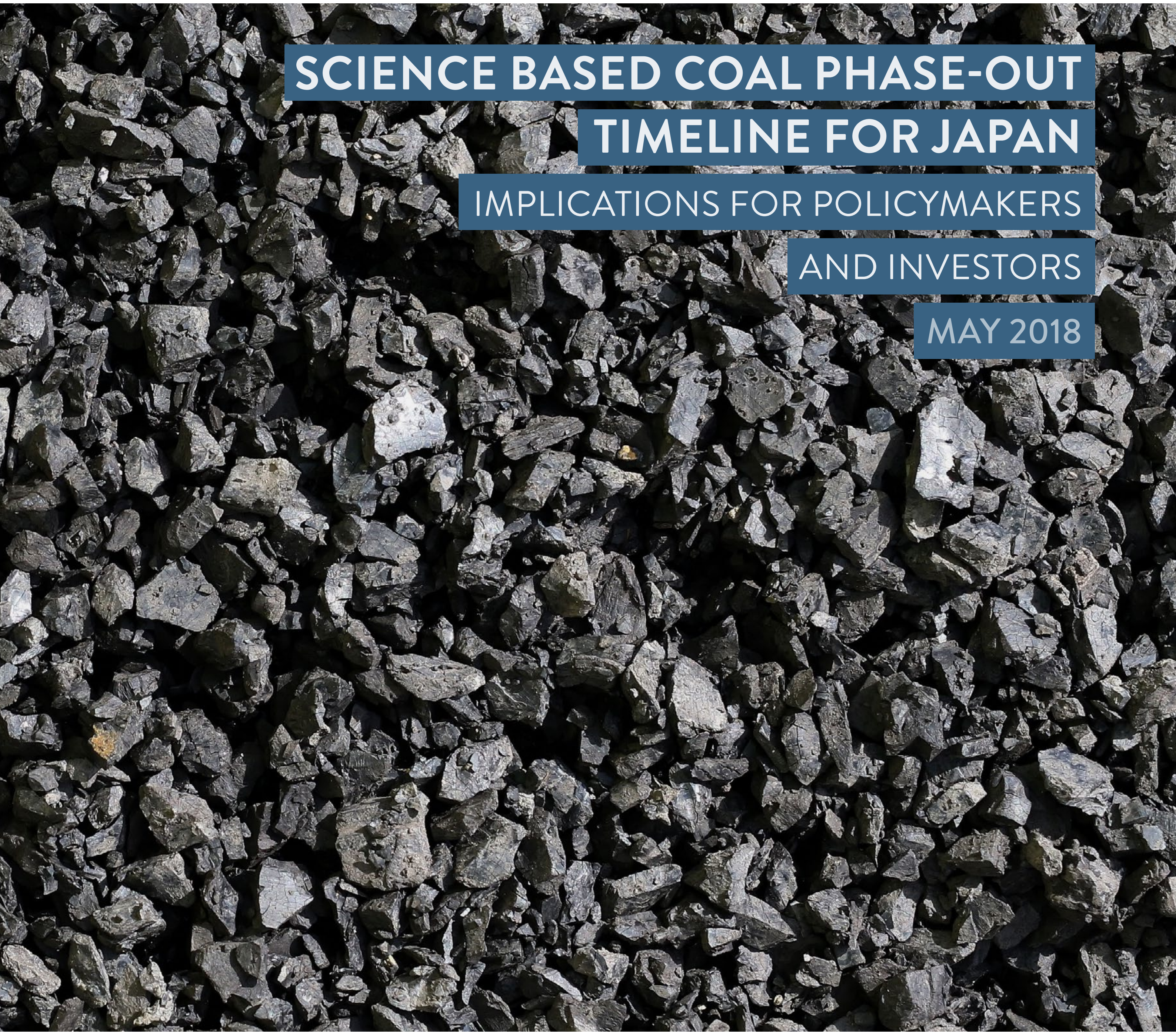
CLIMATE ANALYTICS

SCIENCE BASED COAL PHASE-OUT TIMELINE FOR JAPAN

IMPLICATIONS FOR POLICYMAKERS AND INVESTORS

MAY 2018



In collaboration with

RENEWABLE ENERGY INSTITUTE

AUTHORS

Paola Yanguas Parra	Climate Analytics
Yuri Okubo	Renewable Energy Institute
Niklas Roming	Climate Analytics
Fabio Sferra	Climate Analytics
Dr. Ursula Fuentes	Climate Analytics
Dr. Michiel Schaeffer	Climate Analytics
Dr. Bill Hare	Climate Analytics

GRAPHIC DESIGN

Matt Beer	Climate Analytics

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IMPLICATIONS FOR POLICYMAKERS AND INVESTORS

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EXECUTIVE SUMMARY

INTRODUCTION

The Paris Agreement temperature goal is hold the global average temperature rise well below 2 degrees Celsius above pre-industrial levels and pursue efforts to limit this to 1.5 degrees Celsius. To achieve this goal globally aggregated zero greenhouse gas emissions need to be reached in the second half of this century.

This requires a rapid decarbonisation of the global power sector, and especially of coal generation, which accounts for about 40% of global electricity emissions and is the most carbon-intensive source of electricity generation.

In Japan, about 90% of greenhouse gas (GHG) emissions come from energy-related sources, and electricity generation contributes to about 40% of its CO2 emissions. In 2016, more than half of the electricity emissions in Japan came from coal, which is equivalent to about 20% of total GHG, making it a major contributor to climate change.

Currently, in addition to the 45 GW of coal power generation capacity, Japan has plans to construct about 18 GW of new and additional coal power plants, of which 5 GW are already under construction.

To achieve the Paris Agreement goal and its national commitments, addressing emissions from coal should be the primary focus for Japan.

1 COAL EMISSIONS IN LINE WITH THE PARIS AGREEMENT

To identify an emissions budget for coal power plants in Japan, the Paris Agreement temperature goal needs to be translated into emissions pathways for sectors that are consistent with this agreement at the national level.

An important and useful source for this date are Integrated Assessment Models (IAMs) scenarios, which identify economically and technologically feasible emissions pathways consistent with a given climate target, while minimising global costs.

We have used an available scenario that approximates the Paris Agreement temperature goal (holds warming below 2°C with 85% probability, or greater, and with a more than 50% chance of remaining below 1.5°C by 2100), and derived cost-optimal pathways for electricity generation from unabated coal plants, globally, and for Japan.

The cost-optimal emissions pathway shows that coal power plant emissions need to decrease steeply in the coming years and be mostly phased out by 2030 in Japan. Globally, emissions of unabated coal need to be phased out at the latest by 2050 to remain in line with the Paris Agreement.

2 COAL EMISSIONS IN JAPAN - EMISSIONS FROM THE CURRENT AND PLANNED CAPACITY

To estimate the emissions from coal-fired power plants for the existing 45 GW of capacity as well as the planned additional 18 GW of plants in Japan, we have made some business as usual assumptions - a unit lifetime of 40 years and a capacity factor (utilization rate) linearly decreasing from current levels of 76% to 56% in 2026 based on previous literature estimates.

Under business as usual, there is a huge gap between the current and planned emissions from coal generation in Japan and the Paris Agreement budget for the period 2018-2050. The Paris Agreement budget would be exceeded about three times if all the planned power plants were to be built.

Alternative scenarios where only half or a quarter of the planned coal power plants are built to replace old and less-efficient capacity (which we assumed are retired after reaching the average lifetime of 40 years) still result in emissions far exceeding a Paris Agreement budget for coal.

Even the lifetime emissions from Japan's existing coal capacity (without considering planned additions) significantly exceed the Paris emissions budget if these plants are operated until the end of their technical lifetime. The age distribution of Japanese coal capacity shows that coal would continue to be a part of the electricity mix until at least 2060.

In order to achieve the Paris Agreement's long-term temperature goal, Japan will need to implement early retirement of currently-operating power plants and/or dramatically reduce their utilisation rate. Any additional coal capacity will only increase the difference between committed emissions and cost-optimal pathways consistent with the Paris Agreement, regardless of the assumptions made.

3 IMPLICATIONS OF THE ANALYSIS RESULTS TO BUSINESSES AND TO COAL REGULATIONS IN JAPAN POLICYMAKERS

Japan needs to start discussions on a coal phase-out policy now.

The current emissions reduction target - based on the energy mix in 2030 - is not in line with what is required under the Paris Agreement.

Moreover, current plans for coal generation capacity are inconsistent not only with a Paris Agreement compatible cost-optimal strategy but also with its own nationally determined targets for electricity generation as well as emissions reductions.

Current policies to address emissions from coal generation, such as an efficiency standard of 42% or voluntary action cannot limit new coal generation capacity without a binding reduction target for the sector and give a wrong incentive for renewal, which strengthens the dependency on coal.

Sending a clear signal for a decarbonised future now may lead to an expansion of investment in the entire economy and avoid additional expenditure on coal generation capacity, as Japanese firms are increasing their cash holdings and manufacture equipment is becoming old and requires renewal.

When starting a public discussion on coal phase-out, it would be a constructive step for Japan to assess the costs associated with phasing out coal and compare them with the associated benefits such as climate protection, air quality improvements, reduction of fuel cost and energy dependency.

NEW COAL CAPACITY INVESTORS

The top ten new coal capacity investors in Japan are J-Power, Chugoku Electric, JERA, Kyushu Electric, Kobe Steel, Chubu Electric, KENES (100%Kansai Electric), Marubeni, Mitsubishi Corporation and Tokyo Gas.

Significant reputational and climate risks are a growing concern for global investors, which own a 30% share in listed companies in Japan and have already started to divest from some of these top ten investors in coal capacity.

Changes in the regulatory environment represent a significant latent risk for coal investors in Japan, given the international commitments the country acquired under the Paris Agreement, which are required to be revised and strengthened every five years.

Even if the Japanese government were to continue to support efficient coal in the future, current energy supply and demand trends are not favouring new coal capacity. The electricity demand decreased by almost 10% in just five years from 2010 while the renewable energy share increased about 5%, pushing down the average capacity factor of thermal power plants.

In addition to decreasing energy demand, the biggest challenge new thermal capacity will face is the drastic cost decline of renewables and storage technology. BNEF estimates that for Japan a new utility scale solar PV will be cheaper than combined cycle gas turbines in less than five years and cheaper than coal in 2024.

Under those circumstances, the economic viability of all the new coal capacity currently planned to come online as late as 2027 is highly questionable, and investors risk not being able to fully amortizing their investment nor generating the revenue they expect.

ENERGY USERS

Japanese companies such as Aeon, Askul, Fujitsu, Fujifilm, Kirin, Panasonic, Ricoh, Sekisui House, Sony etc. are increasingly committing to international initiatives such as RE100 and Science Based Target (SBT). For these companies, any coal-fired power generation in Japan beyond the Paris Agreement can undermine the achievement of their commitments.

Moreover, Japanese companies risk losing competitiveness in the global market because of slow domestic deployment of renewables and expansion of carbon intensive energy sources such as coal power generation.

> More than 100 Japanese factories in Apple's supply chain are required to set emissions reduction targets and they are encouraged to improve energy efficiency and procure renewable energy. In 2017, 756 audits were conducted, and supplier performance has been evaluated.

> Top foreign investors in Japan such as Black Rock, Baillie Gifford, Vanguard Group, Norges Bank Investment Management, UBS Asset Management, Axa Investment Managers, are becoming more sensitive about how climate-related risk affects the business, and some have already divested from companies on whose business relies on coal.

The establishment of Renewable Energy Users Network (RE-Users) is a clear signal from the electricity users' about the need to shift away from fossil fuels.

4 COAL PHASE-OUT POLICIES

Lessons on policies leading to an effective coal phase-out can be gained from international experiences. Countries such as Austria, Canada, Finland, UK, Italy, the Netherlands, France, and other members of the "Powering Past Coal Alliance," have already set a clear timeline for coal phase-out.

Market-based policy instruments such as carbon pricing are one option for discouraging coal use. In Japan, a Carbon Pricing Consideration Committee has discussed potential effective new policies.

Regulatory approaches can also be an effective tool to enable coal phase-out: strict air pollution or CO2 emissions standards can make a new coal-fired power plant uneconomic or make modernisation - or shut down - of existing plants necessary. Such effective standards can be observed in several jurisdictions such as UK, Canada and in the EU.

Another important development that has pushed coal out of the market internationally is the increasing renewable power generation - the result of both policy and market forces - that has resulted in a dramatic reduction of costs of renewable energy and storage technologies.

International experience shows that managing the impact on workers, coal owners, industry and energy users, as well as communicating the benefits and co-benefits of coal phase-out can increase the success and political acceptability of coal phase-out policies and instruments.

In countries like UK, Canada and US, benefits are officially investigated, quantitatively assessed and compared to the cost of phasing out coal, which has historically resulted in the implementation of stricter environmental standards.

CONCLUSION

The Paris Agreement sets a clear, science based pathway to decarbonisation globally. For Japan, in common with most countries, the consequences includes rapid decarbonisation of the power sector, with coal-fired power plants leading the way and need to be mostly phased out by 2030.

Additional coal plants are completely inconsistent with the Paris Agreement and the discussion should now be on how to phase out existing coal-fired power plants in orderly manner.

Most countries which have set a phase-out timeline have set it between 2020-2030, which gives an indication of the urgency of starting a national conversation on the future role of coal in Japan.

Phasing out most of the coal generation that supplies about 30% of Japan's electricity now in less than 15 years needs a rapid but feasibly and likely beneficial shift in climate and energy policy in Japan. An extension of the current standards and voluntary action will not address the problem.

A clear policy signal and structured phase-out plan will benefit the public and industry in many ways, and will also be beneficial for coal related businesses, workers, owners and investors to make a sound transition.

As of April 2018, most of Japan's proposed new 43 coal plants are in the Environmental Impact Assessment process required before securing funds to operate after 2020. The timing to send the right policy signal for investment is now.

To achieve the Paris Agreement's temperature goal Japan will need to progressively increase its national emissions commitments (NDC) under this Agreement which will not be possible event with existing coal capacity, hence addressing emissions from coal should be a primary focus for Japan's climate and energy policy.

INTRODUCTION

The Paris Agreement was a milestone for international climate action with most countries submitting a Nationally Determined Contribution (NDC). Recent assessments have confirmed however, that there is still an emissions gap between targets expressed in the NDCs and current policy developments. Even if fully implemented, the NDCs will deliver by 2030 only a third of the emissions required to stay well below 2°C (Climate Action Tracker, 2017a; UNEP, 2017). This highlights the urgent need to strengthen climate action in the short term, and the need for more ambitious NDCs by 2020.

One of the key short-term steps toward closing the emissions gap is the avoidance of new coal-fired power plants and the phase-out of existing ones (Climate Action Tracker, 2016; Climate Analytics, 2016; Kuramochi et al., 2017; UNEP, 2017).

Coal-fired power plants produce 38% of global electricity (IEA, 2018), and coal-fired power generation is the most carbon-intensive source for electricity production, making carbon emissions from coal a leading contributor to climate change. Without additional policy interventions, the number of coal-fired power plants will continue to increase globally, with around 209 GW of coal capacity currently under construction and 447 GW in planning (Shearer, Mathew-Shah, Myllyvirta, Aiqun, & Nace, 2018).

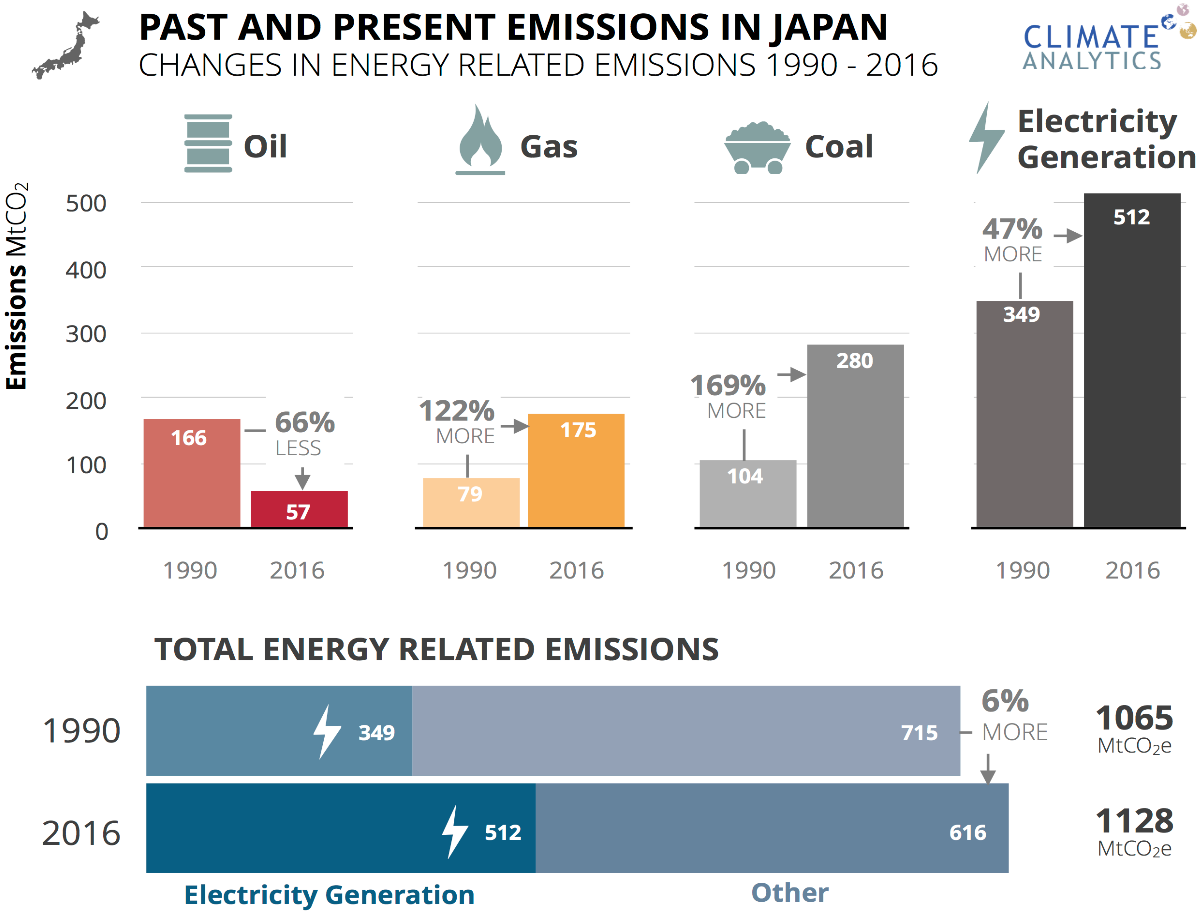

Figure 1 CO_2 Emissions from Energy Related Sources and Share of Emissions from Coal. Source: Own elaboration bases on (MOEJ, 2018) and(METI, 2018)

In Japan, energy-related CO_2 emissions make up about 90% of its total greenhouse gas (GHG) emissions. Of the energy-related CO_2, the electricity generation including auto-producers accounts for about 45% of the emissions in 2016. This means Japan's CO_2 emissions are greatly affected by its energy sources. As illustrated in Figure 1, in 2016, more than half of the electricity generation emissions in Japan came from coal-fired power plants, which is equivalent to 18% of total GHG emissions, and almost 2.7 times compared to 1990. Between 1990 and 2016, 93% of the increase in energy-related emissions is explained by the increase in emissions from coal power generation capacity. Therefore, in terms of climate change measures, addressing emissions from coal should be a primary focus for Japan.

However, contrary to what is needed to achieve the national emissions reduction targets and the Paris Agreement's long-term temperature goal, 18 GW of new and additional coal power plants are planned to come online in Japan over the next decade, while only 760 MW have concrete plans for retirement. Even if all the capacity reaching its technical lifetime of 40 years were to retire (as illustrated in Figure 2 the net capacity would still increase under current plans.

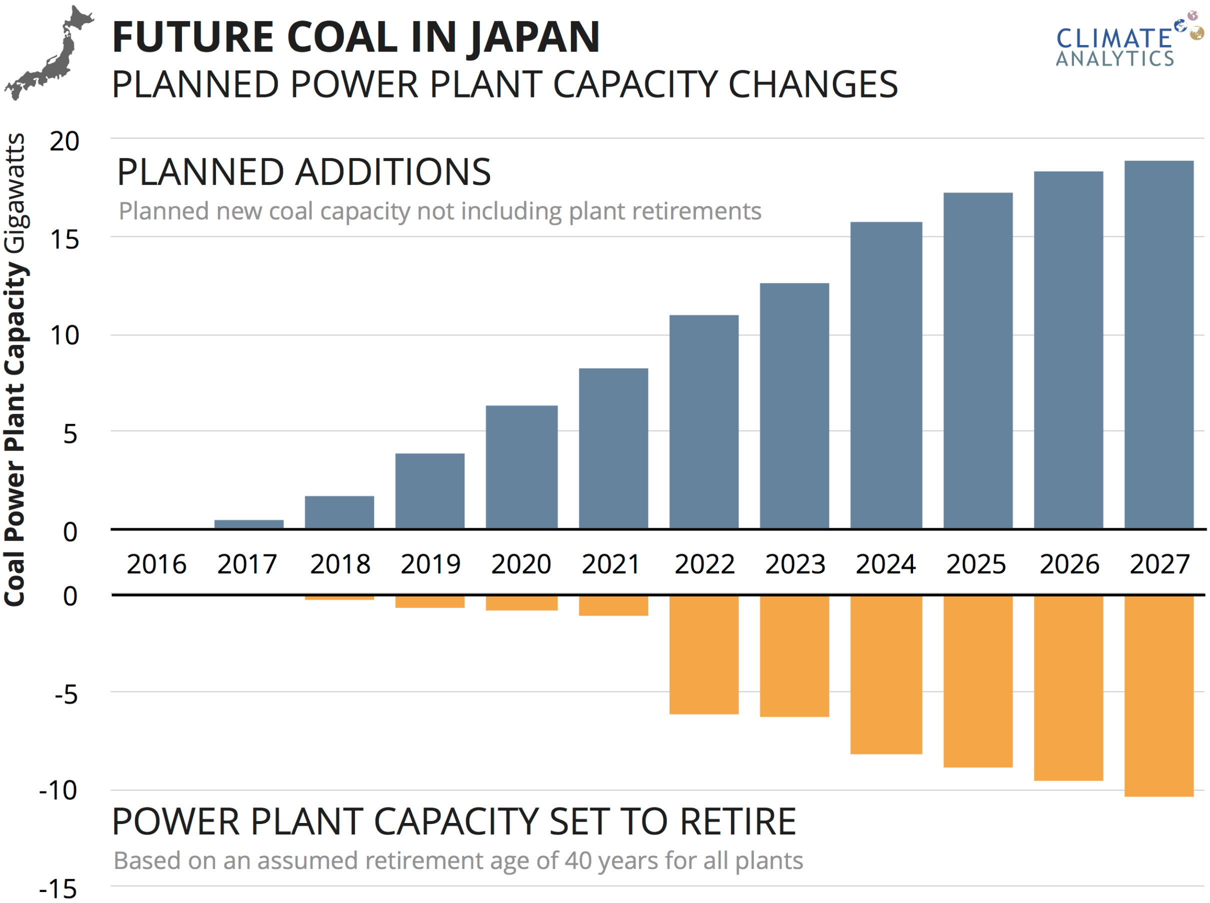

Figure 2 Projected net coal capacity additions (GW). Source: Climate Analytics - REI coal plants database (version Feb 2018) Note: The yellow bars show potential retirements assuming a retirement age of 40 years for all plants. However, currently announced retirements are only 760 MW.

With these developments in planning, the question arises as to whether Japan - with its current coal policies - is on the right pathway to achieving its NDC and Paris Agreement goals. In this report we will explore the implications of the Paris Agreement for coal-fired power generation in Japan by comparing the emissions of current and planned coal capacity with benchmark emissions pathways from energy-economy models. We will consider scenarios with a limited expansion of the coal capacity and discuss to what extent replacements to more efficient capacity will be an effective measure to mitigate emissions as required to be in line with the Paris Agreement.

1 COAL EMISSIONS IN LINE WITH THE PARIS AGREEMENT

The Paris Agreement aims to strengthen the global response to the threat of climate change by keeping global temperature rise of this century "well below 2˚C and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius above pre-industrial levels" (UNFCCC, 2015). The agreement, which also includes a goal to peak global greenhouse gas emissions as soon as possible, and achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of the century, has been ratified by 174 Parties including Japan, US, China, India and EU.

More than two decades of international climate negotiations laid the groundwork for the Paris Agreement and its long term temperature goal, which goes beyond the previous Cancun Agreement's 2°C temperature limit.

There are ample energy-system emissions scenarios consistent with holding warming to below 2°C, with various degrees of likelihood of exceeding this level. These scenarios come from Integrated Assessment Models (IAMs), which identify economically and technologically feasible emissions pathways consistent with a given climate target, while minimising global costs. For this reason, emissions pathways derived from IAMs are typically called "cost-optimal" pathways. The range and depth of literature available for the evaluation of the 1.5°C limit is not as ample yet.

After the assessment of the available scenarios, as a proxy for Paris Agreement we use scenarios that hold warming below 2°C with 85% probability, or greater, and with a more than 50% chance of remaining below 1.5°C by 2100[1]. The scenarios selected are consistent with previous publications looking at coal phase-out at the global and regional levels which conclude that, to meet the Paris Agreement, coal phase-out is needed by no later than 2030 in countries that are part of the Organisation for Economic Co-operation and Development (OECD) and the European Union, and by no later than 2050 in the rest of the world (Climate Analytics, 2016) (Rocha et al., 2017). These scientific-based benchmarks for coal phase-out dates have been acknowledged by a number of countries to set their own national targets for coal phase-out, as spelled out in the declaration of the Powering Past Coal Alliance (Powering Past Coal Alliance, 2017).

Also, it is essential to note that the coal phase-out date in this scenario is consistent with the many models and scenarios newly published in the multi-model study published in 2018 in the lead up to IPCC's Special Report on 1.5°C (Rogelj et al., 2018) – see supplementary information figure 14, panel b). Out of a total of 13 scenarios using 5 different models, 11 show a global coal phase-out by 2050 (without CCS).

Based on the chosen global emissions scenarios, and making use of a downscaling methodology described in Annex IV, we derived cost-optimal pathways for electricity generation from unabated coal plants (i.e. coal-fired power plants without carbon capture and storage), in line with the Paris Agreement temperature limit globally, and for Japan.

1 More information about the scenario selection for this report, limitations of IAMs and a comparison of the scenarios selected with other energy models is provided in Annex I, II and III.

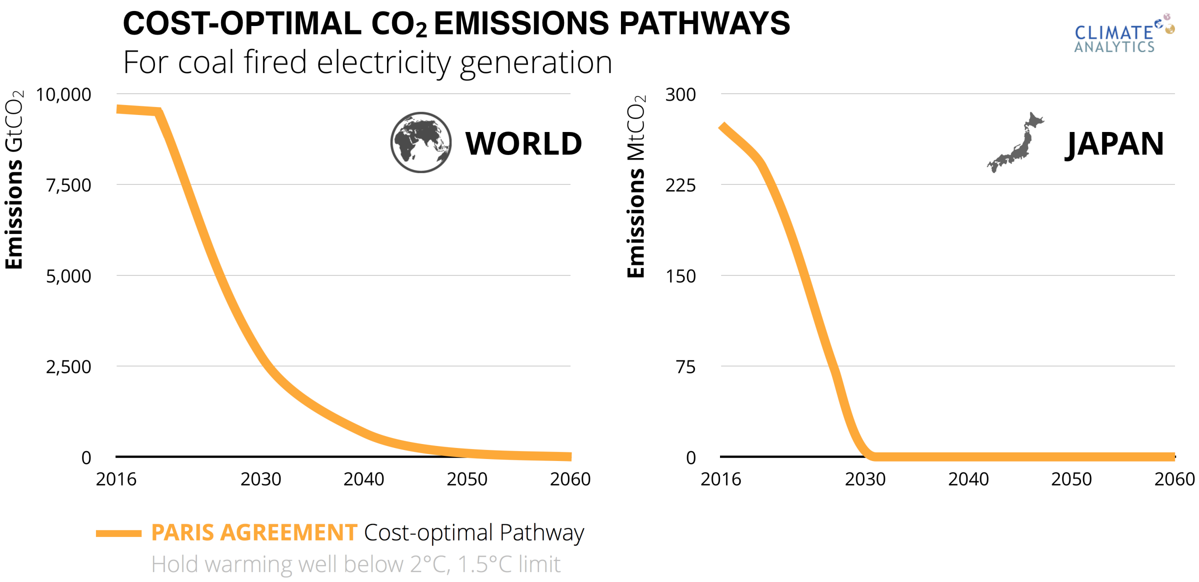

Figure 3- Cost-optimal CO_2 emissions pathways for coal fired electricity generation

The cost-optimal emissions pathways show that emissions of unabated coal need to be phased out[2] at the latest 2050 globally to remain in line with the Paris Agreement. In Japan, coal power plant emissions need to decrease steeply in the coming years and be phased out by 2030. In the second half of the century, emissions for unabated coal need to be zero for Japan and the rest of the world.

It must be noted that in order for this report to be robust and revelant for current policy discussions in Japan, we have adjusted the national emissions pathways obtained from the downscaling exercise to reflect some constraints for deployment of specific technologies. In particular, the share of nuclear generation in the power sector is constrained to maximum 10% in 2030, after taking into account the developments following 2011 Fukushima nuclear accident, which are not accounted for in the original emissions pathways from the IAM selected. Although this is less than half of the government current projection, several recent energy scenarios for Japan consider a similar projection and is considered to be more realistic (BNEF, 2015; Buckley & Nicholas, 2017; Kuramochi, 2015).

[2] Year of reductions of 90% or more below 2010 levels - analogous to assessment of emissions from energy supply sector in IPCC AR5 WG3 (SPM)

2 COAL EMISSIONS IN JAPAN

2.1 EMISSIONS FROM CURRENT AND PLANNED CAPACITY

Contrary to what is needed to achieve the Paris Agreement's long-term temperature goal, a resurgence of coal appears to be underway in Japan. Japan is the only member of the G7 looking to significantly increase its coal generating capacity and is one of the top financers for overseas coal projects[3]. (Schulz & Schwartzkopff, 2015). The graph below clearly illustrates the situation: instead of a transition to a coal-free energy mix, Japan is constructing 5 GW of coal power, with an additional 13 GW in the pipeline[4]. These would add to the operating 45 GW. The ~18 GW planned coal capacity expansion will result in either a massive amount of stranded assets - or emissions exceeding the national mid-term and long-term mitigation targets, contrary to what is required to achieve the Paris Agreement's goal.

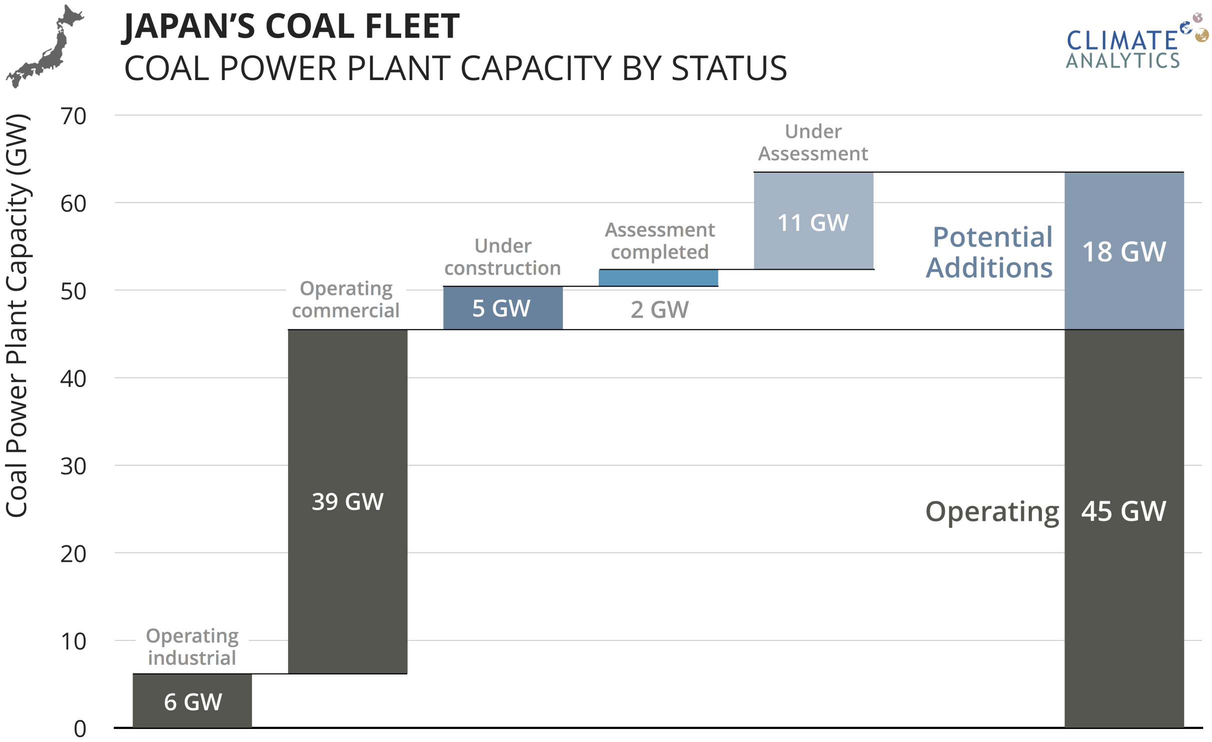

Figure 4 - Current and planned coal power plants in Japan. Source: Calculations Climate Analytics based on REI coal plants database (version Feb 2018).

A more detailed analysis of operating capacity shows that the average age of an operating coal plant in Japan is 25 years. The oldest unit (Niihama Nishi power station Unit 1) opened in 1959 and, since then, an average of 2.8 coal power units have come online in Japan every year. In the same period, only a handful of units have been decommissioned, leaving the country with 24 operating units, with a combined capacity of 3.6 GW, which exceeds the average global retirement age of a coal power generation unit of 40 years (the average retirement age of these units in Japan is 49 years).

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3 Looking internationally coal plays a large role in Japan's export policy, with Japanese companies being amongst the world's biggest manufacturers of coal technology (Toshiba, JGC, Mitsubishi Heavy Industries (MHI), and Hitachi). Between 2007 and 2013 Japan provided $16.8bn in financing for overseas coal projects –more than double that of any other OECD country.

4 The figures presented in this report are based on the coal-fired power units operating and planned as of February 2018. More recently, the two J-Power Takasago coal-fired generation units in Hyogo Prefecture (1200 MW) have been cancelled.

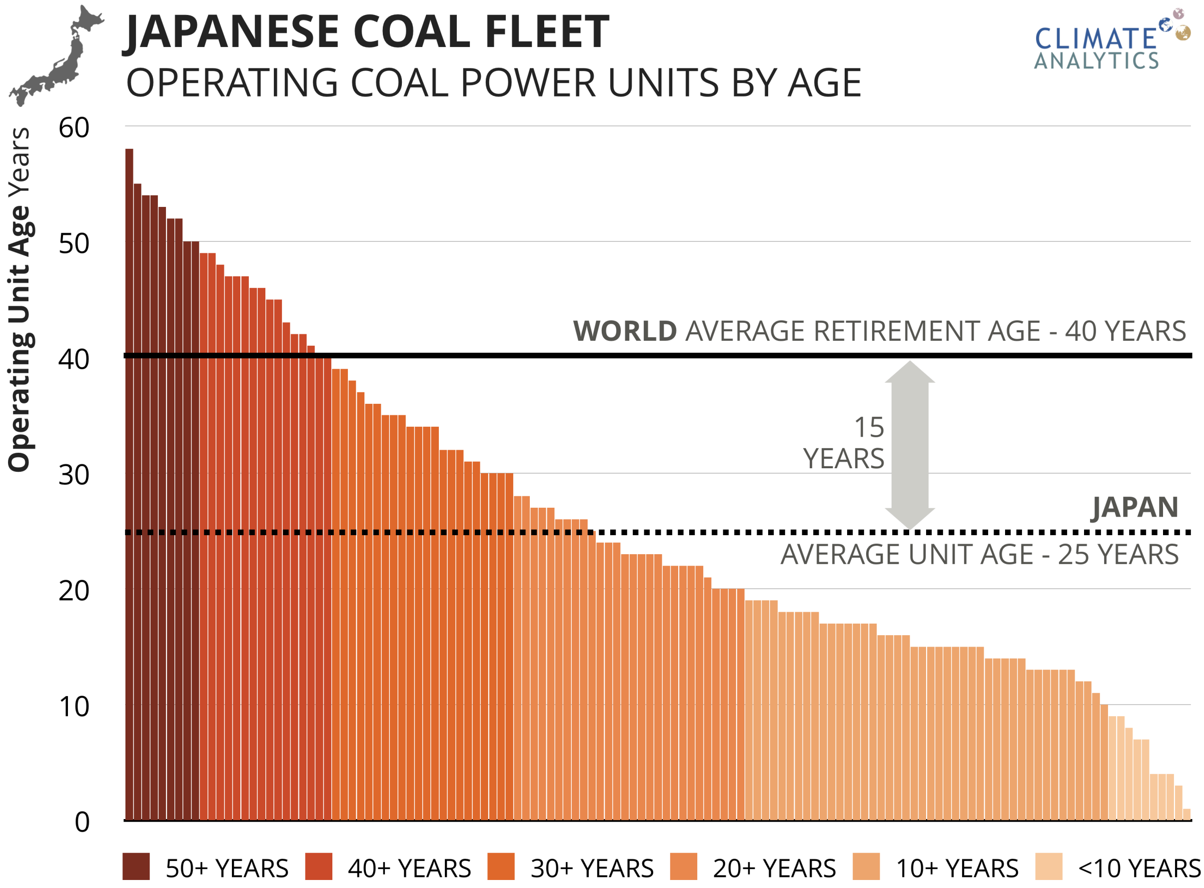

Figure 5 – Age distribution operating coal power generation units in Japan. Source: own calculations based on REI coal plants database (version Feb 2018).

The age distribution of Japanese coal capacity shows that if all plants were to operate until the end of their technical lifetime, coal would continue to be a part of the electricity mix until at least 2060. This means that even if the planned expansion of coal capacity is cancelled, Japan is likely to see either a massive amount of stranded assets related to coal power generation or emissions exceeding the national mid-term and long-term mitigation targets in the next decades. Here, we calculate the emissions that would result from current (operating + under construction), and planned (assessment completed and under assessment) coal power plants in Japan in order to estimate the emissions gap between current and planned infrastructure for coal power generation, national targets, and least cost emissions pathways compatible with the Paris Agreement.

Based on the information provided in a coal power plant database and methodology (described in detail in the ANNEX V - Estimating CO_2 emissions from coal plants), we estimate Japan's CO_2 emissions from the current and planned coal power plants, differentiating for each power plant unit. We assume no further additions beyond what is currently planned.

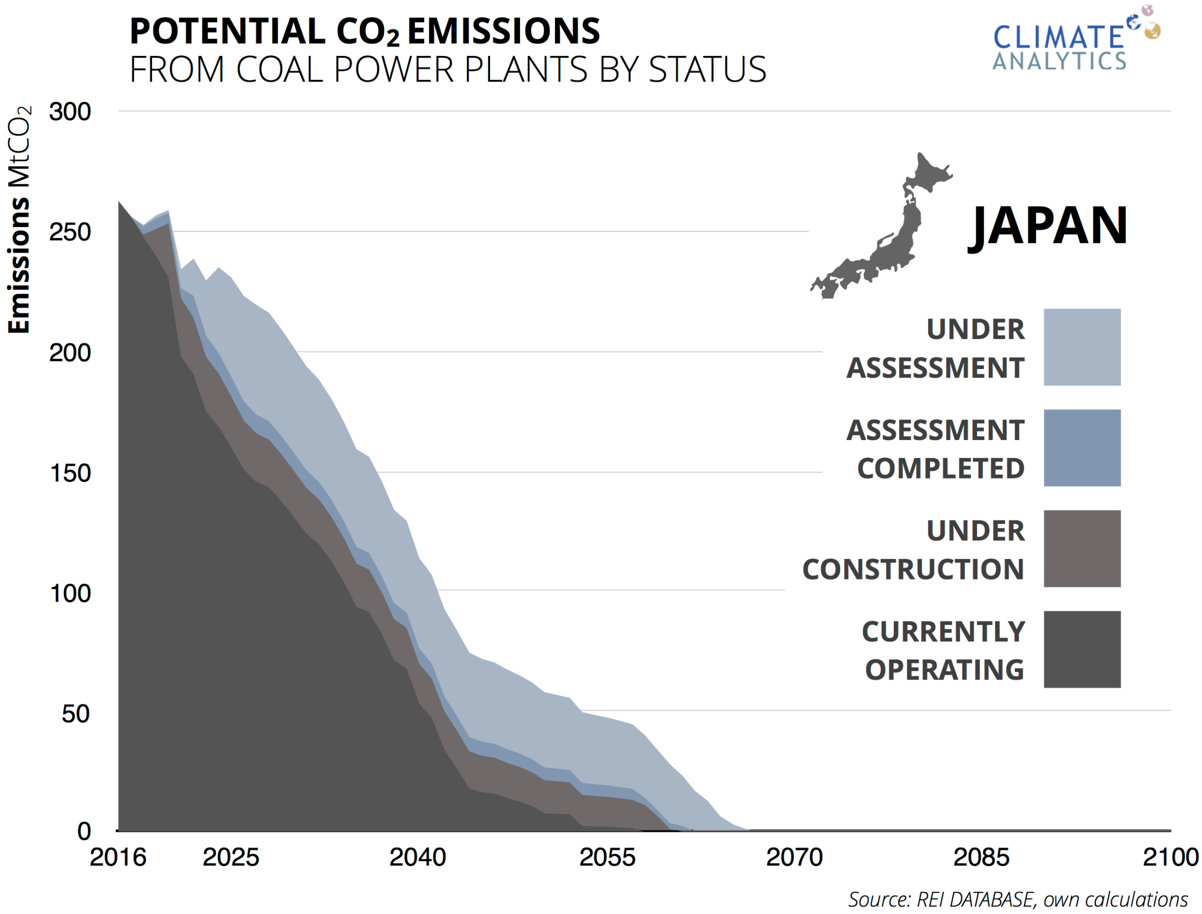

Figure 6 – Potential CO_2 emissions from coal power plants in Japan

Our key assumptions to estimate emissions are lifetime and utilisation rate: we have assumed units retire after they reach their technical lifetime (40 years), which is also the global average coal plant retirement age. Under current circumstances, there is a large uncertainty about the future utilisation rates of coal power plants in Japan.

The capacity factor of thermal power plants rose to 62% in 2012 (oil 42%, gas 68% and coal 78%) to make up for the reduced supply capability of nuclear power plants. However, it has been in decline since 2013 through improvements in energy savings and efficiency, as well as an increase in renewable energy, leading to a capacity factor of 53% in 2016 (oil 18%, gas 58% and coal 76%).

The Electricity Supply Plan by Organization for Cross-regional Coordination of Transmission Operators, Japan (OCCTO) in 2017 assumes that the capacity factor of coal-fired power plants will decline from 80% in 2015 to 69% in 2026. However, under more realistic assumptions about energy demand, coal capacity and renewable energy uptake, simulations by REI indicate that the capacity factor of coal-fired power plants may decline to 56% —significantly below the Electricity Supply Plan's estimated 69% (Okubo & Kitakaze, 2017).

Additional simulation by REI show that if most nuclear reactors that have applied for restart as of April 2017 remain closed, and nuclear energy is limited to 5% of electricity supply, the capacity factor of coal-fired plants could reach 62%. However, if electricity demand declines by about 5% due to energy efficiency improvements, the capacity factor of coal-fired plants may become 49%. To address the uncertainty around those assumptions we estimate emissions under three scenarios (see ANNEX V -

Estimating CO_2 emissions from coal plants for further details). The figures presented in the main body of this report correspond to our full expansion scenario, which assumes a moderately declining energy demand and is consistent with a capacity factor decreasing linearly from current levels (76% in 2016) to 56% in 2026.

The gap between emissions from coal power plants, national targets, and the Paris Agreement

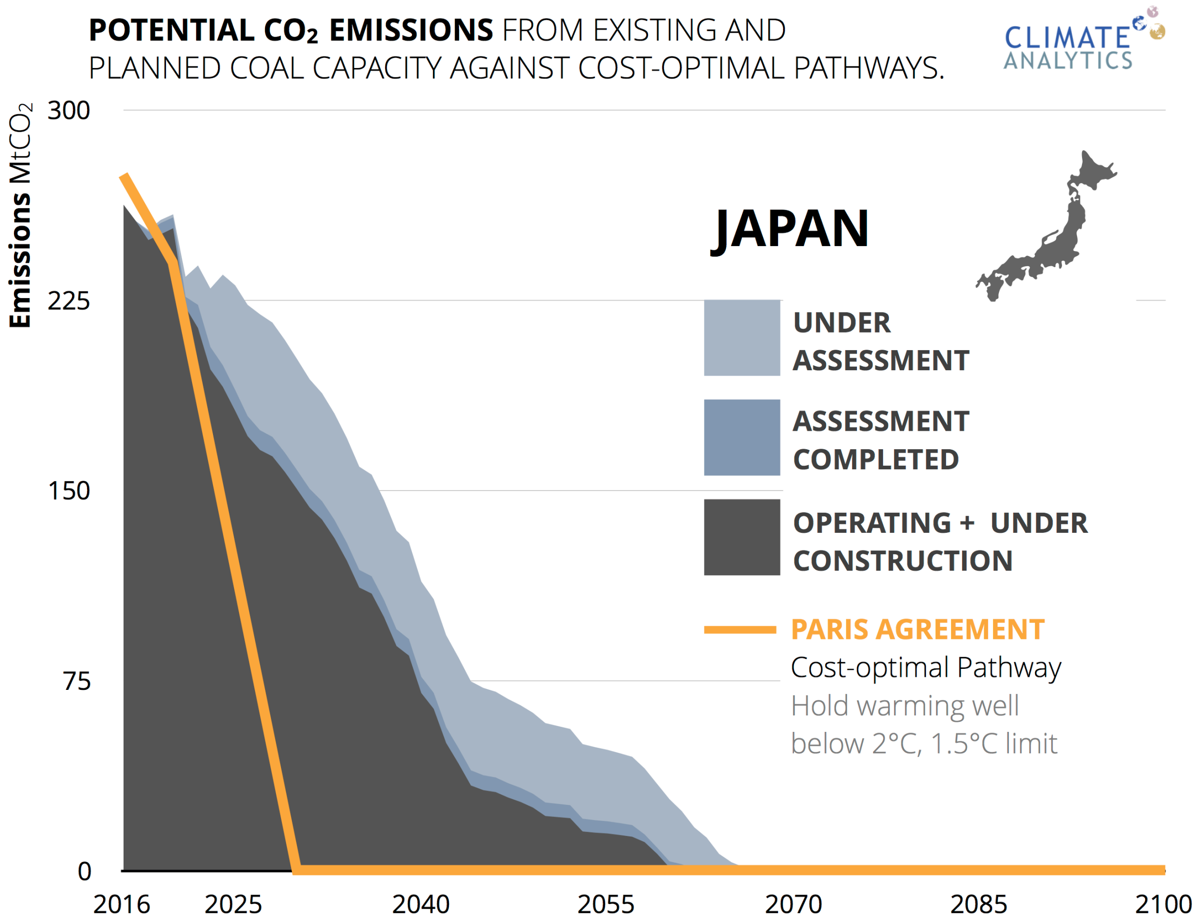

Figure 7 - Emissions from existing and planned coal-fired power plants compared with the coal emissions pathways in line with the Paris Agreement temperature goal. To calculate the cost-optimal regional/country level pathways from electricity generation from coal in line with the Paris Agreement's long-term temperature goal, we downscaled the aggregated coarse IAMs regions using Climate Analytics' SIAMESE model to derive the pathways for Japan.

As shown in Figure 7 even with no new coal power plants coming online, cumulative CO_2 emissions from current coal-fired electricity generation capacity would exceed the Paris Agreement compatible cost-optimal emissions budgets for the remainder of the century. This is also true for the alternative emissions scenarios where we have assumed varying utilisation rate (see ANNEX VI – Sensitivity analysis for further details). **In order to achieve the Paris Agreement's long-term temperature goal, our results show that Japan will need to implement early retirement of currently-operating coal-fired power plants and/or to reduce dramatically their utilisation rate**.

Moreover, opening any new power plants will only increase the difference between committed emissions and cost-optimal pathways consistent with the Paris Agreement.

In this study, we have taken into account the current uncertainty of what new capacity will come online in the future and have estimated two additional emissions scenarios:

- Moderate expansion scenario: assumes that only half of the projects currently under assessment and announced will come online, which is 6.5 GW out of 13 GW. Under this moderate scenario, capacity factors of operating plants will rise to 59.4% from our baseline scenario (52.6%) to make up for the plants that will not come online.
- Limited expansion scenario: assumes that only a quarter of the projects currently under assessment and announced will come online, which is 3.3 GW out of 13 GW. Under this limited expansion scenario, capacity factors of operating plants will rise to 63.2% from our baseline scenario (52.6%) to make up for the plants that will not come online.

The results of the three scenarios (baseline, moderate, limited expansion) are summarised in the table below, which shows cumulative emissions in between 2018 and 2050 in comparison with the Paris Agreement compatible budgets for coal for the same period:

Table 1 Summary of the three scenarios

Scenario	2018- 2050		2018-2100	
	Cumulative emissions ($MtCO_2$)	Share of PA coal budget	Cumulative emissions ($MtCO_2$)	Share of PA coal Budget
Full expansion	5 328	292%	5 843	320%
Moderate Expansion	4 904	269%	5 212	286%
Limited expansion	4 789	263%	5 017	275%

The main conclusion that can be derived from our alternative emissions scenarios is that while limiting the number of coal generation units coming online can reduce a certain amount of emissions, additional substantial measures will be needed to keep emissions in line with the Paris Agreement.

Firstly, if the cancellation of new units is replaced by a lifetime extension of currently operating units, the effect on emissions will be, at best, neutral. Also, the new capacity needs to be phased out after 5-10 years of operation to stay within the Paris Agreement budget, which will not be economically feasible, meaning that any new capacity will most likely increase the emissions gap and make mitigation of CO_2 emissions more expensive. Moreover, it is not always the case that new capacity is more efficient than currently operating capacity: as shown in Figure 8 of 43 proposed new coal units, five small-scale units are planned to be inefficient Subcritical Coal combustion technology and 13 additional similar scale units do not provide any information on technology, which are potential Subcritical.

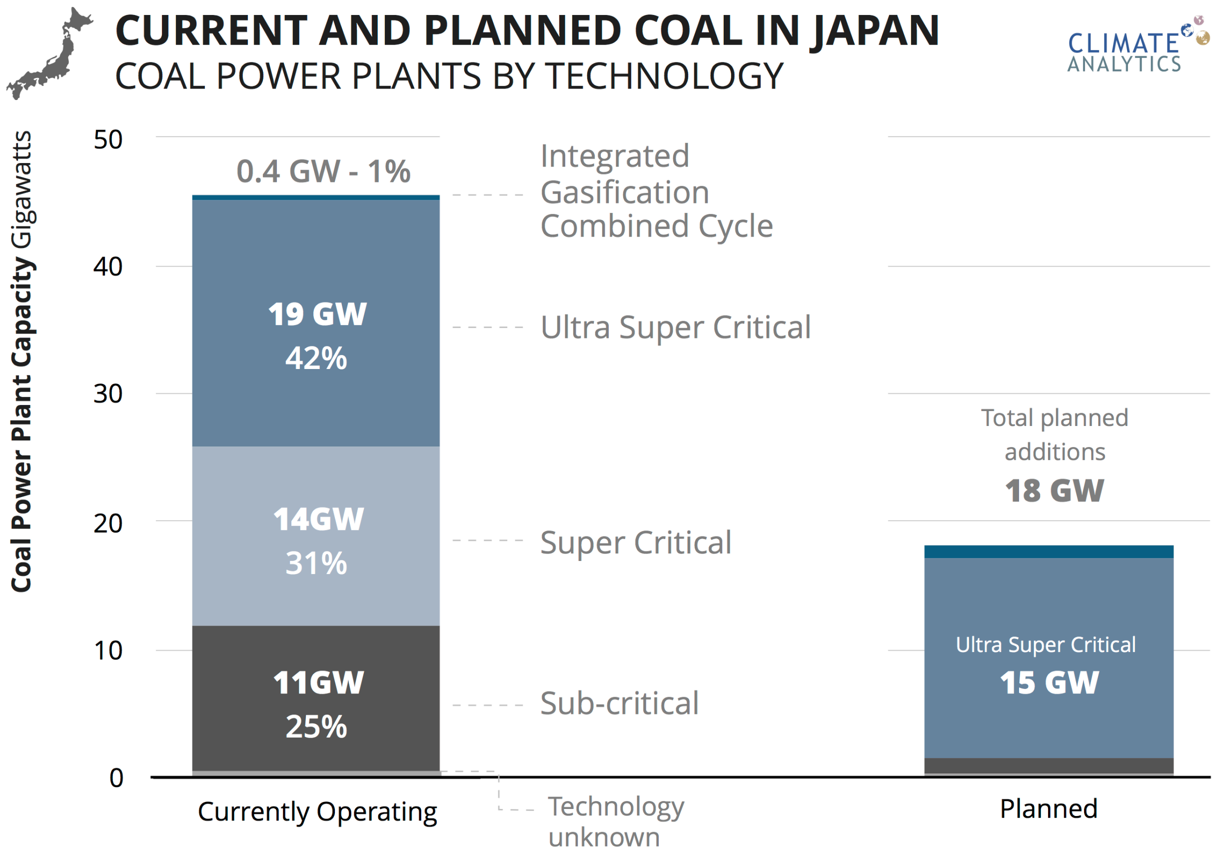

Figure 8 Operating coal-fired power by technologies

Secondly, even under a limited expansion of coal capacity, emissions reductions will depend on the utilisation rate of the remaining power units, which ultimately is determined by the availability of alternative power sources.

The following sections of the report will examine policy instruments in Japan, in light of the findings derived from the emissions scenarios presented in this report.

Adequacy of national targets

Japan's Nationally Determined Contribution (NDC) includes an emissions reduction target of 26% below 2013 levels by 2030, which is approximately 1 042 $MtCO_2eq$ in 2030 emissions (Government of Japan, 2015). Japan's NDC is enshrined in the Plan for Global Warming Countermeasures, mandated by the Global Warming Countermeasure Promotion Act (MOEJ, 2016), adopted by the Cabinet on 13 May, 2016. Japan ratified the Paris Agreement on 8 November 2016.

In parallel to developing its GHG target under the NDC, Japan developed the 2015 Long-Term Energy Demand and Supply Outlook (METI, 2015a), an energy strategy that forms an integral part of achieving this target. As shown in Table *2*, this strategy foresees that in 2030, 20–22% of electricity will be supplied by nuclear energy, 22–24% by renewable energy and the remaining 56% by fossil fuel sources, of which coal is expected to generate 26% of the power.

Table 2- Japan's electricity mix by fuel in 2030 under different scenarios

SHARES OF DIFFERENT FUELS IN ELECTRICITY MIX				
Fuel	2015	2030		
	Observed	Japan's Long-term Energy Outlook	World Energy Outlook 2017- Current Policy Scenario	Cost-optimal Paris Agreement electricity mix
Nuclear	1%	20–22%	17%	10%
Renewables*	16%	22–24%	22%	35%
Coal	33%	26%	32%	3%
Oil	10%	3%	3%	1%
Gas	40%	27%	25%	51%

** Includes Bioenergy.*

As shown in Table *2*, under current policy projections (as estimated by the International Energy Agency) Japan is still far from meeting its national targets for its electricity mix as outlined in the Long-Term Energy Demand and Supply Outlook when it comes to coal, which is expected to miss the target by over 6%.

Moreover, the share of coal generation under current policy projections of the World Energy Outlook assumes an underlying coal generation capacity of 53 GW in 2030. A comparison against actual planned coal developments depicted in Figure 2 shows that the Agency assumes no new coal beyond the power plants currently approved and under construction, which is more ambitious than our moderate and limited expansion scenarios. Should any of the planned coal plants currently under assessment be approved and built, either the national coal generation target will be missed by a larger difference, or the utilisation rate of all coal power plants will need to be reduced substantially, compromising the profitability of plant operators.

Moreover, when the national targets and current policies are compared against the results derived from the Paris Agreement-compatible pathway for Japan, it is clear that the 2030 targets are not yet aligned with a cost-optimal strategy to limit warming to well below 2°C, as they allow for a continuation in the use of coal beyond 2030 and have a very conservative renewable energy target. This shows there is also an ambition gap in the nationally determined targets for electricity generation.

These conclusions have been confirmed by independent assessments of Japan's NDC 2030 reduction target and current policy projections, which have found the target and current policy developments to be inconsistent with holding warming to below 2°C, let alone limiting it to 1.5°C as required under the Paris Agreement, but are instead consistent with warming between 3°C and 4°C (Climate Action Tracker, 2017b). Regarding the unabated coal-fired power share for 2030 under the NDC (26%), independent assessments have also confirmed that it is close to the upper end of the value ranges observed for all the modelling exercises for GHG emissions (Kuramochi, 2015).

In accordance with Article 4 of the Paris Agreement, all Parties should strive to formulate and communicate long-term low greenhouse gas emissions development strategies. In this context, in its Plan for Global Warming Countermeasures, Japan set a GHG emissions reduction target of 80% below current levels by 2050 (MOEJ, 2016). Independent assessments have found that Japan's long term target is consistent with warming between 2°C and 3°C and could only be consistent with keeping warming below 2°C if other countries make much deeper reductions and comparably greater effort (Climate Action Tracker, 2017b).

Beyond 2030, results from the scenario analysis by Climate Analytics show that, like coal, other unabated fossil fuels (i.e. oil and gas without carbon capture and storage) will also need to decrease rapidly in Japan's electricity mix, while renewable energy sources will need to be phased in quickly. Moreover, energy-economy scenarios reflect cost-optimal strategies based on current technology cost, which means that if renewable energy and storage prices keep dropping at current rates, the future share of renewables resulting from these models could be underestimated while the share of natural gas could be overestimated. This means that the share renewables in 2030 could be even higher than the result of this analysis shown in Table *2*.

In summary, current plans for coal generation capacity in Japan are inconsistent, not only with a Paris Agreement compatible cost-optimal strategy, but also with its own nationally determined targets for electricity generation. This means that in order to honour its commitments under the Paris Agreement, Japan will need to reverse its current trend of expanding coal-fired generation capacity and instead urgently implement policies to enable a quick coal phase-out from the electricity mix. It 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.

3 IMPLICATIONS OF OUR ANALYSIS TO BUSINESSES AND POLICYMAKERS IN JAPAN

The results of our analysis have tremendous implications for government, developers and for investors in Japan's planned and existing coal-fired power generation.

The primary reason for the significant number of planned new and additional coal capacity is the 2011 Fukushima nuclear accident, which resulted in the shutdown of all nuclear power, which had supplied about 30% of the electricity at that time. In addition, foreseeing the full electricity retail market liberalisation that began in 2016, and the upcoming abolishment of regulated retail tariffs from 2020, incumbent utilities and newcomers to the market have tried to secure their supply from cheap energy sources (Okubo & Kitakaze, 2017). And in the absence of an effective carbon pricing system - currently set at about USD $2–3 per t$CO_2$, coal is still regarded as a cheap energy source in Japan, not taking into account its high environmental cost. The government is also supporting efficient coal as an important "base-load power" and there are no binding measures for the energy sector to reduce its greenhouse gas emissions.

However, our analysis shows that the policy and investment in energy projects cannot remain the same for Japan after the Paris Agreement's coming into force. The Implications of the analysis result to policymakers, coal-fired power owners and investors, and energy consumers will be discussed below.

3.1 COAL POLICIES AND IMPLICATIONS FOR POLICYMAKERS IN JAPAN

Japan's coal fired power plant regulations are developed based on the Long-term Energy Supply and Demand Outlook which foresees 56% of the electricity in 2030 will come from fossil fuels: coal 26%, gas 27% and oil 3%.

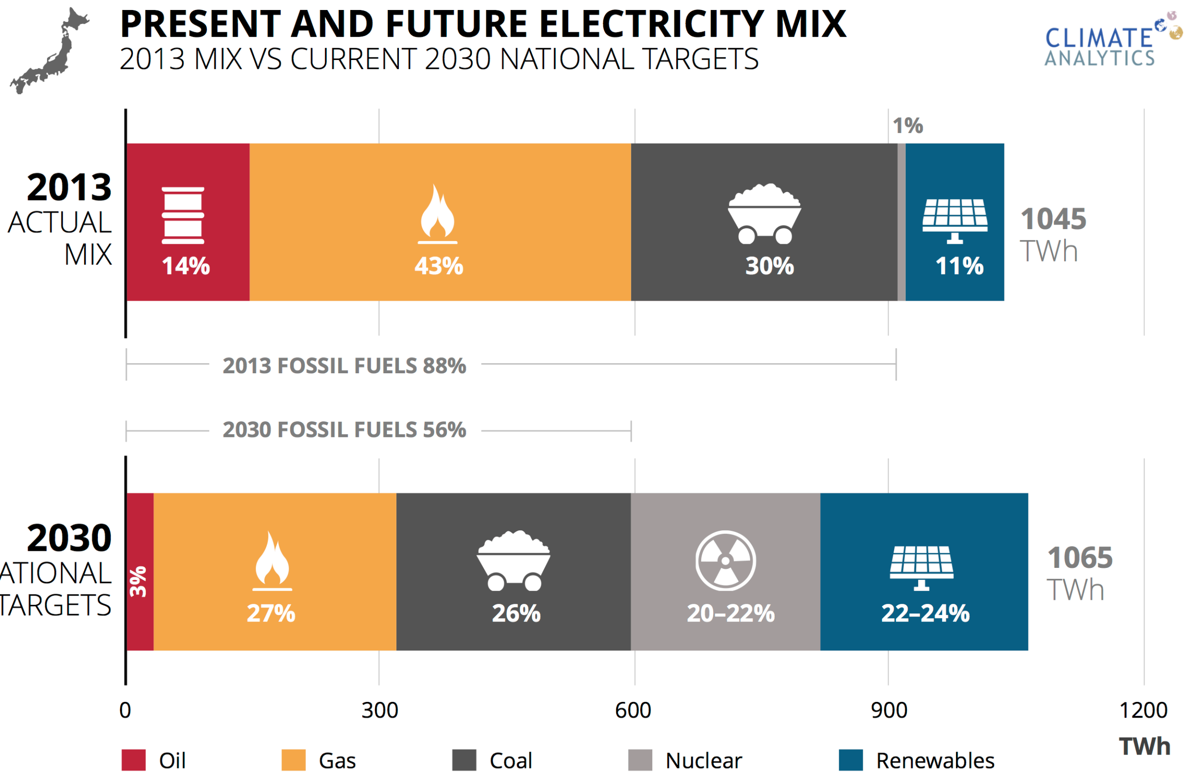

Figure 9 Electricity mix in 2013 and 2030 target

The Outlook assumes the efficiency of thermal power will be of the highest-efficiency, which means Ultra Super Critical (USC) level (METI, 2015a) - and coal is encouraged to achieve 42% (High Heating Value – or HHV) under the Energy Efficiency Law, which is merely a benchmark recommendation(METI, 2017).

Another requirement is that retailers need to make the non-fossil power supply ratio equal to 44% or more, the same as in the 2030 energy mix. In addition to these requirements, power producers derived their own voluntary target to achieve emissions factor of 0.37 kg-CO_2/kWh based on the given 2030 energy mix (FEPC, 2015).

There are several problems and loopholes in these regulations and standards, but most importantly, there are currently no policies that can stop new capacity additions. There are no binding reduction targets for the energy sector, nor an effective compliance system. The policies instead give incentives to build new, energy-efficient coal power plants. Our analysis has made it clear, however, that even if all the new capacity were to be replaced, that in itself is not only not enough in terms of climate protection, but it also sends the wrong signal to risk developer's sound business.

If Japan is to implement policies based on its global agreement, and if it proceeds with its plan, it needs to either run its coal-fired capacity at a very low level, or stop it before it reaches a point of making a profit.

The Fukushima nuclear disaster demonstrated that nuclear is expensive and unreliable as climate neutral electricity source and has many additional problems such as the disposal of nuclear fuel. These risks should be evaluated when considering the decarbonisation of the electricity sector. Instead, renewable energy share in the energy mix can be increased even more than the cost-optimal pathway result shown in Table *2* as cost of renewable continues to decline. Even in Japan, the cost of solar halved in the last 5 years and wind is becoming below JPY14/kWh. Many jurisdictions have 40-50% target for 2030. Given the need for significant emissions reductions, there needs to be a substantial change in climate and energy policy to be in line with the global goal Japan has committed to under the Paris Agreement.

An effective policy tool to send a signal, which has been considered by the Ministry of Environment (MoE), is **carbon pricing.** In March 2018, the MoE put together a report from the Carbon Pricing Consideration Committee discussion, which had been established a year ago (MoE, 2018). Although no concrete proposal is yet on the table, the most important point of the report is that it shows carbon pricing can be implemented in a way that is consistent with economic growth.

The Japanese business federation has been opposing carbon pricing, insisting that this will harm Japan's economic development. However, the report - with its almost 300 pages of supporting documents - tries to address most of those concerns. For example, the UK, Sweden, Germany, France and Switzerland, where higher carbon pricing has been introduced, achieved bigger economic growth than Japan during the first commitment period of the Kyoto Protocol.

Carbon pricing would induce capital investments and could lead to an increase in energy and carbon productivity of the economy as has happened in many other countries. The summary concludes that it will not be possible to realise zero carbon in the second half of the century with an extension of the existing measures, but carbon pricing can set a common direction and smoothly guide society towards decarbonisation. According to the Ministry of Finance business statistics, Japanese firms are increasing their cash holdings and manufacturing equipment is becoming old and requires renewal, imposing a clear signal that a low-carbon development may lead to an expansion of investment in the entire economy.

Table 3 Emissions performance standard of coal-fired power station

Country	Policy / Source	New capacity emissions limit	Existing capacity emissions limit
Canada	Pan-Canadian Framework on Clean Growth and Climate Change	420 gCO_2/kWh	Same as new capacity by end of 2029 (in consideration)
UK	Emissions Performance Standard: EPS	450 gCO_2/kWh	Same as new capacity by 1st Oct 2025
US	Clean Power Plan (proposed to be repealed)	635 gCO_2/kWh (1 400 $lbCO_2$/MWh)	Require states to reduce their 2005 emissions levels by 30% by 2030. Each state to produce its own guideline, which will be reviewed.

Source Compiled by REI from policies and measures from each country

Another direct measure and effective policy signal is to set a strict **emissions standard** as implemented in several other countries. The UK government set the Emissions Performance Standard (EPS) in 2013 which sets the maximum new power plant CO_2 emissions at 450 gCO_2/kWh, which is not possible to achieve with even the most efficient coal technology (USC) currently deployed, nor with

IGCC, and which made new construction uneconomic. The US and Canada introduced similar policies, setting a standard of about 635gCO_2/kWh and 420 gCO_2/kWh respectively for new coal capacity (Table 3).

After setting the standard for the new capacity, governments are now moving to address the existing plants. In January 2018, the UK government decided to apply an emissions performance standard for the existing coal-fired power generation by 1 October 2025, its deadline for a coal phase-out. The date has been chosen to align with the capacity market, so that the unabated coal-fired generators will not participate in bidding. The government had been considering whether to set mandatory CCS for existing power stations or alternatively to apply the emissions limit. It chose the latter policy, based on its response to consultation (Department for Business Energy & Industrial Strategy, 2018), stating that CCS technology development is too far away, and "our assessment concurs with many of the responses to the consultation that suggest the likely relative cost of retro-fitting full-chain CCS on relatively inefficient and aged power stations will be prohibitive without significant support". It should be also noted that with declining cost of renewables, CCS is becoming less and less attractive, as it increases the cost and decreases efficiency.

Canada is considering adopting the same regulation for its existing coal capacity so that all units meet a stringent performance standard by 31 December 2029. The government estimates in its Regulatory Impact Analysis Statement that it will not only significantly reduce CO_2 emissions but also bring environmental benefits. "Over the period of 2019 to 2055, estimated environmental benefits from avoided climate change damage and improved health outcomes are $4.9 billion. Total industry costs from the proposed amendments are estimated at $2.2 billion, producing net benefits of $2.7 billion over the same period"(Canada, 2018).

Similar regulations, related to air quality, can be equally effective to incentivise the closure of coal-fired power plants. For instance, it has been estimated that the "Best Available Technique" (BAT) standards for Large Combustion Plants adopted in 2017 by the European Commission are currently exceeded by 82% of EU coal-fired power plants and that the combined cost to upgrade them by 2021 amounts to 7.9 -14.5 EUR billion (DNV GL-Energy, 2016) .

In the US, while the Trump Administration has proposed repealing the Clean Power Plan, the Mercury and Air Toxics Standards (MATS), which requires significant reduction of these emissions and encourages a fuel shift as well as closing old coal power plants, remains active. MATS has also faced challenges after the US Supreme Court ordered the Environmental Protection Agency (EPA) to provide an additional assessment of its costs, but the EPA has concluded that it is wholly reasonable in light of the standards' massive health benefits. It estimated that it will prevent up to 11,000 premature deaths and more than 100,000 asthma and heart attacks each year (US EPA, 2016).

As these cases demonstrate, governments are not only phasing out coal for climate reasons alone, they also recognise the additional benefits this will bring, including clean air and health improvements. Such benefits have been officially investigated, quantitatively assessed and compared to the cost of phasing out coal. In the Japanese context, it could be a constructive step to make the costs and benefits of a coal phase-out process clear when starting a public discussion.

3.2 IMPLICATIONS FOR COAL-FIRED POWER STATION OWNERS AND INVESTORS

The results of this analysis show a significant policy risk for new coal-fired power developers if Japan is sincere about meeting its global climate commitments. Figure 10 shows the owners and investors by share of their involvement in new coal-fired power plant plans. The top investors are J-Power and incumbent utilities, which have been the regional monopolies. These utilities are dominant not only for existing coal capacity but plan to increase coal in the future. In addition, trading houses such as Mitsubishi and Marubeni, as well as gas, steel and paper companies, are joining the competition in the course of market liberalisation.

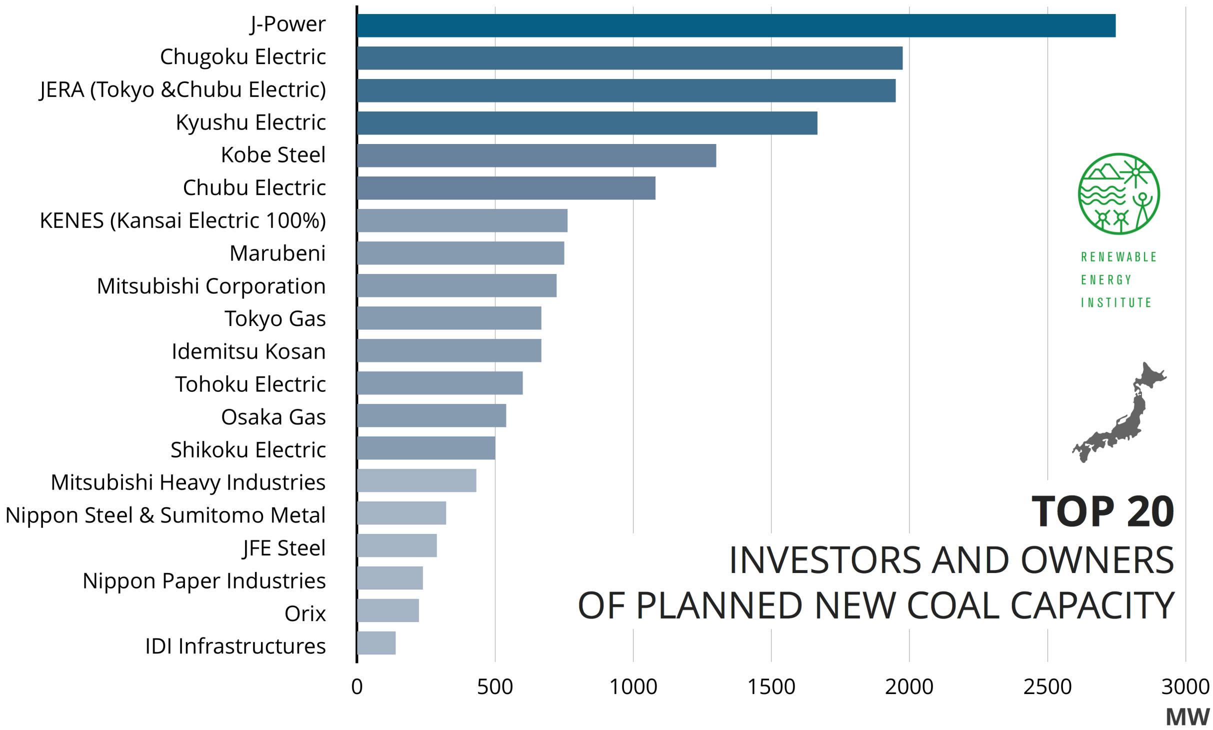

Figure 10 Capacity of new coal-fired power generations by investors and owners Source: REI-Climate Analytics database (version Feb 2018) Note: For this figure, the capacity is divided by the share of involvement of investors in the project and aggregated at the investor level.

In addition to the policy risks, there is a reputational risk for investors that their investment is not in line with the global climate goal, which is of growing concern not only for many institutional investors around the world, but also some Japanese companies. Many of the top electricity capacity investors such as J-Power, Chugoku Electric, Kyushu Electric, Tohoku Electric and Shikoku Electric, but also Hokkaido-, Hokuriku-, Okinawa-Electric are already affected by global institutional investors' divestment activities. According to the Japan Exchange Group (JPX, 2017), 30% of the share of the 3636 listed companies in Japan is owned by foreign investors, who are much more sensitive on this issue. Among the top 30 foreign investors of listed companies in Japan, many investors such as Black Rock, Baillie Gifford, Vanguard Group, Norges Bank Investment Management, UBS Asset Management, Axa Investment Managers are becoming more sensitive about how climate related risk affects the business and some already started to divest from companies which rely their business on coal.

Two of the world largest insurance companies, AXA and Allianz, have announced divestment from companies depending on coal for more than 30% of their business or planning to build more than 500 MW of new coal power capacity. Since 2017, AXA, Zurich, SCOR and Allianz have decided to stop insuring new coal projects, and Swiss Re has announced that it will adopt such a policy soon. So far 16 insurers have divested an estimated $22 billion from coal companies (Urgewald, 2018). These announcements cover companies listed in the "Global Coal Exit List" (GCEL), was developed by the German NGO Urgewald, which identifies the companies that are planning new coal projects and provides key statistics on 775 companies to enable financial institutions to assess the 'coal content' of their portfolios. According to this database there are a number of Japanese companies that are at risk of this divestment strategy. These include the entities listed in Figure 10, as well as the Sumitomo Corporation, Ube Industries, Hokuriku-, Hokkaido-, Kansai-, Kyushu-, Okinawa-, Tohoku-Electric Power, TEPCO, Mitsui Matsushima and others.

Another implication of this analysis is that the share of other electricity sources must increase. From the current energy supply and demand trend, it seems that developers have underestimated in their plans the energy demand, renewable energy development and the global climate negotiations. Japan's electricity demand decreased by around 10% in just five years from 2010 and the renewables' share increased to 15% in 2016 (Okubo & Kitakaze, 2017). Because of this trend, thermal power plants are already finding less space to operate.

Even if investors may not see any policy risks at the moment, the drastic cost decline of renewables is most likely to affect their business. In terms of the levelised cost of electricity (LCOE), renewable energy sources are cost competitive with fossil fuel and nuclear power in many parts of the world, and Japan will not be an exception. The speed of the cost decline will be drastic for solar. BNEF estimates that a new utility scale solar PV will be cheaper than combined cycle gas turbines in less than five years and cheaper than coal in 2024. The best new onshore wind projects will be cost competitive with new coal before 2030 (Figure *11*). If carbon pricing is introduced, the cost competitiveness could be achieved much earlier.

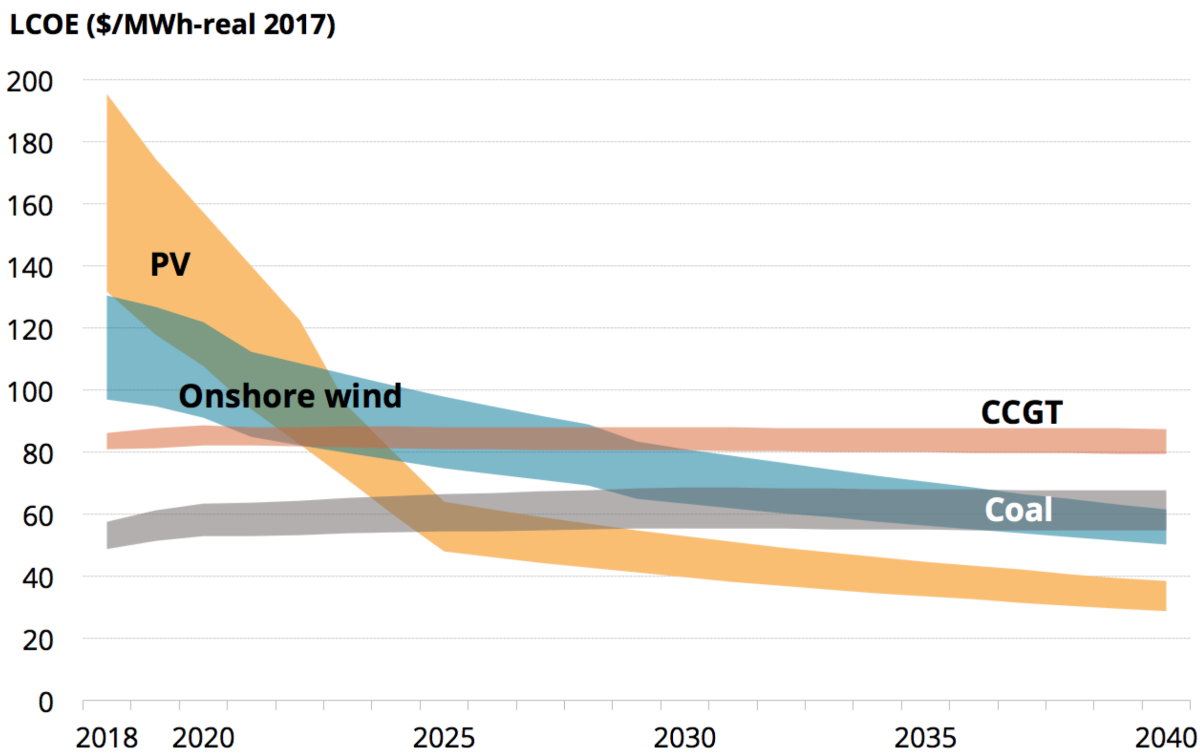

Figure 11 1H 2018 LCOE Forecast 2018-2040, Japan- Utility scale PV and Onshore Wind vs Coal Source: Bloomberg New Energy Finance

As most of the new planned coal capacity will start operating after 2020, the question arises as to whether it can compete with renewables, which can operate without fuel costs, when the LCOE for these sources is expected to fall continuously. There is a significant business risk if owners and investors are estimating their economic feasibility with a 70% capacity factor and a 40-year operational lifetime (METI, 2015b) in their business plans - based on their past experience and cost calculations done by METI.

In their 2050 outlook, the Japan Photovoltaic Energy Association (JPEA) set the installed and operational cumulative solar goal as much as 100 GW in 2030 and 200 GW by 2050 to achieve an 80% emissions reduction by 2050 and it expects solar will be a major energy source in Japan (JPEA, 2017). In its 2050 vision, the Japan Wind Power Association (JWPA) expects that wind power capacity will be more than 75 GW and will supply 20% of Japan's electricity by 2050 (JWPA, n.d.).

Stakeholders that own existing coal plants and those developing a new coal capacity need strategies to diversify their activities away from coal. Incumbent utilities could benefit from a new business model to be profitable and survive as we move to a decarbonised future. Here, utilities can learn from the experience in Europe and avoid their risks. European power companies, which have painfully underestimated the development of renewables, and were slow to address energy transition and electricity system reform, are now transforming their business to cleaner sources, strengthening energy networks and customer optimisations (Zissler, 2017).

3.3 IMPLICATIONS FOR ENERGY CONSUMERS

The implications of this analysis are not only relevant for coal project developers, investors, and policymakers. Japanese companies are increasingly committing to international initiatives such as RE100 and Science Based Target (SBT) (Table 4). The SBT aims to provide businesses with a sector-specific and research-backed method to set their emissions goals in line with the Paris Agreement. This initiative is based on the 2°C scenario developed by the International Energy Agency (IEA). As of 13 April 2018, out of 380 corporates committed to SBT, 15 Japanese companies from different business sectors such as Daiichi Sankyo, Fujifilm, Kirin Holdings, Sony, Marui Group, Panasonic, Dentsu, and Lixil were approved by SBT, and 42 additional companies are waiting their approval. In March 2018, the MoE set their own targets to support 100 corporates to gain SBT approval by FY 2020 and 50 corporates joining RE100 during the same period (MoEJ, 2018).

For these companies, the increase of coal-fired power generation beyond the Paris Agreement goal will not be in line with their own commitments. Moreover, Japanese corporations are at risk of losing global competitiveness because of the slow domestic deployment of renewables and the increased emissions from coal-fired power plants. Companies joining RE100, such as Apple, are asking their supply chain to reduce its emissions and increase its share of renewables. More than 100 Japanese factories in Apple's supply chain are required to set emissions reduction targets and are encouraged to improve energy efficiency and procure renewable energy. These are companies such as Alps Electric Co., Ltd, Asahi Glass Co., Ltd, Japan Aviation Electronics Industry Ltd., Kyocera Group, Murata Manufacturing Co., Ltd,Panasonic Corp,Rohm Co., Ltd, Sharp, Sumitomo Chemical Co., Ltd., and Toray. In 2017, Apple conducted 756 audits, and suppliers have pressure to achieve high performance as they are evaluated.

An increasing number of investors -such as, for example, such as Climate Action+ 100, are asking for climate-related risk disclosure from their investing corporates. In April 2018, the Renewable Energy Users Network (RE-Users) established itself in Japan based on the company's increased demand of renewables. While there are not yet any Japanese members in the "Powering Past Coal Alliance," this is a signal from the electricity users' side that they would like to shift away from fossil fuelled electricity. The developers of new electricity capacity will need to consider these trends in proceeding with their plans.

Table 4 Global initiatives and its Japanese members - as of 13th April 2018

Initiatives	Content	Participants	Nr. Of Japanese corporates	Companies involved
SBT	To set emissions reduction target in line with the level of decarbonisation required to keep global temperature increase below 2˚C compared to pre- industrial temperatures, as described in the IPCC Report	380	15 approved (42 waiting for approval)	Daiichi Sankyo Co., Ltd,Dentsu Inc, FUJIFILM Holdings Corporation, Fujitsu Limited,Kawasaki Kisen Kaisha, Ltd., Kirin Holdings Co Ltd,Komatsu Ltd, Konica Minolta, Inc., LIXIL Group Corporation, MARUI GROUP CO., LTD,Nabtesco Corporation, Panasonic Corporation, Ricoh Co., Ltd., Sony Corporation, TODA Corporation
RE100	Commitment to go 100% renewable	131	6	Aeon, Askul, Daiwa House, Ricoh, Sekisui House, Watami,
EV100	Committed to accelerate the transition to EVs	18	2	Askul Aeon
Climate Action +100	Investor initiative to engage with the world's largest corporate greenhouse gas emitters to curb emissions and strengthen climate-related financial disclosures	256 (USD $28 trillion in assets)	1	Sumitomo Mitsui Trust Bank
Powering Past Coal Alliance	Committed to moving the world from burning coal to cleaner power sources	28 Countries 8 Sub-national 28 Business	0	

Source Compiled by REI from each initiatives' information

4 COAL PHASE-OUT POLICIES

In previous sections we have demonstrated that current plans for coal-fired generation capacity in Japan are inconsistent with both a cost-optimal strategy for limiting global warming to 1.5°C by 2100, and the medium and long-term national emissions reductions plans the country has set for itself. In this section, we discuss a number of policy options and instruments currently under discussion or implemented around the globe that could be used to align energy planning with national emissions reduction commitments in Japan.

Policies leading to an effective coal phase-out can be broadly divided into two types: market-based policy instruments - such as taxes and subsidies - and regulatory approaches, such as standards, bans and quotas. Each jurisdiction has different needs and priorities in terms of coal phase-out, depending, for instance, on the importance of coal in its energy mix, the scale of planned expansion, or the amount of resources and reserves of this fuel. There is not a one-size-fits-all policy instrument to achieve a coal phase-out. A combination of different market and non-market policy instruments might be necessary to achieve a fast, effective, and socially accepted coal phase-out.

Governments have multiple options for enabling and speeding up a coal phase-out through market instruments, including the removal of coal subsidies, the enforcement of taxes on local air pollution, and the use of a carbon price to internalise the climate change impacts of burning coal (Steckel et al., 2017). Taxes on local air pollution as well as a carbon price strongly discourages the use of coal in the electricity mix, as it is the most emissions-intensive fossil fuel and coal-based power generation is responsible of a high share of local air pollution (International Energy Agency (IEA), 2016; Parry, Heine, Lis, & Li, 2014; Peng, Yang, Wagner, & Mauzerall, 2017; Steckel et al., 2017)

As of 2016, about 40 national jurisdictions and over 20 subnational jurisdictions (cities, states, and regions), covering 13% of global greenhouse gas emissions and including seven out of the world's ten largest economies, had carbon pricing schemes, including emissions trading and carbon taxes in place (World Bank and Ecofys, 2016). The list of jurisdictions implementing carbon pricing is increasing steadily including some major economies. China is starting to implement carbon pricing, and Brazil is currently in the planning phase of their national scheme.

However, carbon prices observed in implemented schemes are typically much lower than the social cost of carbon[5] and too low to have a meaningful impact on coal plants (Carbon Pricing Leadership Coallition (CPLC), 2017). They would need to be increased significantly in the short term and to prohibitive levels for coal-fired power plants over the remainder of the century (Pearce, 1991).
Carbon pricing has already proved to be an effective policy to discourage the use of coal and a price increase could provide the right economic incentives for a quick coal phase-out. The United Kingdom is an excellent example of the effects of high carbon prices on coal generation: a minimum price introduced in addition to the EU's carbon trading mechanism has led to a carbon price increase and a substantial reduction in the share of coal in power generation from close to 40% in 2012 to 7% in 2017 (Agora Energiewende and Sandbag, 2017). The Netherlands' phase-out is another case for carbon pricing: by cancelling allowances and incorporating a supplementary carbon price, the government has avoided paying compensation to asset owners until now (Gray & Watson, 2017), although the details of the policy are still under discussion and future compensation has not been discarded.

In the absence of adequate economic incentives as a result of market-based instruments, additional policy measures are needed to reduce lifetimes and capacity factor of current coal capacity and prevent the construction of additional capacity.

Taxes on local air pollution or air quality legislation could make the operation of coal-fired power plants increasingly expensive and indirectly reduce coal power plants' lifetimes. These policies have also been implemented in many jurisdictions and have played an important role in the retirement of many coal power generation units. For instance, analysis shows that the new air quality standards introduced in the framework of the Industrial Emissions Directive in the European Union would require modernisation or shut down of 82% of the coal power units in the EU (DNV GL-Energy, 2016).

While stringent emissions standards will likely lead to decommissioning multiple coal plants, this policy could have some unintended consequences for emissions mitigation if companies decide to

5 The social cost of carbon is quantification in monetary terms of the costs and benefits of emitting one additional ton of CO_2, that can be used to weigh the benefits of and costs of reducing emissions.

invest in retrofitting existing non-compliant coal plants (e.g. by installing new filters). This would result either in a prolongation of the lifetime of the power plant and strengthening of the path dependency in the power sector, or in increased stranded assets and overall cost of climate policy implementation (Erickson, Kartha, Lazarus, & Tempest, 2015).

Another important policy development that has pushed out coal of the market is increasing renewable power generation due to a dramatic reduction of costs. Many renewable energy technologies are already cost-competitive with fossil fuels (Lazard, 2017) and, in the long, term investing in renewable energy is the least risky option, from a political, economic, legal, social and ecological perspective (Bos & Gupta, 2017).

However, renewable energy technologies can still be perceived as risky by some investors. Therefore, to incentivise the deployment of renewable energy, policy instruments for de-risking clean investment, as well as additional investments in improved grid infrastructure and storage facilities need to be scaled-up (Steckel et al., 2017; Steckel, Edenhofer, & Jakob, 2015; Steckel, Jakob, Marschinski, & Luderer, 2011).

Renewable energy deployment as well as coal phase-out bring huge development co-benefits, ranging from health benefits (e.g. related to air quality and noise control, etc.) to economic benefits (e.g. energy independency, stability in balance of payments, reduced dependency on commodities, etc.) (Bollen, Guay, & Corfee-Morlot, 2009; Fay et al., 2015; International Energy Agency (IEA), 2016; Lott, Pye, & Dodds, 2017; Murata et al., 2016; Peng et al., 2017; Steckel et al., 2017). The communication of those co-benefits, as well as of avoided climate impacts through ambitious climate action can also play an important role in shaping energy planning and climate policy.

Finally, a regulatory approach that directly tackles coal phase-out, known as planned phase-out by regulation, can reduce the lifetime of coal plants while providing stakeholders with certainty to ensure a smooth transition to alternative power sources in countries and regions where coal plays an important role. By discouraging new coal investments this measure also reduces the risk of stranded assets. An increasing number of jurisdictions, including many European countries, states like California and New York, and cities like Beijing and Delhi, have already announced phase-out dates or created specific national regulations to achieve this goal (Greenpeace, 2017).

The following table summarises some examples of national commitments as of December 2017:

Table 5- Examples of national coal phase-out plans globally

Country	Coal phase-out date	Coal phase-out status
Austria	2025	The companies operating Austria's last two coal plants will phase out coal by 2018 and 2025, respectively. Austria is a signatory to the Powering Past Coal Alliance[6].
Finland	2030	A legal ban would make Finland the first country in the world to enshrine its 2030 coal phase-out decision in national law: In August 2017, the Finnish Government announced that it will put forward such a coal phase-out law in 2018. Finland is a signatory to the Powering Past Coal Alliance.
France	2021	France had committed to a coal phase-out by 2023 under the previous administration. President Macron has reconfirmed this commitment, bringing it forward to 2021. France is a signatory to the Powering Past Coal Alliance.
Italy	2025	In October 2017, the Italian government announced a coal phase-out by 2025 as part of the National Energy Strategy, signed in November. Italy is a signatory to the Powering Past Coal Alliance.
Netherlands	2030	In October 2017, the incoming Dutch government announced a full shutdown of coal-fired power plants by 2030. Three of the remaining plants have only recently been completed, meaning that they will operate for less than half of their expected lifetimes. Netherlands is a signatory to the Powering Past Coal Alliance.
United Kingdom	2025	The UK was the first country in the world to announce a coal phase-out policy in 2015. Its coal capacity is already halved from around 30 GW in 2010. Only five years ago, coal was generating more than 40% of the UK's power, it has come down to 7% in 2017.The UK, together with Canada is the initiator of the Powering Past Coal Alliance.

Source: Own elaboration based on information from the Beyond Coal Europe campaign (Beyond Coal, 2017).

Lastly, even with a high carbon price and regulatory policy measures for coal phase-out in place, additional policies are needed to ensure a smooth transition while avoiding a disruptive transition both in terms of the phasing in of alternatives (e.g. support for developing infrastructure and integration of variable renewable energy) as well as regarding regional structural change in regions, which rely heavily on coal mining and/or power stations for employment (Australian Council of Trade Unions, n.d.; *Energiewende: Lessons from Germany's Just Transition from Coal | Delta Institute*, n.d.; Steckel et al., 2017; The Stanley Foundation, 2017; Wiseman, Campbell, & Green, 2017).

Some of the stakeholders, including coal sector workers and coal owners and operators can be negatively impacted by a coal phase-out and in certain jurisdictions may have the power to veto proposed reforms. Therefore, managing the impact on workers, coal owners, industry and energy users, as well as communicating the benefits and co-benefits of coal phase-out can increase the success and political acceptability of coal phase-out policies and instruments (Steckel et al., 2017).

A review of international policies for coal phase-out leads to the conclusion that there is not a one-size-fits-all policy instrument to achieve coal phase-out but rather a combination of market and non-market policy instruments might be necessary to achieve a fast, effective, and socially

[6] The Powering Past Coal Alliance was launched on 16 November 2017, an alliance committed to shift the world energy from coal to cleaner power sources (Powering past coal Alliance, 2017). As of 27 April 2018, 28 countries, 8 sub-national governments and 28 businesses and organisations had joined the alliance. Here, government partners commit to phasing out existing traditional coal power and placing a moratorium on any new traditional coal power stations without operational carbon capture and storage, and business and other non-government partners commit to powering their operations without coal.

accepted coal phase-out. Increasing efficiency of each of these policies should be part of a broader framework for tackling emissions from coal-fired power plants and coal phase-out in line with the Paris Agreement temperature and emissions goals. But such a framework requires a clear strategy that includes a timeline for coal phase-out and the role of different policies in replacing coal by other sources of energy.

CONCLUSION

The Paris Agreement sets a clear pathway for coal-fired power plants to be phased out in Japan mostly by 2030. By no later than 2050, coal needs to be completely phased out all globally. The discussion should now not be on whether to allow new coal capacity but on how to phase out coal-fired power plants.

Our analysis shows that Japan needs to address not only the new 43 planned coal-fired power plants, but the existing coal capacity also needs to be addressed. A drastic change in Japan's energy sources is needed in a relatively short time period. Neither an efficiency standard of 42% for coal-fired power plants nor voluntary action with an emissions factor of 0.37 kg-CO_2/kWh will bring emissions anywhere close to achieving the reductions required under the Paris Agreement.

Phasing out most of the coal generators which supply about 30% of Japan's electricity now in less than 15 years may seem an unachievable goal at first. It surely requires a fundamental change to its power systems, which rely heavily on imported fossil fuels. However, changes can happen very fast and drastically, as it is in the case of UK, which has reduced its electricity share from coal from 40% to 7% in just five years.

Although not foreseen, Japan itself has experienced a drastic reduction of a particular energy source when all nuclear reactors - which had supplied 30% of its total electricity - had to shut down. For coal, Japan can plan ahead for 2030 and conduct a detailed analysis on cost of transition and its benefits, and consider standards for a phase-out - such as facility lifetime, efficiency, emissions of pollutants, distance to district residence, profitability - and come up with a cost-effective phase-out schedule.

While considering costs, it is also important to consider the additional benefits of phasing out coal through avoided air pollution and its health impacts, energy independency, lower costs and increased employment Cases in the US, Canada and UK, show how such calculations and assessments have been implemented to move the coal phase-out discussion forward.

According to the IEA and the International Renewable Energy Agency (IRENA), the global transition to a decarbonised energy sector is likely to not only help prevent dangerous climate change, but is also likely to yield economic benefits of up to $10 trillion every year by 2050 and a boost to the world GDP of $19 trillion (IEA &IRENA, 2017).

The deployment of renewable energy will benefit all energy customers as energy costs, and energy prices will continually drop whereas for coal such cost reductions cannot be expected. It is time to prepare for an era where renewable energy will provide the lowest cost energy and become the dominant energy source in Japan.

Most of the countries which have set a phase-out timeline have set it between 2020-2030, which is in line with Paris Agreement benchmarks for the power sector and highlights the urgency of starting national debates around this issue in other countries. Starting the phase-out discussion as early as possible will also benefit the coal-related businesses, workers, owners and investors to make a sound and just transition. It is much easier to regulate new coal power units before they get constructed. One aspect that makes the transition away from coal easier in Japan when compared to some other countries is that Japan has no large-scale coal mining. Currently, many of those with a coal mining industry are imposing much higher carbon pricing systems as well as CO_2 emissions standards than in Japan.

Most of Japan's new proposed 43 coal-fired power plants are in the Environmental Impact Assessment process before securing funds to operate after 2020. The right policy signals now can still prevent developers from investing in these projects and prevent Japan going completely off a path that would address the global climate issue.

ANNEX I - TRANSLATING THE PARIS AGREEMENT GOAL INTO EMISSIONS SCENARIOS

The literature provides a broad variety energy-system emissions scenarios consistent with holding warming to below 2°C, with various degrees of likelihood of exceeding this warming level. The various degrees of likelihood[7] reflect the uncertainty in the carbon cycle and in the temperature responses of Earth's systems to changes in GHGs' concentrations in the atmosphere. The broad variety of scenarios is further extended by the different ways in which fossil fuels can be replaced by a plethora of alternatives, depending on estimates of potentials, costs etc., which also vary in time and space. The range and depth of literature available for the evaluation of 1.5°C limit has not been as abundant yet, but the past weeks (March-April 2018) have finally seen publications of a broad range of models and scenarios for 1.5°C as well (Kriegler et al 2018; Rogelj et al 2018; Strefler et al 2018; van Vuuren et al 2018). This development is so recent, however, that the underlying data of these many new 1.5°C scenarios is not yet publicly available.

Both 1.5°C and 2°C energy-system scenarios come from Integrated Assessment Models (IAMs). IAMs combine the current knowledge of energy systems and climate-model projections to identify economically and technologically feasible emissions pathways consistent with a given climate target, while minimising global costs. These are the so-called "cost-optimal" pathways.

Based on our assessment of the available scenario data (Schleussner et al., 2016) we use as a proxy for achieving the Paris Agreement long-term temperature goal, scenarios that hold warming below 2°C with 85% likelihood, or greater, and with at least 50% likelihood of remaining below 1.5°C by 2100[8], recognising that many countries may view scenarios that overshoot the 1.5°C limit as being inconsistent with the Paris Agreement long-term temperature goal. To ensure maximum relevance of this analysis for policymakers, we require scenarios with global emissions in 2020 as close as possible to current projections. We opt therefore for a class of scenarios often called in the literature "delayed action" scenarios, which usually assume that countries will meet their 2020 mitigation pledges, before beginning deeper action to meet a long-term temperature goal[9].

Based on the considerations described above, one scenario was selected from the Integrated Assessment Model MESSAGE model (IIASA, 2016), to be the basis of this analysis: our Paris Agreement 1.5°C scenario with overshoot is a pathway that accelerates global action from 2020 onwards[10]. Essential to note is that the coal phase-out in this scenario is consistent with the many models and scenarios newly published in the multi-model study published in 2018 in the lead up to IPCC's Special Report on 1.5°C ((Rogelj et al., 2018) – see supplementary information figure 14, panel b). Out of a total of 13 scenarios using 5 different models, 11 show a global coal phase-out by 2050 (without CCS).

Based on the chosen global emissions scenario, we derived cost-optimal pathways for electricity generation from unabated coal plants (i.e. coal-fired power plants without carbon capture and storage), in line with the Paris Agreement's temperature limit globally and for Japan. After the assessment of the available scenarios,

[7] Likelihood is defined here as the percentage of 600 different carbon-cycle/climate model realizations for the same emissions scenario, which hold warming below a given limit. For instance, if for a given emissions scenario, 300 out of 600 climate model runs show warming below the warming limit, there's a 50% likelihood that warming remains below that limit for this emissions scenario. All emissions scenarios were evaluated using the same method and coupled carbon-cycle/climate model configurations that we applied in our contributions to IPCC's Fifth Assessment Report in its Working Group III report and Synthesis report.

[8] The 1.5°C consistent scenarios published to date overshoot a 1.5°C global mean warming above pre-industrial in the 21st century by about 0.1°C to 0.2°C, before returning to 1.5°C or below in 2100 with at least 50% likelihood (median warming in 2100 of 1.4°C) and have simultaneously a likelihood of about 85% to hold warming below 2°C during the 21st century.

[9] IAMs usually compute results for periods of five or ten years length. MESSAGE has 10-year periods from 2010 onwards. Since the scenarios prepared for AR5 where run before 2014 – the year when AR5 was published – the first period for which immediate climate policy is assumed is 2010, whereas it is 2020 for delayed climate policy.

[10] Our scenario temporarily allows for an increase in temperature by more than 1.5°C in the 21st century. However, due to reduction in emissions and later CO2 removal from the atmosphere, the global temperature above pre-industrial average goes down to 1.5°C by 2100 with at least 50% likelihood.

we use as a proxy for Paris Agreement, scenarios that hold warming below 2°C with 85% probability, or greater, and with a more than 50% chance of remaining below 1.5°C by 2100.

While global and regional (e.g. OECD in aggregate) pathways are a direct output of the MESSAGE model, Japan's cost-optimal pathway is an outcome of Climate Analytics' SIAMESE model (Sferra et al, 2018 – In review), consistent with other reports looking at national implications of global and regional energy models (Rocha et al., 2016)(Climate Analytics, 2017). SIAMESE (Simplified Integrated Assessment Model with Energy System Emulator) is able to downscale the results of aggregated IAMs regions. In terms of the equations, SIAMESE mimics the structure of IAMs, where energy consumption is allocated in all countries using a welfare maximisation approach. In this report we employ SIAMESE to downscale the results of the OECD region from MESSAGE to Japan. SIAMESE is also calibrated based on historical energy consumption data for Japan.

While providing results over the 21st century, SIAMESE takes into account current policies in place in Japan. In particular, the share of nuclear generation in the power sector is constrained to maximum 10% in 2030, after taking into account the developments following 2011 Fukushima nuclear accident, which are not accounted for in the original emissions pathways from the IAM selected. Although this is less than half of the government current projection, several recent energy scenarios for Japan considers similar projection (BNEF, 2015; Buckley & Nicholas, 2017; Kuramochi, 2015),

In this study we assume that a phase-out of coal-fired power plants is achieved whenever emissions are reduced by more than 90% compared to 2010 levels[11]. The cost-optimal emissions pathways show that globally emissions of unabated coal need to be phased out[12] by the latest by 2050 worldwide to remain in line with the Paris Agreement. In Japan, coal power plant emissions need to decrease steeply in the coming years and be phased out by 2030. In the second half of the century, emissions for unabated coal need to be zero for Japan and the rest of the world.

It must be noted that all MESSAGE scenarios assumed full technological availability, i.e. all technologies that are present in the model are deployed at rates determined by the model under the respective constraints – e.g. fossil fuel resources, costs of nuclear energy or renewable energy potentials. In practice, there may be other constraints placed upon technologies. For example, concerns with nuclear power in many jurisdictions are well known and may limit future deployment in at least some regions like Japan. One of the advantages of using the SIAMESE model, is the possibility of adding additional constraints to technologies deployment.

[11] This simplification is needed to give a useful interpretation of model results, as some residual coal consumption could remain in the energy mix due to algorithm/optimization reasons in the models. See also IPCC AR5 WG3

[12] Year of reductions of 90% or more below 2010 levels - analogous to assessment of emissions from energy supply sector in IPCC AR5 WG3 (SPM)

ANNEX II - EMISSIONS SCENARIOS UNDER OTHER ENERGY-SYSTEM MODELS

We have chosen Integrated Assessment Models (IAMs) emissions scenarios in this report, as they provide collectively state-of-the-art knowledge of energy system, and are the basis of the scientific work supporting the adoption of long-term temperature goals. As mentioned above, until recently only some IAMs had produced data on 1.5°C scenarios like that used in this report. While several new key 1.5°C papers have now been published, underlying detailed data is not (yet) publicly available, but the results are consistent with the scenario in this analysis (see above).

However, IAMs are not the only energy-system models. Here we analyse in a stepwise and transparent manner the advantages and disadvantages of using IAMs in comparison to models often used by policymakers in their energy planning, such as the ones International Energy Agency (e.g. World Energy Outlook (IEA, 2017a) and Energy Technology Perspectives(IEA, 2017b) .

The WEM (World Energy Model) developed by the International Energy Agency is at the core of the World Energy Outlook projections. WEM provides valuable information for specific countries (covering the majority of emissions) under different scenarios: *Current Policies Scenario* (CPS), *New Policies Scenario* (NPS) and a *Sustainable Development Scenario (SDS*). Key results include the energy (and electricity) mix and the associated CO_2 emissions.

However, the time horizon of the IEA WEM is only around 25 years and results are provided until 2040, which makes it difficult to compare with long-term temperature goals. Apart from its short time horizon, a key limitation of the WEM is the lack of interaction between the supply and energy demand. Higher energy prices are a key incentive for energy efficiency improvements that ultimately lower energy demand and those types of feedback loops are not taken into account by WEM, whereas those feedbacks are reflected in IAMs. Overall, while WEM provides very useful information to complement our understanding of energy systems in the short-term, it cannot answer key questions regarding long-term mitigation strategies, such as the trade-off between short-term and long-term mitigation actions.

Some of the shortcomings of the WEM model are addressed by the TIMES model, which is the primary analytical tool used for the IEA’s Energy Technology Perspectives publication. The IEA/ETP 2017 has published results for three scenarios produced with this model: current trajectory, 2°C Scenario (2DS) and Beyond 2°C Scenario (B2DS). In the Beyond 2°C scenario (B2DS), the energy sector reaches carbon neutrality by 2060 to limit future temperature increases to 1.75°C by 2100 (IEA, 2017b).

In order to better understand how these different models relate to and complement each other, we looked into the resulting pathways for energy-related emissions as well as for emissions from coal-fired power plants and compare them to an IAM (MESSAGE) scenario used as a proxy for a pathway consistent with the Paris Agreement 1.5°C global temperature limit as referenced in the Paris Agreement.

The carbon budget (total CO_2 emissions) associated with the 1.5°C scenario analysed here is around 450 $GtCO_2$ for the period 2010-2100 (Rogelj et al. 2013). All the scenarios depicted in Figure 12 already emit around 1000 $GtCO_2$ for the period 2010-2050 (twice the Paris Agreement compatible budget for the whole century). This means that all these scenarios require negative emissions in the second half of the century to prevent an increase in temperature above 1.5°C by 2100.

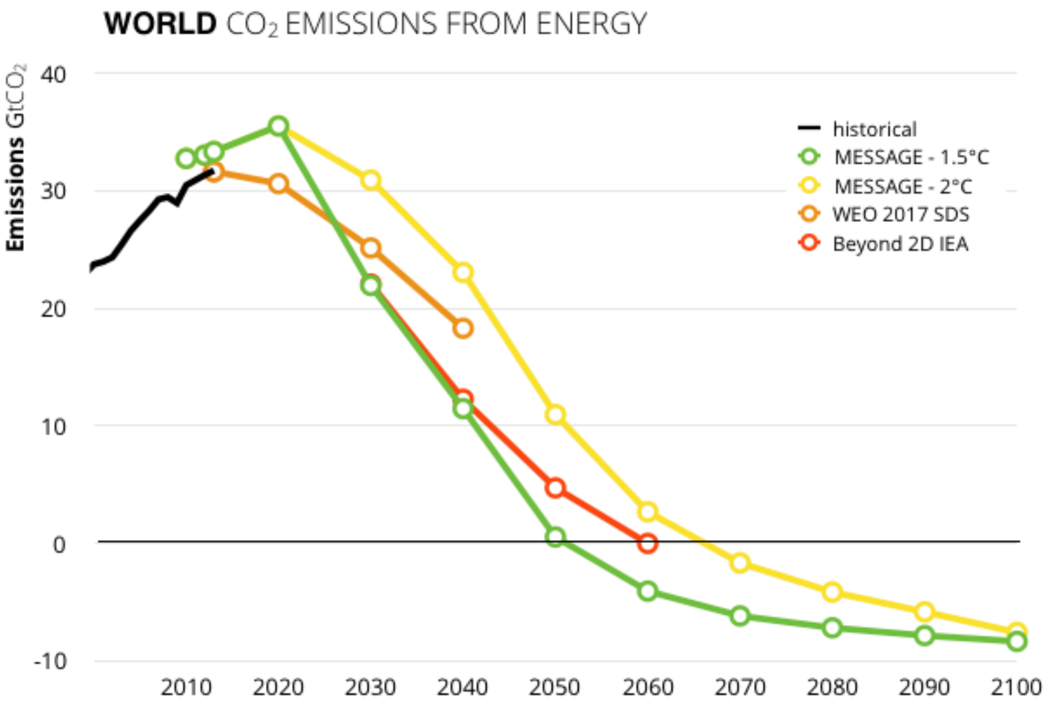

Figure 12: CO_2 emissions from energy in a cost-optimal pathway (MESSAGE) in line with 1.5°C, WEO2017 SDS, and ETP.

It is therefore clear that delaying mitigation action does not only increase the overall mitigation costs and undermine the probability of limiting warming to the agreed level, but also increases reliance on negative CO_2 emissions.

This leads to the very important conclusion that, regardless of the model considered coal replacement by low-carbon alternatives decreases the need for later compensation by negative CO_2 emissions and thus also the environmental, social and political costs of their implementation. Also, earlier emissions reductions hedge against the risk that negative emissions technologies will not deliver at the scale currently implied by the models.

Research in the scientific community is ongoing in many of these areas, including in relation to the consequences of limitations of use and deployment of certain technologies for sustainability, or other considerations, in achieving global warming limits. These issues are not covered in this report, but remain important to any real-world deployment of options described here.

ANNEX III - SCENARIO LIMITATIONS OF IAMS

IAMs combine the current knowledge of energy systems and climate-model projections to identify economically and technologically feasible emissions pathways consistent with a temperature limit, while minimising global costs. **IAMs consider a timeframe spanning from the recent past until the end of the 21st century** and divide the world into a dozen to about 25 regions. IAMs provide so-called **"cost-optimal" pathways**, as the results are based on a global cost-minimisation approach.

IAMs explicitly encompass the interplay between the increasing economic activity, the energy sector, and the implications for climate change. Each of those is usually represented in dedicated modules.

The economy module consists of a stylised representation of economic activities like GDP, consumption, investments, and trade between regions. The energy module calculates future energy demand, based on socioeconomic projections (GDP and population) and energy prices. A land use module takes into account other physical trade-offs, such as the availability of biomass, reductions in agricultural emissions and deployment of afforestation and reforestation. Finally, GHG emissions are used to compute the response of Earth's climate using a climate model.

A solution algorithm maximises an economic utility function under a set of constraints. **By imposing a constraint on the carbon budget, radiative forcing or global temperature increase, IAMs provide global cost-optimal mitigation pathways, i.e. they find the globally cheapest way to achieve the climate target**.

According to the literature on IAMs results, the earlier strong climate action is implemented, the cheaper the combined global cost of meeting a temperature limit over the whole of the century. This conclusion is quite robust across all IAMs.

However, IAMs have limitations. For example, as model updates are time consuming, IAMs often rely on out-dated information regarding for example the near-term effect of current developments in energy, air pollution and climate policies, and recent developments in energy technologies and markets, like the price of renewables, which is now decreasing at a faster pace than expected. An out-dated representation of the latter usually results in higher penetration rates of CCS technologies to the detriment of renewables in the short term. Another limitation is the lack of co-benefits considerations (like decreased air pollution and avoided damages like less sea-level rise), which are not accounted for monetarily in those models.

Also, IAMs assume perfect markets with mitigation scenarios often being implemented via a global emission-trading scheme, which usually leads to large financial transfers from high-income countries to lower income regions where mitigation is cheaper. This might lead to counterintuitive results especially in comparison to approaches that take into account fairness principles, such as deep emissions reductions in low-income countries compared to developed regions. Therefore, IAM results should be taken with a "grain of salt" as non-economic considerations associated with such financial transfers could be seen as unrealistic or undesirable.

Finally, one key limitation of IAMs is the lack of "short-term" dynamics. These models typically assume "perfect foresight" (that is, all relevant information over the whole model time horizon is available and taken into account) and therefore find the optimal solution throughout the whole century, unless near-term dynamics are explicitly prescribed (such as near-term mitigation "delay" compared the cost-optimal, early action pathway). Notably, most IAMs provide projections only for time steps of 5 or 10 years apart. In this regard, **other models can complement IAMs results and provide more relevant insights in the short term.**

ANNEX IV - SIAMESE

The **S**implified **I**ntegrated **A**ssessment **M**odel with **E**nergy **S**ystem **E**mulator (SIAMESE) is able to downscale the energy-system characteristics of a particular IAM at the country level, by providing cost-effective scenario in line with a global temperature target. At the same time, SIAMESE can take into account specific policy in place and expected energy trends (e.g. limited nuclear developments) at the country level. Therefore, it can provide insights to policymakers on how to realistically improve current policies and pledges in line with the Paris Agreement long term target.

In this study we downscale the OECD90 energy consumption results of the MESSAGE model to Japan. At the base year (2010), the model is calibrated based on observed energy consumption, GDP and population data. In a way, this calibration process sets some preferences regarding the energy mix composition. More precisely, SIAMESE allocates energy consumption in the regions by equalising the marginal utility of energy, under a welfare maximisation approach. Energy prices are endogenous in the model[13] and coincide with the marginal utility of energy.

In terms of the equations, SIAMESE mimics the structure of Integrated Assessment Model, where the economic output (GDP) is a function of capital, labour and energy consumption by using a CES (Constant Elasticity of Substitution) production function.

This version of SIAMESE focuses on downscaling electricity generation from the OECD region of the MESSAGE model. In terms of gases, SIAMESE focuses on CO_2 emissions only (excluding LULUCF) and on while it does not cover other GHG such (e.g. CH_4, N_2O etc.). Other gases' emissions can be downscaled by using a simple (proportional) downscaling technique or via several other methods, such as using marginal abatement cost curves.

[13] SIAMESE determines the energy prices for each fuel, based on energy consumption levels from the MESSAGE model.

ANNEX V - ESTIMATING CO_2 EMISSIONS FROM COAL PLANTS

To estimate emissions resulting from currently operating and planned coal power plants in Japan we used the Global Coal Plant Tracker (GCPT) database, which provides information on every known coal-fired power generation unit, including its location, status, investor, capacity, combustion technology[14] and fuel, year of opening and planned retirement. For this analysis we use the information provided in the July 2017 version of the GCPT. For an up-to date list of status of plants under development of assessment, as well as additional characteristics of the units like the observed historical load factors and fuel use, which allow for a more accurate estimation of the emissions produced by each plant, we merged the GCPT data with information provided by a national database for coal power plants hosted and coordinated by the Renewable Energy Institute of Japan (REI), which reflects status of coal power units as of February 2018.

The Global Coal Plant Tracker data used in this report comprise of detailed information per plant concerning the country, its capacity, status and combustion technology, which allows to estimate CO_2 from these plants, using the following formula:

Yearly emissions:

$$Emi_{it} = Cap_i * \frac{1}{eff_i} * lf_{it} * ef_i * \boldsymbol{\phi}$$

with:

$\boldsymbol{Emi_i t}$ are the yearly emissions of plant unit *i* in $MtCO_2$ in a particular year *t*

$\boldsymbol{Cap_i}$ is the Capacity of plant unit *i* in MWel. MWel describes the electrical output of a power plant (unit). About two thirds (actual value depending on the combustion technology) of the energy contained in a coal power plant's fuel is lost while converting it into electricity. The thermal energy released during the conversion is usually not used anymore but gotten rid of via cooling towers or rivers.

$\boldsymbol{eff_i}$ is the conversion efficiency of a power plant unit: How much of the energy contained in the fuel (coal) is converted to electricity. In general, this is higher for modern plants. In the case of Japan, it ranges between 38.5 and 45.3 percent, with an average of 39.7 percent.

$\boldsymbol{lf_{it}}$ is the load factor of the power plant in a particular year t. The load factor is the ratio of the actual power plant output over its theoretical maximum output and is usually calculated over the course of a year. The theoretical maximum output can be calculated by assuming that a power plant runs at its nameplate capacity 24 hours a day, 365 days a year. I.e. a power plant unit with a capacity of 100 MW has a theoretical maximum output of

$$100\ \mathrm{MW_{el}} * 24\,\frac{\mathrm{hours}}{\mathrm{day}} * 365\,\frac{\mathrm{days}}{\mathrm{year}} = 876.000\ \mathrm{MWh}.$$

Actual output over a given year is lower since the plant will always operate at full output – e.g. due to demand fluctuations – and has to be taken offline completely for maintenance. To address the uncertainty around those assumptions we estimate emissions under three scenarios:

- Full expansion: Declining energy demand and partial nuclear re-start, all the planned coal capacity comes online. Consistent with capacity factor declining to 52.6% in 2026.

[14] The database distinguishes between different combustion technologies in the following categories: subcritical, supercritical and ultra-supercritical without or with CCS, ranking from least to most efficient respectively. We do not consider coal fired power plants retrofitted with CCS technology further in our analysis.

- Moderate expansion: Declining energy demand and partial nuclear re-start, only half of the planned coal capacity comes online. Consistent with capacity factor declining to 59.4% in 2026.

- Limited expansion: Declining energy demand and partial nuclear re-start, only a quarter of the planned coal capacity comes online. Consistent with capacity factor declining to 63.2% in 2026.

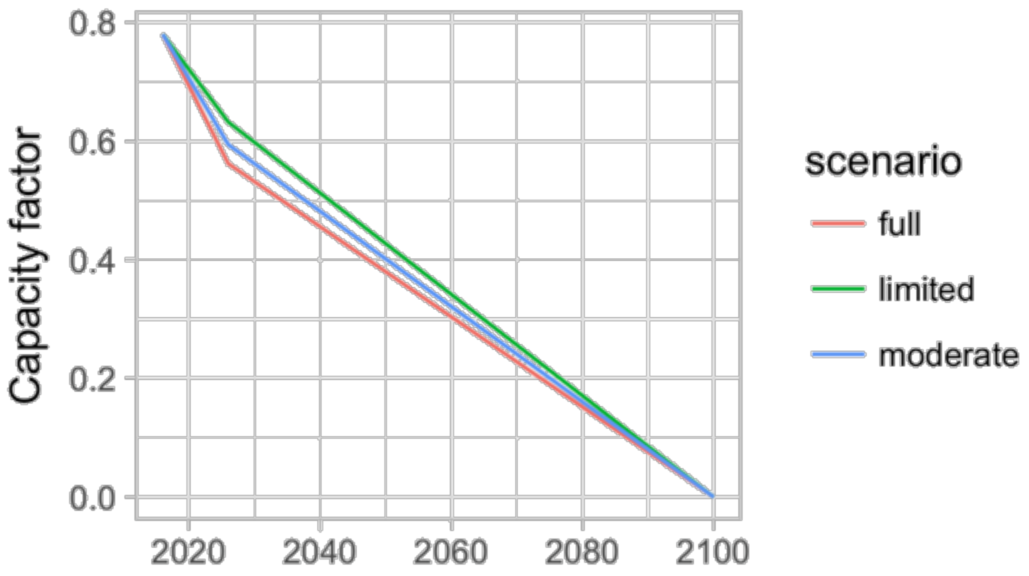

Figure 13- Capacity factor assumptions under three scenarios

ef_i is the emissions factor, which contains information on how much CO_2 is released for a given amount of coal burned. Unit is kg CO_2/TJ. Higher grade coal contains a higher share of carbon, which is converted to CO_2 during combustion. We use emissions factors from (IPCC, 2006). Since this source contains only emissions factors for pure types of coal, we assumed a 50/50 share for plants that use two different coal grades, e.g. bituminous and sub-bituminous coal.

ϕ is a conversion factor to end up with the correct units ($MtCO_2$/yr).

Calculating lifetime emissions:

$$Lifetime\ Emi = \sum_{2017}^{\mathrm{T}} \mathrm{Emi}_{\mathrm{it}}$$

with T being the last year the plant unit is in operation.
For simplicity, we assume that the shutdown of a given unit happens on 31 December of the respective year. T is calculated as $2017 + \mathrm{lifetime} - \mathrm{ifetime} - \mathrm{Open}$. The decisive assumption here is the lifetime, and for plants that are not yet in operation, the opening year. Lacking sufficient historical observations on unit closures, we assume an average lifetime of 40 years. For unit not yet in operation, we assume the following:

Status	Opening year
Construction	2018
Permitted	2021
Pre-permitted	2023
Announced	2025

In Japan 24 units, with a combined capacity of 3.6 GW that are currently operating exceeds the age of 40 years (average age of these units 49 years). For those plants we assume they will remain open for another 4 years, which is the standard deviation of the age of those 22 units.

ANNEX VI – SENSITIVITY ANALYSIS

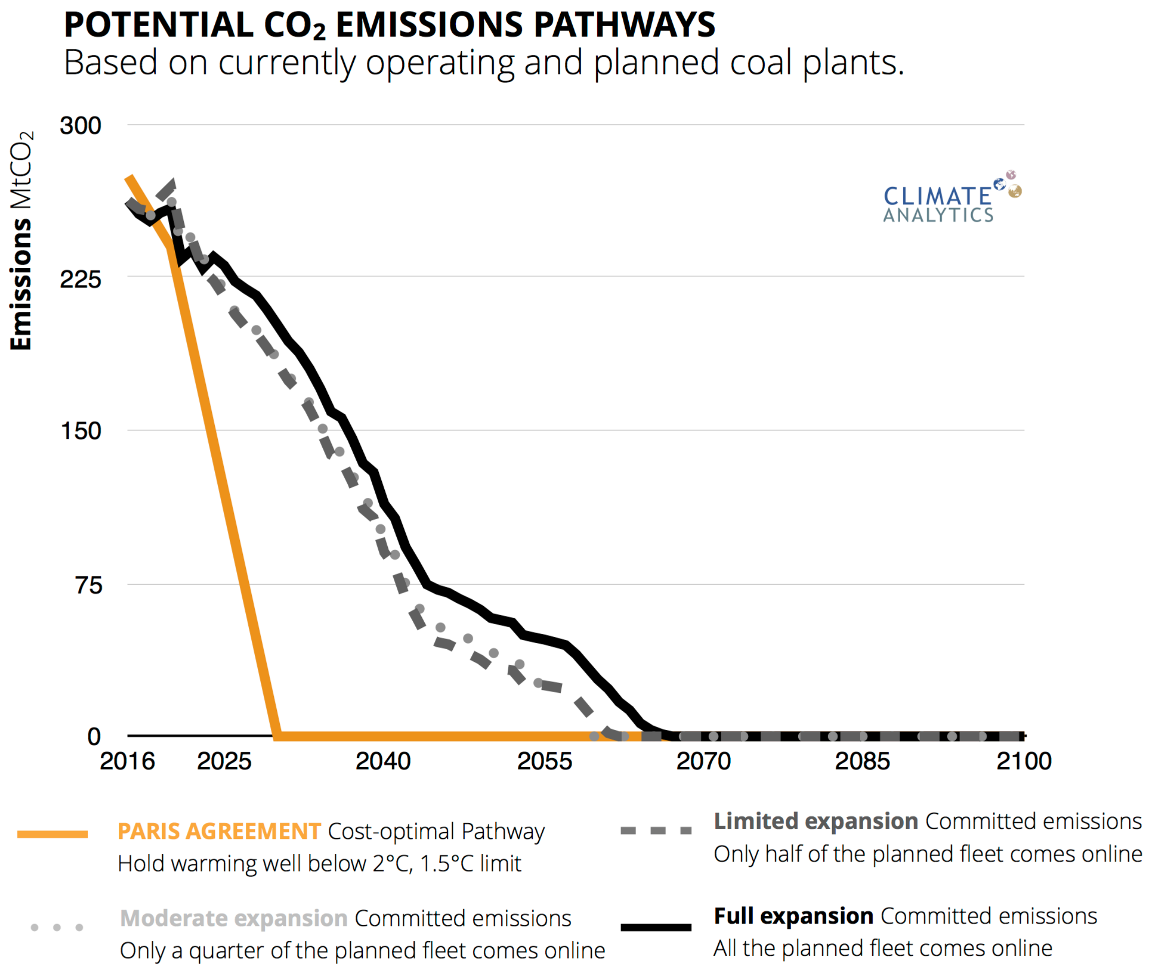

Figure 14- Potential CO_2 emissions pathways based on different levels of coal-fired power plant expansion

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www.climateanalytics.org

Climate Analytics gGmbH
Ritterstr. 3
10969 Berlin
Germany
+49 302 5922 9520
contact@climateanalytics.org

Climate Analytics Lomé
61, rue 195 Quartier Agbalépédogan
s/c BP 81 555 Lomé
Togo
+228 22 25 65 38 / 22 25 74 74
togooffice@climateanalytics.org

Climate Analytics Inc. New York
115 E 23rd St, 5th Floor, Suite #511
New York, NY, 10010
USA
+1 718 618 5847
info.ny@climateanalytics.org

Climate Analytics Australia Ltd.
Level 1
1121 High Street
Armdale, Victoria 3143
Australia
info.aus@climateanalytics.org

@CA_Latest

ClimateAnalytics

company/climateanalytics-ggmbh

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