emissions[b] in the second half of the century in accordance with the best available

[b] Defined as a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases.

science. The IPCC AR6 Working III made net zero GHGs in the second half of the century an explicit criterion for assessment and established a **subcategory C1a.** All C1a pathways achieve net zero greenhouse gas emissions around 2070-2075. These pathways also reach net zero CO_2 emissions around 2050, in line with the findings of the Special Report on 1.5°C[22].

We filter the pathways to only select power sector transitions which are compatible with reaching net-zero GHG emissions at the global level. We do this by selecting only pathways which are subcategory C1a or display faster emissions reductions in the South Korean power sector than the C1a pathways (Appendix A). This provides a set of 27 pathways for analysis.

4. Data availability

This set of 27 pathways is further filtered based on data availability. To facilitate downscaling to the national level, data must be available at the level of the ten major world regions or R10 level[c]. This gives a set of 23 pathways. Of these, two were identified as duplicates, giving a final set of 21 pathways which form the basis of the analysis.

Appendix A provides further detail on the scenario selection process, including a table of all pathways and a flow chart which summarises the filtering process used to select the final pathways for analysis.

Downscaling methodology

IAMs provide global pathways which reach the Paris Agreement goals. In these pathways, data is not provided at the national level but for a set of "macro regions", representing geographical groupings of countries. The selected pathways provide data at the R10 level, representing the world by ten major regions. A downscaling algorithm is applied to obtain national mitigation pathways from these 1.5°C compatible pathways. The downscaling process follows the following steps:

1. Historical emissions and the electricity generation mix in the South Korean power sector are identified for a base year (2019).
2. The projected emissions and electricity generation mixes for the macro region South Korea is located in are identified from the IAM pathway.
3. The generation mix of the macro region is downscaled to the national level. This is done by finding a fuel price equilibrium for the macro region, equating marginal fuel prices across all countries in the macro region. This gives a cost-effective electricity generation allocation, mimicking the internal logic of integrated assessment models.

[c] These ten world regions are China+, India+, Pacific OECD, Rest of Asia, Middle East, Africa, Europe, Latin America, North America and the Reforming Economies. South Korea is generally found within the Pacific OECD, Rest of Asia or China+ macro region in these models.

4. Once the energy consumption has been downscaled to the national level, projected emissions can be calculated via an emission factor calibration.

A detailed description of the downscaling method[d] can be found on the 1.5°C National Pathways Explorer website.

Estimating a 1.5°C compatible emissions envelope for the power sector

Having selected 21 pathways for analysis and downscaled the power sector transition from the macro region to South Korea, it is necessary to calculate a 1.5°C compatible emissions envelope for the power sector. This envelope is the level of future power sector emissions that the South Korean electricity system would need to fall below, if it is to align with 1.5°C.

The emissions envelope is inferred by calculating **model-weighted percentiles** from the distribution of pathways. This ensures that the contributions of each modelling framework are treated equally in the analysis and corrects for any model-related bias in the initial ensemble. For more details see Appendix B.

We take the 5-50th percentiles as the 1.5°C compatible power sector emissions envelope for South Korea. We do not consider pathways above the median as compatible with the Paris Agreement's 1.5°C long-term temperature goal. This is because if one country was to track a higher percentile in the distribution (e.g., the 90th percentile), this would require a corresponding increase in effort from other countries to compensate for this and ensure 1.5°C compatibility at the global level.

Additionally, South Korea's fair share of global emissions reductions exceeds the level observed in cost-effective downscaled pathways[23]. Therefore, aiming for the lower half of the emissions range can help South Korea achieve its highest possible ambition and align with the principles of equity and fairness that are at the heart of the Paris Agreement. We then focus our analysis on the median of this 1.5°C compatible range, which is the 25th percentile of the overall distribution of pathways.

Some of the downscaled pathways deploy large amounts of BECCS in electricity generation to achieve a net-negative power sector. However, the viability of large-scale BECCS deployment is unclear due to environmental constraints[24,25] and because of national or regional carbon dioxide storage limitations[26]. The latter would also apply to technology such as direct air carbon capture and storage or DACCS[27] and is particularly true in South Korea where the viable CO_2 storage potential could be minimal[28]. At the same time, the sustainability of biomass in South Korea is being challenged[29]. Large-scale biomass consumption can drive land-use change (with associated emissions),

[d] The method has been updated to downscale all countries above a GDP threshold of 1% in the macro region simultaneously.

negatively affect biodiversity and food security, and threaten the rights of traditional land users[30].

In our analysis, we assume that:

a) The desirability and viability of large-scale BECCS deployment in South Korea are low, and the possible level of BECCS deployment is small. BECCS deployment is strongly constrained by the need for sustainable biomass resources, such as waste residues, and the need for CO_2 storage resources.
b) CO_2 storage limitations in Korea imply that domestic DACCS deployment will also be minimal.
c) Any BECCS or DACCS deployment that is achieved should be used to compensate for emissions in truly hard-to-abate sectors, such as agriculture, and is not used to facilitate continued fossil gas generation in the power sector. Therefore, zero emissions in the power sector require zero fossil fuel combustion in the power sector.

The challenges involved with achieving net-negative emissions in South Korea further emphasise the importance of rapid emissions reductions to limit total cumulative emissions. This means that the phase-out schedule developed for fossil gas in this report should be seen as the minimum level of action required. Without net-negative emissions, fossil fuels may need to be phased out of the power sector at even greater rates.

Results

Behaviour of pathways

Figure 1 shows how the 21 selected 1.5°C compatible pathways behave in terms of their power sector characteristics in 2030. The figure classifies each pathway's performance across seven key indicators, which are:

- The level of power sector emissions reductions in 2030 (relative to 2019 levels),
- The level by which unabated fossil gas and unabated coal-fired generation is reduced between 2019 and 2030,
- The share of nuclear, non-biomass renewable and fossil generation equipped with carbon capture and storage (CCS) in 2030, and
- The change in total electricity generation in 2030 (relative to 2019).

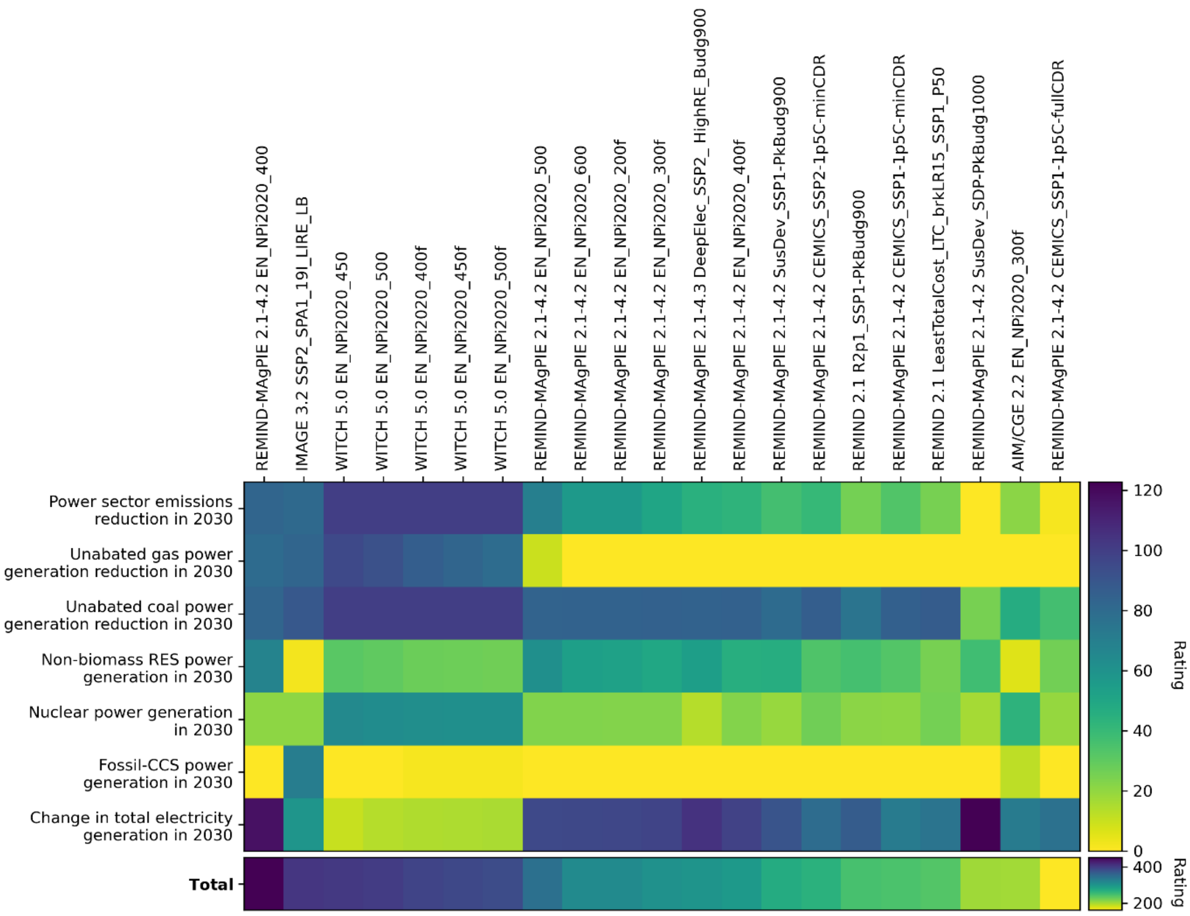


Figure 1: Behaviour of selected pathways in 2030

The figure shows how different pathways reduce power sector emissions by phasing out fossil fuels and replacing them with different low-carbon generation technologies (renewables, nuclear and fossil fuels coupled with CCS). In each dimension, the pathways are scored between 0 and 100, which represents: the % reduction in emissions, fossil gas and coal-fired generation between 2019 and 2030; the % of electricity generated by renewables, nuclear and fossil fuels with CCS in 2030; and the % change in total electricity generation relative to 2019. These numbers can then be aggregated to provide an overall ranking for each pathway, shown in the total bar below.

Figure 1 highlights a range of key insights. Substantial reductions in power sector emissions are achievable by 2030, with some pathways achieving almost total decarbonisation by this date. Pathways achieve these emissions reductions by rapidly phasing out coal-fired generation and, in several cases, strongly reducing unabated gas-fired generation also by 2030[e].

Pathways replace fossil fuels with different forms of low-carbon generation. Pathways produced by WITCH and AIM predominantly use nuclear, while the pathway from the IMAGE model focuses on the deployment of fossil CCS technologies. Meanwhile, pathways produced by REMIND rely more heavily on renewables to displace fossil generation. For all models but the WITCH model, a notable increase in total electricity generation can be observed, as electrification of end-use sectors drives decarbonisation across the whole energy system. Figure 1 shows the diversity of pathways which are collectively used to infer the fossil gas phase-out date for the South Korean power sector. This diversity of pathways enhances the robustness of the results then calculated.

Note that the number of pathways in Figure 1 that show a given characteristic (such as a faster or slower fossil fuel phase-down) is influenced by the number of pathways provided by each model, as each model uses different assumptions and provides its

[e] Figure 1 highlights that there are multiple REMIND scenarios which do not reduce fossil gas generation in South Korea by 2030. This could potentially be due to the following factors:

1. In the REMIND model, South Korea is included in the Rest of Asia macro region. This region has relatively low GDP per capita, due to the inclusion of many developing countries such as Pakistan and Afghanistan. REMIND differentiates carbon prices on the basis of GDP per capita, and therefore the carbon price in this region (pre-2050) is the third lowest of all macro regions [31]. The lower carbon price leads to slower reductions in fossil gas in the REMIND pathways in South Korea.
2. As a result of this lower carbon price in the macro region, REMIND only reduces fossil gas generation in the most stringent scenarios, where the total carbon budget from 2020 onwards is 500GtCO_2 or less. In these stringent scenarios, the carbon price becomes high enough to still drive fossil gas out of the South Asian power sector.
3. However, while a low carbon price could be justified for many countries in this macro region, this does not necessarily hold for South Korea, which would therefore need to reduce fossil gas generation faster than envisaged in these REMIND pathways.

The large number of REMIND pathways means that these particular model dynamics are overrepresented in the pathway ensemble. The use of model-weighted percentiles is designed to correct for this bias.

own unique perspective on energy transition dynamics. More pathways demonstrating a particular dynamic does not mean this dynamic is more likely to occur, but rather represents the fact that a particular model has contributed more to the overall ensemble. This is why we use a model weighted analysis to derive our fossil gas phase-out schedule, as this ensures the contributions of each modelling framework are weighted equally (Appendix B).

1.5°C compatible emissions pathways for the power sector

We use our set of downscaled pathways to calculate an emissions envelope for the power sector in South Korea. This represents an emissions level which should not be exceeded if South Korea is to align with the 1.5°C temperature limit.

We calculate this envelope by taking model-weighted percentiles from the distribution of pathways. This approach ensures that models which provide many scenarios in the overall ensemble do not unduly bias the results of the analysis (see Methods). The 1.5°C compatible range is then defined as the 5-50th percentile, and we focus on the median of this range (the 25th percentile), keeping in mind that targeting ambitious emission reductions in this decade:

a) reduces the need for net-negative emissions in later decades, for example, via BECCS or DACCS for South Korea uncertain technical feasibility, and
b) aligns with the principles of equity and fairness stated in the Paris Agreement.

Figure 2 shows the resultant 1.5°C compatible emissions envelope for the South Korean power sector.

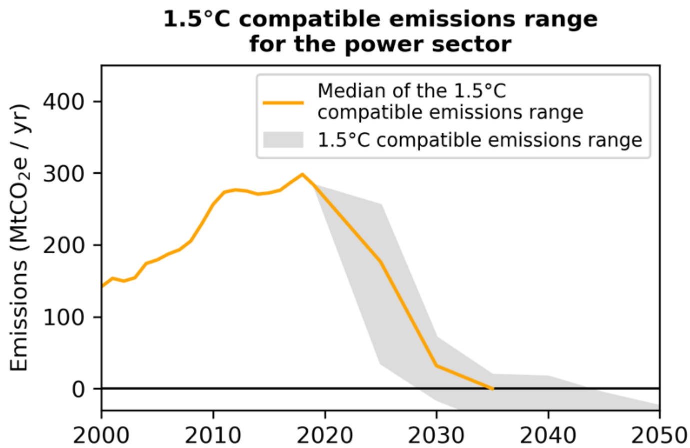


Figure 2: 1.5°C compatible power sector emissions for South Korea

Accounting for model-related bias in the ensemble, the median 1.5°C compatible emissions envelope falls to near-zero emissions by 2035, while the lower percentile of the distribution reaches zero emissions by the late 2020s/early 2030s. Achieving this would require the displacement of all fossil-based electricity generation, including fossil gas.

Gas phase-out requirements in the power sector

The emissions envelopes can then be used to determine 1.5°C compliant phase-out schedules for coal and gas in the South Korean power sector.

Figure 3 shows the emissions envelope for the power sector in 1.5°C compatible pathways. We assume that coal-fired power generation in South Korea is phased out by 2029, as previous work has shown that this is required to align with the 1.5°C temperature limit[3]. The remaining emissions within the envelope can be allocated to fossil gas.

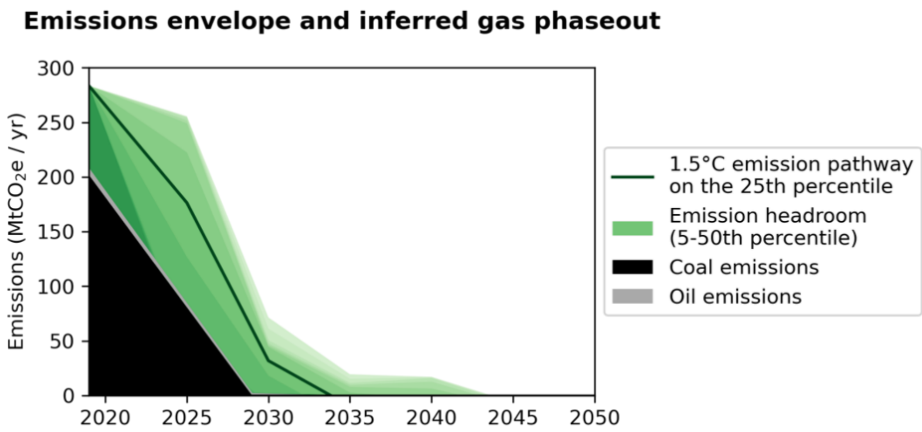


Figure 3: Emissions envelope for gas in the South Korean power sector

The inferred headroom for continued fossil gas power generation (in green) shows that the remaining emissions budget for the power sector is predominantly allocated to coal. When using the 25th percentile of all downscaled emissions pathways, the headroom for future fossil gas generation falls to zero by 2034 (dark green line in the figure). The figure also shows the impact of moving from this middle pathway to higher or lower levels in the distribution (between the 5th and 50th percentiles).

Figure 4 then shows the resultant fossil gas generation that would be compliant with this remaining emissions headroom. If South Korean power sector emissions are to follow the 25th percentile of the emissions distribution, then fossil gas generation can increase a very small amount (by 13%) between 2022 and 2025, before being reduced to zero by 2034.

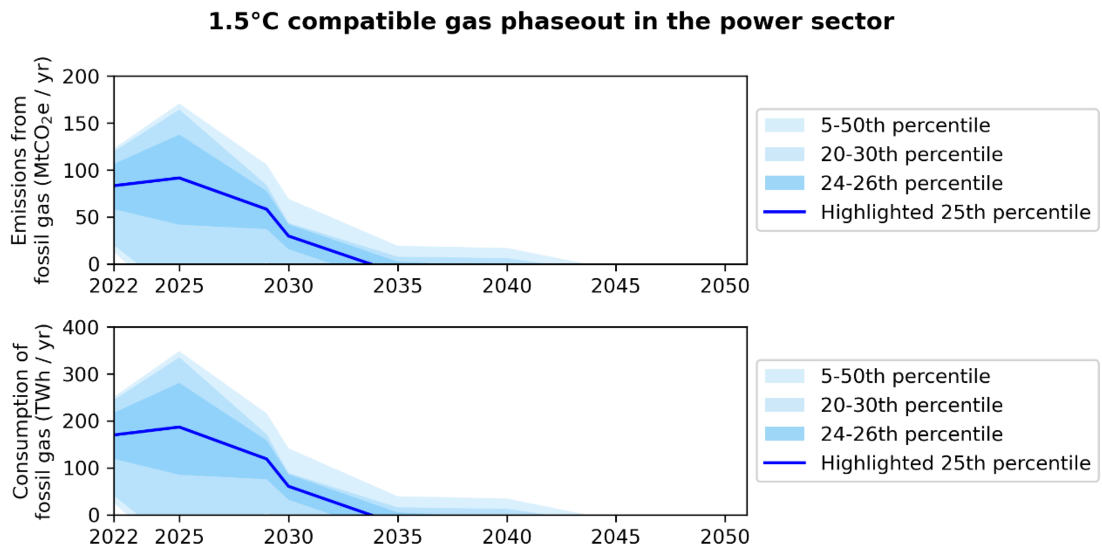


Figure 4: 1.5°C compatible phase out of fossil gas in the power sector

Moving to higher percentiles in the ensemble distribution increases the emissions head room for fossil gas generation in 2025. However, this remaining headroom for fossil gas is predicated on an immediate and linear phase out of coal by 2029. If the coal phase-out is delayed by any amount, the near term head room for fossil gas would diminish rapidly.

Also, the uncertainty of the emissions head room available for fossil gas out to 2025 does not affect the long-term compatibility of fossil gas with 1.5°C. By the mid-2030s, emissions from fossil gas need to fall to very low levels, requiring either a substantial reduction in the number of power plants, or their utilisation factor.

Substantially expanding gas generation for the next three years before embarking on a rapid phase-out would lead to high levels of stranded assets and a disruptive and more costly transition. Increasing gas-fired power generation would also lead to greater reliance on LNG imports at the very moment where international gas prices are reaching record highs.

If South Korea seeks to minimise stranded assets, and account for the current record prices on international gas markets (which the pathways used in this analysis do not reflect), the 25th percentile represents a suitable pathway to infer a gas phase out schedule in South Korea. In this pathway, **South Korea should aim to phase out fossil gas in the power sector prior to 2035.**

The limited (up to 13%) potential increase in fossil gas power generation until 2025 begs the question: would this require new capacity deployment?

In 2020, the average capacity factor of fossil gas plants in South Korea was 41% (weighted to account for plant capacity). However, there is substantial variation in capacity factors, with some plants operating considerably below this value.

If all current plants could reach the 2020 fleet-wide average capacity factor of 41%, fossil gas generation would rise by 28% without the need for new capacity installations. This suggests that the need for new fossil gas capacity prior to 2025 is close to, if not at, zero. South Korea's current multi-GW pipeline for new fossil gas power plants is therefore incompatible with 1.5°C and should be urgently revised, if South Korea is to align with the Paris Agreement goals.

An illustrative pathway for achieving the fossil gas phase out

We now turn to explore an illustrative pathway which achieves the goal of a 100% fossil-free power sector by 2035. The selected pathway is produced by the REMIND-MAgPIE integrated assessment modelling framework and is the REMIND-MAgPIE 2.1-4.2|EN_NPi2020_400 pathway.

Figure 5 shows the South Korean power sector transition in this illustrative pathway. Fossil fuels are phased out of the power sector by 2035, with large-scale deployment of renewables driving the transition towards 100% clean electricity.

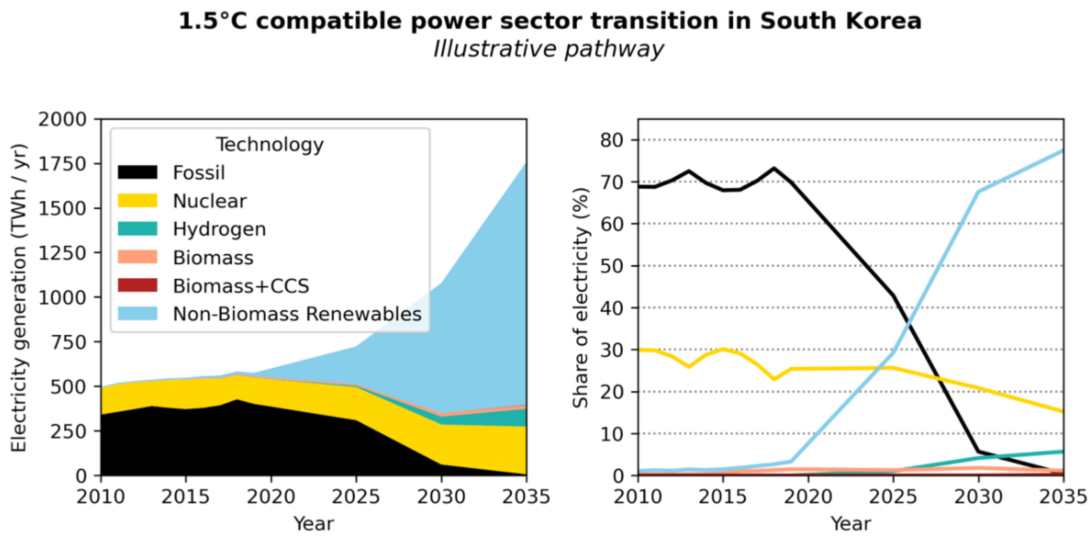


Figure 5: An illustrative power sector transition in South Korea

In the illustrative pathway, electricity generation grows more than three-fold over the 2019–2035 time horizon. This is likely an overestimate, which arises from the fact that, in the REMIND model, South Korea is aggregated into the "Rest of Asia" macro region.

This region contains a range of less wealthy countries such as Afghanistan, Bangladesh and Cambodia. As these countries are likely to experience robust electricity demand growth, the region as a whole is projected to multiply its electricity demand over the next decades[32]. This then feeds through to the downscaled pathway for South Korea. However, in reality, demand growth in South Korea could be smaller[33]. This would reduce the supply-side challenges in scaling up renewables and make it easier to achieve a 2035 fossil gas phase-out.

In the illustrative pathway, the transition to 100% clean power is driven by three key factors which drive fossil fuels out of the energy mix.

First, there is a large-scale deployment of non-biomass renewables (wind and solar), which will become the largest source of power in the South Korean electricity system by the late 2020s, making up over three quarters of power generation by 2035. As mentioned above, the extent of the expansion of wind and solar in South Korea is potentially enlarged due to the pathway overestimating electricity demand in South Korea.

But even with a smaller growth in electricity generation, renewables would play a key role. As the price of wind and solar continues to plummet, their potential to rapidly transform the power sector is growing. Future work will perform a detailed analysis of the potential for renewable energy to displace fossil gas from the power sector.

Second, this deployment of variable renewables is supported by the deployment of green hydrogen generation in the power sector. Hydrogen provides around 5% of total electricity generation in 2030 in the illustrative pathway. Hydrogen performs a valuable role by providing long-term energy storage to help integrate wind and solar into the power sector.

This hydrogen is almost entirely produced by electrolysis – in 2030, 96% of hydrogen produced is electrolytic, with only 4% coming from fossil sources. In 2030, there is approximately 45 TWh of electricity generation from hydrogen. Producing 45 TWh of electricity would require approximately 1.8–2.7 Mt/yr of hydrogen[f]. This represents 46–70% of the expected hydrogen consumption in the South Korean government's hydrogen plan[34]. Assuming Government expectations of 2 Mt/yr green hydrogen imports are met, this would require up to 0.7 Mt/yr domestic production. Again, reducing total electricity demand growth could reduce the need for hydrogen generation in the power sector.

Finally, this illustrative pathway shows a continued role for nuclear in the power sector, although its share of total generation declines over time and within a decade falls below 20%. In absolute terms, the pathways show a substantial increase in nuclear power generation between 2019 and 2035. However, this growth in future nuclear power is likely inflated due to the pathway overestimating total electricity demand. The need for new nuclear could therefore be much lower than shown in this illustrative pathway.

A complimentary bottom-up energy system analysis would be needed to better constrain potential future electricity demand. Efficiency measures and targeted behavioural change can reduce the scale of future electricity demand, which, alongside smart grid design, could reduce the level of nuclear power generation required and address some of the supply-side challenges identified by this illustrative pathway.

[f] Assuming the efficiency of hydrogen to electricity conversion in fuel cells or turbines is 50-75%.

The pathway does not envisage large-scale biomass consumption in the power sector, with biomass providing at most 1.8% of electricity generation in 2030. If biomass is to feature in a future low-carbon energy system, it must be produced sustainably, avoiding upstream emissions from land-use change, competition with food crops, negative biodiversity impacts, and respecting the rights of indigenous peoples who may be the traditional users of the land[30]. The availability of sustainable biomass will be heavily limited, and the majority of biomass should be prioritised for use in construction, paper production and bio-based feedstock production. Large-scale biomass deployment is neither necessary nor desirable in achieving a clean power sector.

A bottom-up power system model and analysis can provide further insights into the cost effectiveness of non-biomass renewables and a feasibility of a rapid fossil fuel phase-out without an increased reliance on nuclear energy. We are undertaking further analysis to be published in a report due early next year, which assess fossil gas phase out in South Korea and the role of renewables in greater detail.

Conclusions

Clean electricity is the cornerstone of the energy transition. If the world is to achieve the goals of the Paris Agreement, countries will need to rapidly clean up the power sector, and then substantially upscale generation to power the industry, transport and buildings of the future.

In this context, it is vital to understand when and how different countries could achieve 100% clean electricity. This report has explored the need and feasibility of rapidly reducing fossil gas generation in the South Korean power sector to align with the 1.5°C temperature limit.

In the 1.5°C consistent emissions envelope calculated in this report, South Korean power sector emissions reach zero by the mid-2030s. The remaining emissions envelope for the power sector is limited and is predominantly consumed by committed emissions from the coal-fired power fleet in South Korea, even as it is phased out prior to 2029.

As a result, the scope for increased gas generation in South Korea is very limited, and fossil gas should be phased out prior to 2035, if South Korea is to align with the 1.5°C temperature limit.

Gas-fired generation only grows at most 13% between 2022 and 2025. This can likely be met entirely via existing plants. There is therefore **virtually no scope for expanding the existing gas-fired fleet**.

While some have posed fossil gas as a bridging fuel on the path to a zero-emissions power sector, the evidence is clear: expanding fossil gas generation is a bridge to stranded assets, increased import dependency, air pollution, and risks derailing South Korea's progress towards its climate targets.

Instead, South Korea has the opportunity set a clear pathway to phase out fossil gas by the mid-2030s and achieve 100% clean electricity on the road to net zero.

References

1. Ember. South Korea | Electricity Transition. https://ember-climate.org/countries-and-regions/countries/south-korea/ (2022).
2. Climate Analytics & SFOC. *Employment opportunities from a coal-to-renewables transition in South Korea*. https://climateanalytics.org/publications/2021/employment-opportunities-from-a-coal-to-renewables-transition-in-south-korea/ (2021).
3. Climate Analytics. Transitioning towards a coal-free society: science based coal phase-out pathway for South Korea under the Paris Agreement. https://climateanalytics.org/media/south_korea_coal_phase_out_feb17_eng.pdf (2020).
4. IPCC. *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. (Cambridge University Press, 2022). doi:10.1017/9781009157926.
5. Carbon Tracker Initiative. Whack-A-Mole: Will South Korea's coal power transition be undermined by overcompensated gas? *Carbon Tracker Initiative* https://carbontracker.org/reports/whack-a-mole/ (2020).
6. South Korean Government. 2050 Carbon Neutrality Framework Act passed by the National Assembly to legislate economic and social transformation towards carbon neutrality. https://www.me.go.kr/home/web/board/read.do?boardMasterId=1&boardId=1473295&menuId=286 (2021).
7. Ministry of Trade, Industry and Energy. Third Energy Master Plan. https://www.etrans.or.kr/ebook/05/files/assets/common/downloads/Third%20Energy%20Master%20Plan.pdf (2022).
8. Ministry of Trade, Industry and Energy. Confirmation and announcement of the 9th Basic Electricity Supply and Demand Plan (2020-2034). https://www.korea.kr/news/pressReleaseView.do?newsId=156429427 (2020).
9. Global Energy Monitor. Global Gas Plant Tracker. https://globalenergymonitor.org/projects/global-gas-plant-tracker/ (2022).
10. IEA. Reforming Korea's Electricity Market for Net Zero – Analysis. *IEA* https://www.iea.org/reports/reforming-koreas-electricity-market-for-net-zero (2021).
11. Ministry of Trade, Industry and Energy. Announcement of the 14th Long-Term Natural Gas Supply and Demand Plan (2021-2034). https://www.korea.kr/news/pressReleaseView.do?newsId=156448879 (2021).
12. EIA. Background Reference: South Korea. https://www.eia.gov/international/analysis/country/KOR/background (2020).

13. Republic of Korea. Submission under the Paris Agreement: The Republic of Korea's Enhanced Update of its First Nationally Determined Contribution. (2021).
14. Ministry of Trade, Industry and Energy. 2030 National Greenhouse Gas Reduction Target (NDC) Upgrade Plan. (2021).
15. Ministry of Trade, Industry and Energy. 1st Basic Plan for Hydrogen Economy Implementation (Summary). (2021).
16. Tachev, V. South Korean Green Taxonomy Declared 'Gas is Green'. *Energy Tracker Asia* https://energytracker.asia/south-korean-green-taxonomy-declared-gas-is-green/ (2022).
17. South Korean Government. Ministry of Environment Report and Explanation - Establishing milestones for 2050 carbon neutrality. http://me.go.kr/home/web/board/read.do?boardMasterId=1&boardId=1483250&menuId=10525 (2021).
18. Lee, C. South Korean president unveils energy plan focused on cutting fossil fuel reliance. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/070522-south-korean-president-unveils-energy-plan-focused-on-cutting-fossil-fuel-reliance (2022).
19. Ministry of Trade, Industry and Energy. Public Subcommittee Working Plan for 10th Basic Plan for Electricity Supply and Demand. https://www.korea.kr/news/pressReleaseView.do?newsId=156523169 (2022).
20. Climate Analytics. *Fossil gas: a bridge to nowhere. Phase-out requirements for gas power to limit global warming to 1.5°C*. https://climateanalytics.org/publications/2022/fossil-gas-a-bridge-to-nowhere/ (2022).
21. Fuss, S. *et al.* Negative emissions - Part 2: Costs, potentials and side effects. *Environmental Research Letters* **13**, (2018).
22. Rogelj, J. *et al. Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development*. *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change* 1–113 (2018).
23. Climate Action Tracker. Country Profile: South Korea. https://climateactiontracker.org/countries/south-korea/ (2022).
24. Creutzig, F. *et al.* Considering sustainability thresholds for BECCS in IPCC and biodiversity assessments. *GCB Bioenergy* **13**, 510–515 (2021).
25. Jones, M. B. & Albanito, F. Can biomass supply meet the demands of bioenergy with carbon capture and storage (BECCS)? *Global Change Biology* **26**, 5358–5364 (2020).
26. Grant, N., Hawkes, A., Mittal, S. & Gambhir, A. The policy implications of an uncertain carbon dioxide removal potential. *Joule* **5**, 1–13 (2021).

27. Shayegh, S., Bosetti, V. & Tavoni, M. Future Prospects of Direct Air Capture Technologies: Insights From an Expert Elicitation Survey. *Frontiers in Climate* **3**, 1–14 (2021).
28. Grant, N., Gambhir, A., Mittal, S., Greig, C. & Köberle, A. C. Enhancing the realism of decarbonisation scenarios with practicable regional constraints on CO2 storage capacity. *International Journal of Greenhouse Gas Control* **120**, 103766 (2022).
29. Song, H. & Lim, J. Forest biomass: Burning the bridge to a renewable future. *Forest biomass* 11 (2022).
30. Energy Transitions Committee. *Bioresources within a Net-Zero Emissions Economy*. 1–116 (2021).
31. Baumstark, L. *et al.* REMIND2.1: transformation and innovation dynamics of the energy-economic system within climate and sustainability limits. *Geoscientific Model Development* **14**, 6571–6603 (2021).
32. IEA. Southeast Asia Energy Outlook 2022 – Analysis. *IEA* https://www.iea.org/reports/southeast-asia-energy-outlook-2022 (2022).
33. Eom, J. *et al.* 2050 Carbon-Neutraality Transition Scenario: Analysis of a Korean Integrated Assessment Model. https://21220177.fs1.hubspotusercontent-na1.net/hubfs/21220177/%5BSFOC%5D%202050%20Carbon-Neutrality%20Transition%20Scenario.pdf (2021).
34. Lee, C. & Ram, A. S Korea to provide 27.9 mil mt/year of 'clean hydrogen' by 2050 | S&P Global Commodity Insights. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/112621-s-korea-to-provide-279-mil-mtyear-of-clean-hydrogen-by-2050 (2021).
35. Schleussner, C.-F., Ganti, G., Rogelj, J. & Gidden, M. J. An emission pathway classification reflecting the Paris Agreement climate objectives. *Nature Communications Earth and Environment* **3**, 1–11 (2022).
36. Riahi, K. *et al.* Cost and attainability of meeting stringent climate targets without overshoot. *Nature Climate Change* (2021) doi:10.1038/s41558-021-01215-2.
37. Luderer, G. *et al.* Residual fossil CO2emissions in 1.5-2 °c pathways. *Nature Climate Change* **8**, 626–633 (2018).

Appendix A: Pathway selection

Selection methodology

Figure A1 highlights the steps taken to select the final 21 pathways for analysis in this report.

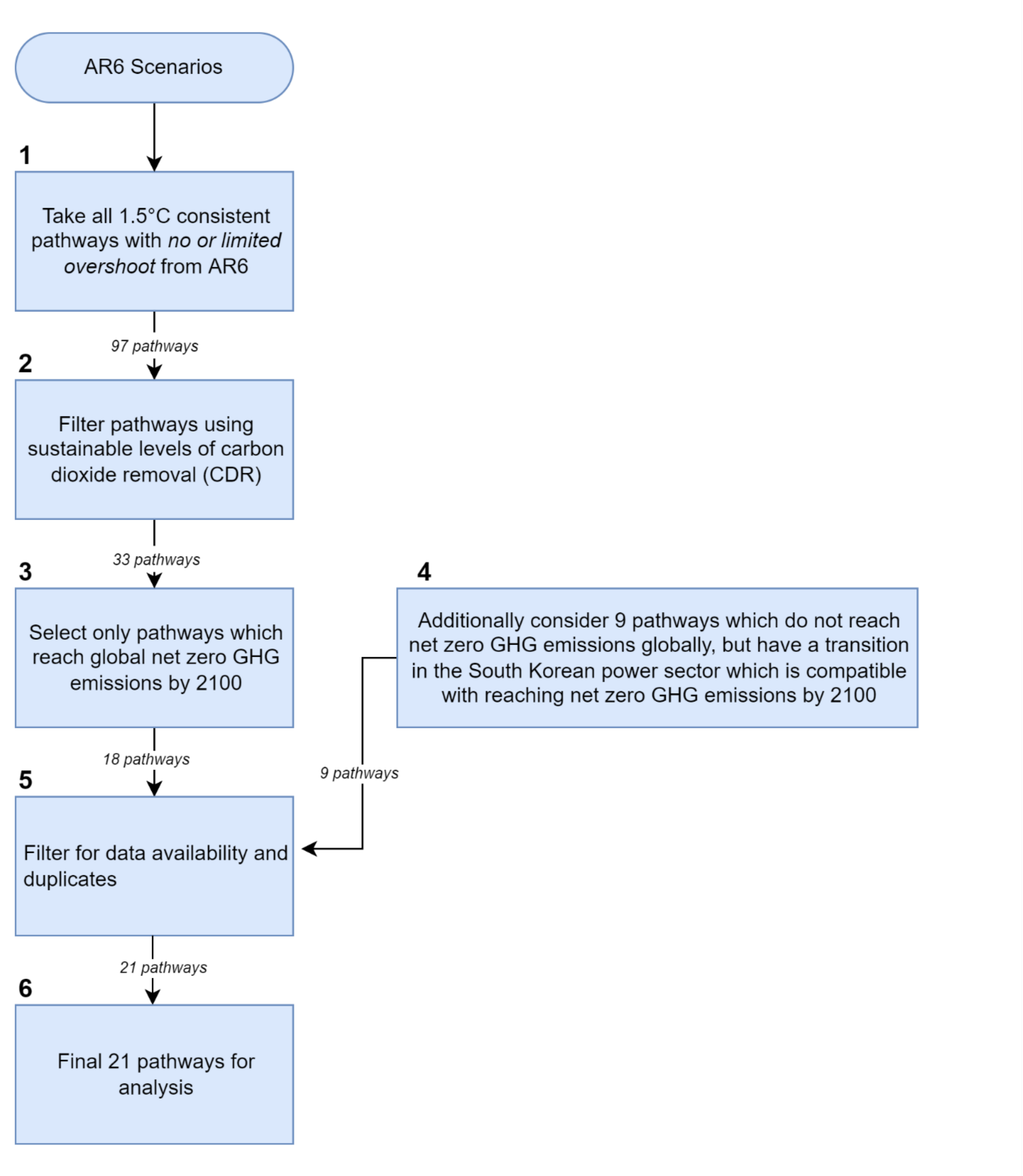


Figure A1: Scenario selection process

Steps 3 and 4 of Figure A1 ensure that all pathways are consistent with reaching global net zero GHG emissions by 2100.

Step 3 selects the 18 **subcategory C1a** pathways for analysis. These are pathways which compatible with both Article 2.1 and Article 4.1 of the Paris Agreement[35], as they reach global net zero GHG emissions by 2100.

Step 4 complements this set of C1a pathways with an additional nine pathways drawn from the **subcategory C1b** IPCC AR6 pathways category that limit warming to 1.5°C. These pathways are selected because, although they do not reach global net zero GHG emissions in the second half of the century, they do display faster emissions reductions in the South Korean power sector out to 2050 than the median of the 22 C1a pathways.

Therefore, although the global emission characteristics of these additional pathways are not compatible with Article 4.1 of the Paris Agreement, the South Korean power sector transition implied by these pathways is consistent with reaching global net zero GHG emissions in the second half of the century.

These C1b pathways do not reach net zero GHG emissions in the second half of the century due to methodological choices in scenario production, including the formulation and implementation of climate targets in the model[36], the assumed scale of CDR available[37], the level of non-CO_2 emission reductions. However, this does not prevent them providing valuable information on the South Korean power sector transition.

Including a subset of C1b pathways expands the pool of potential scenarios used in the analysis and improves the robustness of the phase-out dates thus calculated. This therefore gives a set of 27 pathways which are either in the C1a subcategory, or this ambitious subset of C1b pathways, where all pathways limit global CDR deployment to sustainable levels.

List of pathways selected for analysis

Table A1 summarises the 21 pathways selected for analysis in this report. Pathways highlighted in blue do not reach global net zero GHG emissions (C1b subcategory rather than C1a) but demonstrate a power sector transition in South Korea that is compatible with reaching net zero GHG emissions globally.

Table A1: List of 1.5°C compatible pathways selected for analysis

Model	Scenario
AIM/CGE 2.2	EN_NPi2020_300f
IMAGE 3.2	SSP2_SPA1_19I_LIRE_LB
REMIND 2.1	LeastTotalCost_LTC_brkLR15_SSP1_P50
REMIND 2.1	R2p1_SSP1-PkBudg900
REMIND-MAgPIE 2.1-4.2	CEMICS_SSP1-1p5C-fullCDR
REMIND-MAgPIE 2.1-4.2	CEMICS_SSP1-1p5C-minCDR
REMIND-MAgPIE 2.1-4.2	CEMICS_SSP2-1p5C-minCDR
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_200f
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_300f
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_400
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_400f
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_500
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_600
REMIND-MAgPIE 2.1-4.2	SusDev_SDP-PkBudg1000
REMIND-MAgPIE 2.1-4.2	SusDev_SSP1-PkBudg900
REMIND-MAgPIE 2.1-4.3	DeepElec_SSP2_ HighRE_Budg900
WITCH 5.0	EN_NPi2020_400f
WITCH 5.0	EN_NPi2020_450
WITCH 5.0	EN_NPi2020_450f
WITCH 5.0	EN_NPi2020_500
WITCH 5.0	EN_NPi2020_500f

Appendix B: Model-weighted percentiles

This report uses model-weighted percentiles to define the 1.5°C compatible emissions envelope for the South Korean power sector. This is an approach which is used to prevent one model biasing the results unduly.

The 21 final pathways selected are produced by four different IAMs. Each IAM has its own particular representation of the energy system and key transition dynamics. Therefore, if one model has a greater number of pathways represented in the final ensemble, this can result in one particular set of model dynamics being overrepresented in the final results.

Model-weighted percentiles can correct for this potential bias in the initial ensemble. The approach uses two steps:

1. Each pathway is weighted according to the number of pathways in the total set that are produced by the same model. If a model produces n_{model} pathways, then each pathway received a weight of $1/n_{model}$. This ensures that each model receives an equal overall weighting when calculating statistics from the distribution. As the REMIND integrated modelling assessment produced the majority of the pathways, this approach prevents these scenarios biasing the results unduly.
2. Having given weights to each pathway, percentiles from the distribution can then be calculated.

Figure B1 shows how different percentiles can be calculated from the overall distribution of pathways. The left panel shows the emissions of all 21 selected pathways over time. While different pathways provide a variety of possible future emissions, all pathways achieve a highly decarbonised power sector by mid-century at the latest. Many scenarios go beyond this, achieving zero emissions in the power sector during the 2030s and, in some cases, achieving substantial net-negative CO_2 emissions by 2050.

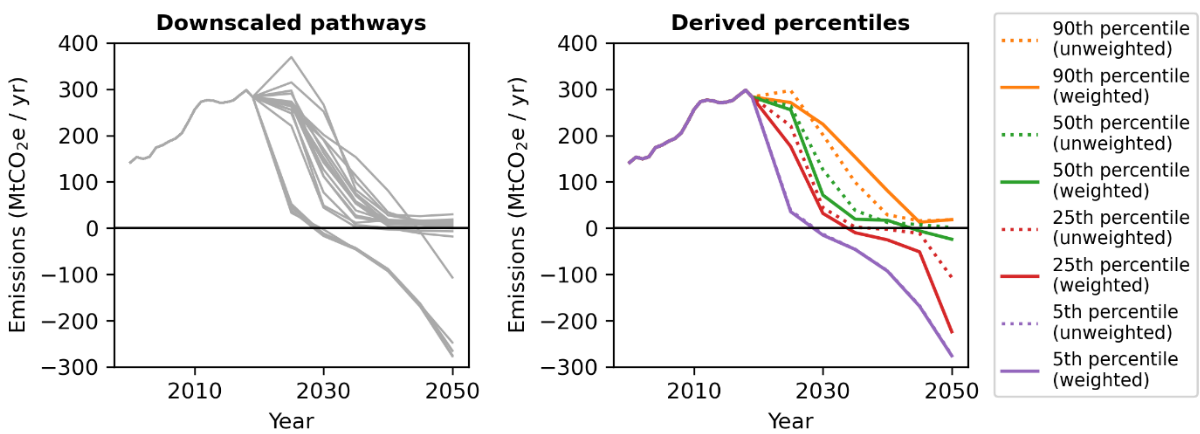


Figure B1: Calculating model-weighted percentiles from the distribution

The right-hand panel shows the resultant quantiles from the distribution, showing both unweighted quantiles (where all pathways are weighted equally), and model-weighted quantiles (where the total contribution of each model is weighted equally). We can see that correcting for the model-related bias in the sample generally leads to lower emissions in the power sector.

This is because downscaled pathways derived from REMIND scenarios (which make up two thirds of the pathways we assess) tend to have higher overall emissions for South Korea. When these scenarios are down-weighted to correct for this over-representation and to weight the contributions from each modelling framework equivalently, the resultant emissions percentiles are reduced accordingly. This demonstrates the value of using model-weighted percentiles to correct for any model-related bias in the initial ensemble of pathways.

CLIMATE
ANALYTICS