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Clean power for a cool planet: Electricity infrastructure plans and the Paris Agreement

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Clean power for a cool planet: Electricity infrastructure plans and the Paris Agreement – Environment Working Paper No. 140

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Keywords: Electricity Sector, Coal, Gas, Renewable energy, Just transition, Environment, Political economy

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Abstract

Meeting the temperature goals of the Paris Agreement requires a transformational change in our infrastructure systems. Given the long lifetime of infrastructure, there is an urgency to build more of the right type of it. The failure to do so will lock-in emissions for decades to come, or create stranded assets. This working paper aims to shed light on the extent to which current electricity generation projects under construction at the global level - the "pipeline" - are consistent with what a low-carbon transition requires. The “pipeline” analysis suggests that the current 200 GW of coal capacity under construction (equivalent to 10% of current installed coal generation capacity) over the next five years is not compatible with a well-below 2°C goal, which will require coal capacity to fall rapidly in coming decades. Further, while renewables now comprise around two-thirds of generation capacity under construction, the rate of installation will need to increase further, according to the International Energy Agency’s recent Sustainable Development Scenario. The note also explores the challenges and opportunities for governments to shift away from fossil fuel energy sources, and the role governments could play to accelerate the low-carbon transition.

Keywords: Electricity Sector, Coal, Gas, Renewable energy, Just transition, Environment, Political economy

JEL Codes: L94, O13, P48, Q4

Résumé

La réalisation des objectifs de l'accord de Paris en matière de température nécessite un changement transformationnel de nos systèmes d'infrastructure. Il est urgent de mettre en place le type d’infrastructure approprié étant donné leur longue durée de vie. Dans le cas contraire, les émissions seront verrouillées pendant des décennies ou créeront des actifs bloqués et obsolètes. Ce document de travail vise à expliquer dans quelle mesure les infrastructures pour la production d'électricité en cours de construction au niveau mondial correspondent aux besoins liés à une transition à faible intensité carbone. L'analyse suggère que les 200 GW de capacité de production liée au charbon en cours de construction sur les cinq prochaines années (équivalant à 10% de la capacité de production liée au charbon déjà installée) ne sont pas compatibles avec l’objectif visant à limiter l’augmentation de la température mondiale bien en dessous de 2 ° C. Atteindre cet objectif nécessite une diminution rapide de l’utilisation du charbon au cours des prochaines décennies. De plus, bien que les énergies renouvelables représentent désormais environ les deux tiers de la capacité de production en cours de construction, leur taux d’installation devra encore augmenter, selon le récent Scénario de Développement Durable de l’Agence Internationale de l’Énergie. La note explore également les défis et les opportunités pour les gouvernements liés à un désengagement vis-à-vis des sources d'énergie à base de combustibles fossiles, ainsi que le rôle que les gouvernements pourraient jouer pour accélérer la transition vers une réduction des émissions de carbone.

Mots-clés: Électricité, Charbon, Gaz, Énergie renouvelable, Transition juste, Environnement, Économie politique

Codes JEL: L94, O13, P48, Q4

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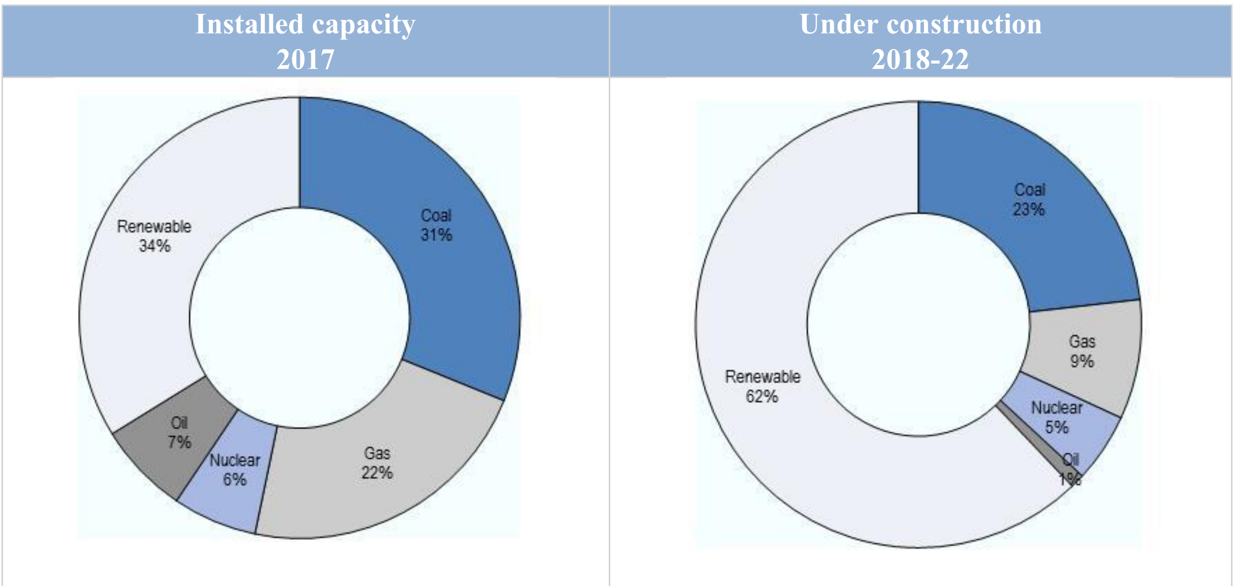
Executive Summary

With the 2015 Paris Agreement, the global community agreed to "*holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels*". With over two thirds of global greenhouse gases emitted by the energy sector - 40% of which come from electricity production - decarbonising electricity infrastructure is essential to achieve these climate goals. The purpose of this study is to establish whether electricity generation infrastructure currently under construction in the next five years – the "pipeline" – is in line with the Paris Agreement.

At the global level, there are approximately 6,300 GW in operation and 1,200 GW should be available in the next five years (currently under construction). An analysis of this pipeline indicates that the installed capacity of renewable power is expanding rapidly. While it represents one third of the installed capacity in 2017, it accounts for almost two thirds of the plants under construction. In contrast, the development of new coal power plants is slowing: currently representing 31% of total installed generation capacity, coal power represents 23% of electricity capacity under construction (Figure 1).

Figure 1. Global electricity generation capacity: installed and under construction, by technology

GW



Note: See Annex A for more details on methodology.
Source: Authors' analysis from i) Platts WEPP (2017[1]) for oil and gas; ii) the Global Coal Plant Tracker (2017[2]) for coal; iii) IAEA (2017[3]) for nuclear; iv) IEA (2017[4]) for renewable energy.

Whilst these results provide encouraging signs that the decarbonisation of the energy sector is in motion, the results of this study suggest that the electricity infrastructure being built is not compatible with meeting the Paris Agreement goals. The IEA's *Sustainable Development Scenario* provides an energy sector pathway to achieve three Sustainable Development Goals (SDGs): universal access to clean energy (SDG 7), clean air (SDG 3.9), and effective action to combat climate change (SDG 13). To be in line with this scenario between 2020 and 2030, the installed capacity of coal should decrease by 2% per year, compared to an expected increase of 3% per year in the period 2010-20. Renewable energy deployment appears to be going in the right direction; however the installed capacity would still need to double in the next ten years to be in line with the IEA scenario.

Beyond improving energy efficiency, there are 3 levers of action that can put the electricity sector back on track. Firstly, coal needs to be phased-out rapidly, particularly in those countries that currently have the largest electricity generation capacity (ie. China, United States and India). This translates into the need to halt new constructions and push existing plants into early retirements. Secondly, renewable energy technology needs to be deployed more rapidly. Thirdly, investment in electricity-demand management systems needs to be ramped up and redirected towards technologies that could help increase the capacity factor of renewable sources of energy (e.g. electricity storage systems and smart grids).

A quick and drastic transition to a low-carbon economy will not only increase the chances of limiting the impacts of climate change, it can also help governments tackle the issue of air pollution which every year has dramatic consequences on human health. Nonetheless, taking climate action is a politically difficult task for governments, with the transition often being perceived as costly and raising issues surrounding affordability. A number of challenges are still to be overcome for the full economic and social benefits of the transition to be reaped.

- *Challenge 1 – Ensuring a just and inclusive transition*. Moving away from carbon-intensive sources of energy is likely to affect different strands of the population in various ways. Jobs in the carbon-intensive energy industries, such as coal or oil, will be cut whilst the labour market in renewable energy is likely to grow. Ensuring that those people whose livelihoods are the most affected by the transition are supported so that they can adapt to a changing labour market is crucial to ensure that the transition is just, inclusive, and ultimately successful. This is particularly important in countries with limited education opportunities and low income households where opportunities to re-skill and relocate are limited.

- *Challenge 2 – Managing stranded assets.* Because some plants will need to be retired before the end of their economic lifetime, the transition will cause some assets to be stranded. The exposure of a country to stranded assets depends on the amount of fossil-intensive infrastructure in its stocks, the capital intensiveness of assets (which relates to the time needed to recover investment costs), and the age of the infrastructure. For countries with older electricity generating infrastructure fleets in need of replacement, developing low-carbon infrastructure is a relatively easier opportunity to grasp given that their fleet is comparatively closer to retirement than for countries that have relatively "young" infrastructure with yet unrecovered investments.

- *Challenge 3 – Compensating for the potential losses in government revenues.* Countries depending on fossil fuel rents may experience a loss of revenue as a result of the decarbonisation of electricity. Whilst this may be seen as a challenge in the short to medium term, this loss of revenue can be compensated by the opening of new revenue streams, via for example, the implementation of carbon pricing instruments or cap-and-trade programs.

Governments have a key role to play when it comes to overcoming the obstacles and maximising the opportunities associated to the transition. As planners, they can raise the ambition of their nationally-determined contributions (NDCs) and formulate long-term strategies under the UNFCCC process. The NDCs can be complemented by the articulation and communication of clear infrastructure plans that can help investors identify bankable electricity infrastructure projects that are in line with the transition. Via these tools, governments can provide direction to investors on where the electricity sector – in terms of infrastructure – may be headed in the short-, medium- and long-terms, as well as work towards achieving internationally agreed targets. As investors, governments can also use their influence in state-owned enterprises – which accounted for 61% of total global electricity capacity installed in 2016 – to redirect the activities of these companies to further accelerate the uptake of low-carbon sources of electricity as well as phase-out coal.

1. Introduction

1.1. The Paris Agreement goals require ambitious climate action

The Paris Agreement adopted at the December 2015 meeting of the UN Framework Convention on Climate Change (UNFCCC) was an important milestone in international efforts to craft an effective response to climate change. Several decades of slow and challenging negotiations on climate mitigation in particular culminated with 195 countries agreeing to "*holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels*" (UNFCCC, 2015[5]; UNFCCC, 2015[6]). In 2018, Parties to the UNFCCC will be called upon to re-evaluate the ambition of their nationally-determined contributions (NDCs) via the Facilitative Dialogue.

As 175 countries have ratified the Agreement, time for implementation has now come; and with it, its challenges. Achieving the Paris Agreement targets requires bold and ambitious action from countries to drastically decarbonise their economies in the short, medium, and long-term (OECD, 2017[7]). Global emissions need to peak as soon as possible, with recent research indicating that global peak needs to take place by 2020 (Figueres et al., 2017[8]; New Climate Institute, 2017[9]). Emissions then need to reduce drastically in order to become net negative in the second half of the century (OECD, 2017[7]).

With around 60% of greenhouse gas (GHG) emissions associated to existing infrastructure (New Climate Economy, 2016[10]; IPCC, 2014[11]), such a transition to a low-carbon economy requires an unprecedented transformation of infrastructure systems. In particular, reducing emissions from the energy sector, which represented 68% of global GHG emissions in 2014 (IEA, 2017[12]), is key.

There are three necessary and complementary measures to decarbonise the energy system: (i) the decarbonisation of electricity generation, (ii) the electrification of end-uses (depending on specific country contexts), and (iii) the improvement of energy efficiency, i.e. reducing the amount of primary energy needed to produce one unit of economic output (IEA, 2017[13]; DDPP, 2015[14]). Combining these three levers in an effective and mutually supportive way can put the world on a pathway to reach zero net emissions in the second half of the century, even as global energy demand increases (OECD, 2017[7]).

This paper focuses on the first lever of action: the decarbonisation of electricity at the global level. There are two important reasons for focusing on electricity:

- **40% of total energy emissions are coming from the electricity sector**; and
- **Electricity demand is likely to grow in a low-carbon future** from 18.5% of total final energy use in 2015 to 27% by 2060 (IEA, 2017[15]; IEA, 2017[16]). This increase is mainly driven by the expected electrification of end-uses (the second lever above) in sectors such as heat or transport, as well as the growing demand for electricity as population grows and developing countries converge towards universal access to clean energy.

Decarbonising other infrastructure – in particular in the transport and agriculture sector - is also central for a low-carbon transition. This paper focuses only on electricity infrastructure due to data limitations in other sectors. In addition, although optimising infrastructure related to electricity transmission and distribution for a low-carbon transition is a significant issue for a number of countries, this paper focuses on electricity generating infrastructure only.

The paper aims to:

- take stock of the extent to which the electricity generating infrastructure under construction in the next five years – the "pipeline" – is in line with a low-carbon scenario (section 2);
- identify what changes need to occur and what challenges and opportunities these provide (section 3); and finally
- explore what governments can do to accelerate the transition, looking more particularly at their role as planners and investors (section 4).

2. To what extent is the electricity sector being decarbonised?

In the power sector, most existing infrastructure was designed for a world of seemingly cheap and abundant fossil fuels, contributing to economic growth in many regions but also to GHG emissions. The electricity sector is still heavily fossil-fuel dependent: in 2014, 67% of the electricity generated globally came from fossil fuels (IEA, 2017[17]). Despite recent progress in the deployment of renewables, solar photovoltaics (PV), for instance, still only accounted for 1% of the global electricity output in 2015 (IEA, 2017[18]). All renewables accounted for 23% when hydropower is included (when excluded, renewables account for less than 10% of the electricity output worldwide in the same year).

This section firstly analyses the power plants *under construction* in the next five years – the "pipeline"[1] – alongside the electricity mix in operation.[2] Secondly, the "pipeline" is compared to what would be needed to reach the Paris Agreement goals, using the IEA *Sustainable Development Scenario* (hereafter SDS) as a proxy.[3] Box 2.1 provides a brief description of the methodology used, and highlights the limitations of the analysis presented in this paper. A more detailed description of the methodology is available in Annex A.

[1] Based on data from Platts WEPP (2017) for oil and gas; the Global Coal Plant Tracker (2017) for coal; IAEA (2016) for nuclear, and IEA (2017[19]) for renewable energy.

[2] Power plants *planned*, *on hold* and *cancelled* are also briefly analysed for coal in section 2.2.

[3] See section 2.2 for a description of the scenario.

Box 2.1. Methodology and limitations

This paper focuses on power plants *under construction* in the period 2018-22, and briefly describes coal power plants *planned*, *on hold,* and *cancelled*. Power plants *under construction* refer to projects where physical construction is proceeding. Plants *planned* are plants that have appeared in corporate or governmental planning, have applied for environmental permits or were granted permission to construct, but have not yet started physical construction. Plants *on hold* represent projects where there is sufficient evidence to indicate that a project is no longer moving forward (e.g. a sponsor announcement or no activity over a period of two years), but not enough evidence to declare it definitively *cancelled*. Plants *cancelled* include projects officially announced as cancelled by the plant sponsor before their full construction (or before construction actually started), having disappeared from company documents (even if no announcement is made), and plants showing no activity over a period of four years, unless there is evidence of the contrary. [4]

The analysis is presented in terms of the generation capacity (expressed in gigawatts – GW) in operation and under construction by 2022, the electricity output (expressed in GWh) and the tonnes of CO_2 emitted or expected to be emitted by 2022.

Using the information on the status of the power plants, together with the date in which the plants were or would be built or retired, a time series of generation capacity in operation has been (retroactively) constructed from 2000 to 2022. Historical data was used for electricity output from 2000 to 2015. Estimates were built for the electricity output from 2016 to 2022, as well as the tonnes of CO_2 emitted from 2000 to 2022. See Annex A for a detailed description.

The results of this paper are estimates and should be interpreted with caution. Country commitments (e.g. commitments to phase-out of unabated coal) are not included in this paper, unless they were implemented before the data updates (see Annex I for more details). The main uncertainties related to the hypotheses made include:

- **Electricity output.** Three assumptions were made while estimating the electricity output between 2016 and 2022: i) all power plants under construction will be built by the expected date; ii) the capacity factor for the next five years will be the same as the one observed on average in the last three years; and iii) power plants will be kept in operation the same number of years as in the past.[5]

Given recent announcements of plants halted, early retirements observed in some OECD countries, and policies in place aiming to ramp up renewable electricity generation, it is likely that at least some of these assumptions do not hold in the next five years.

- **Capacity factor**. Capacity factors are calculated as two-year averages at the technology and country levels. They do not reflect differences within country/regions, or power plants with different ages. For example, the capacity factor used in this analysis may be underestimated if we assume that the newer the power plant, the higher the capacity factor.

- **CO_2 emissions**. CO2 emissions from 2000 to 2015 are based on IEA data on CO2 from fuel combustion (IEA, 2017[12]), for coal only. Estimates for CO2 emissions from 2016 to 2022 are calculated by multiplying estimates of GWh to the average of CO2 intensity between 2011 and 2015, based on IEA data (IEA, 2017[12]).

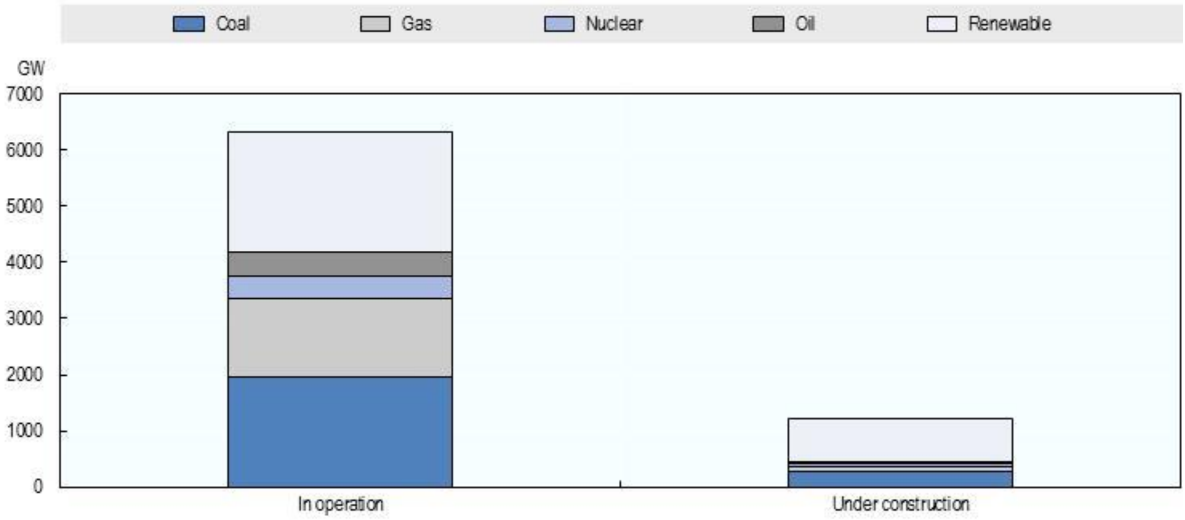
2.1. The electricity infrastructure "pipeline" over 2018-2022

At the global level, there are approximately 6,300 GW in operation and 1,200 GW should be available in the next five years (currently under construction)[6] (Figure 2.1). OECD and G20

[4] https://endcoal.org/global-coal-plant-tracker/methodology/.

countries account for 80% of the electricity generation capacity in operation globally, and 85% of the generation capacity under construction. Three countries – China, India and the United States – account for 72% of the GW under construction in the next five years. China and India account for 85% of coal under construction.

Figure 2.1. Global generation capacity in operation and under construction by 2022, by technology



Note: See Annex A for more details on methodology.
Source: Authors' analysis from i) Platts WEPP (2017) for oil and gas; ii) the Global Coal Plant Tracker (2017) for coal; iii) IAEA (2016) for nuclear; iv) (IEA, 2017[19]) for renewable energy.

2.1.1. Looking at electricity capacity (GW)

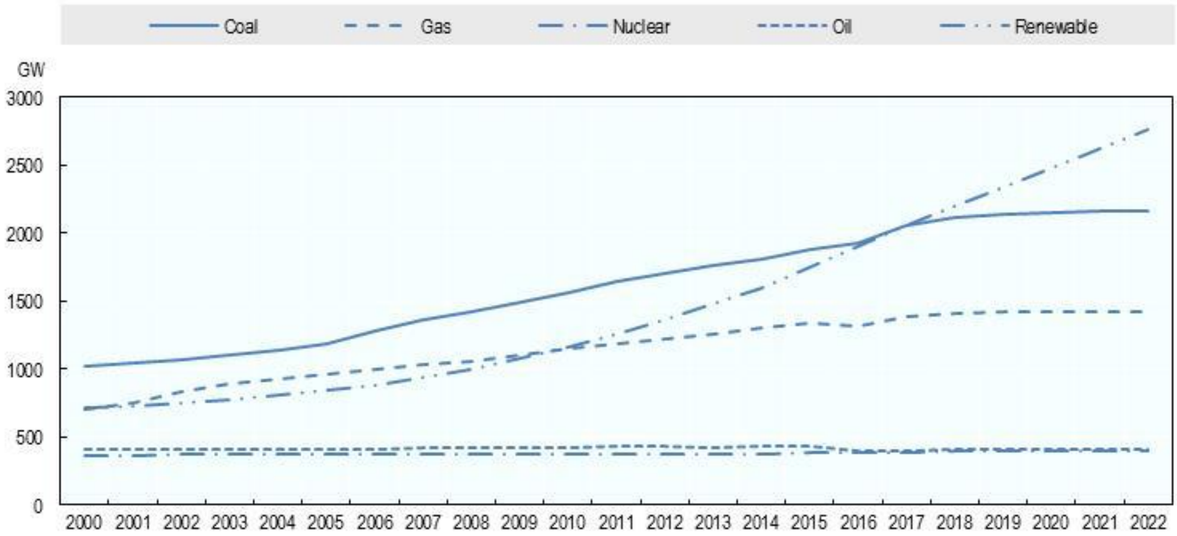
From the perspective of the installed generation capacity, renewable technology is expanding rapidly. Installed renewable capacity exceeded coal generation capacity for the first time in 2016 (Figure 2.2), and is set to increase 43% by 2022 (IEA, 2017[19]).

[5] For plants marked as retired without an observed retirement date, as well as for plants in operation in 2017, a retirement date was estimated based on historical data. This results in the implicit assumption that the average lifetime of power plants including those plants active until 2022 develops as in the sample with observed retirement dates.

[6] Information on *planned* power plants for gas and oil is not analysed in this paper due to data quality concerns. A brief description of plants *planned* for coal is available in section 2.1.1.

Figure 2.2. Global electricity generation capacity by technology

GW, estimates, 2000 to 2022



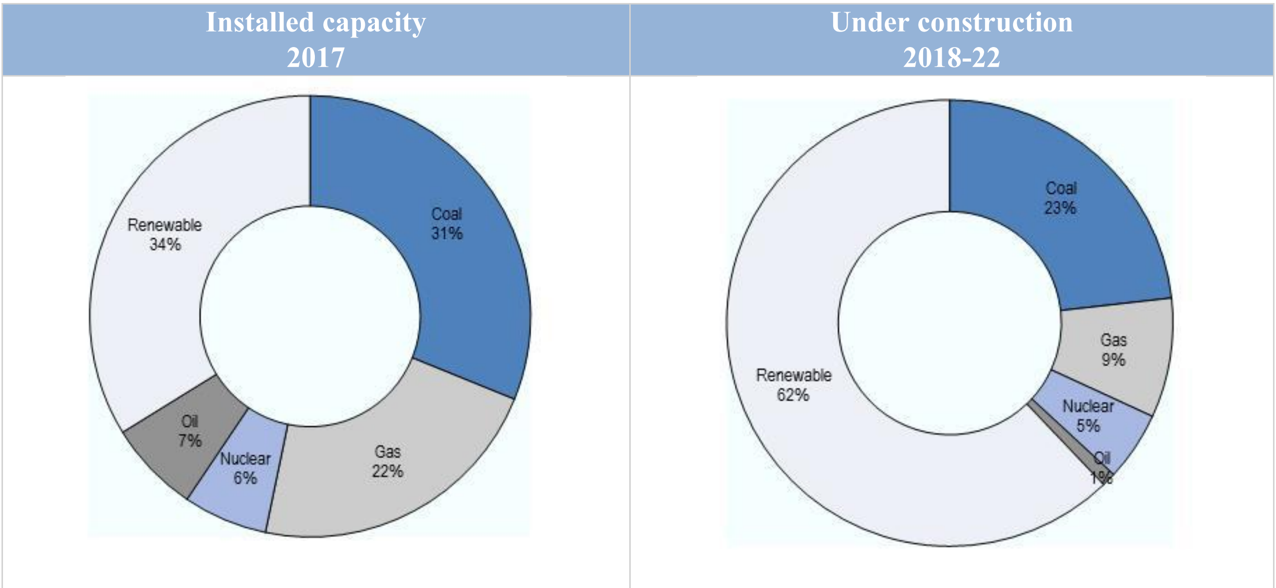
Note: The time series of electricity generation capacity for coal, gas, nuclear and oil have been (retroactively) constructed using the information on the status of plants, together with the date in which plants were built, would be built (for plants under construction), or were (and will be) retired. See Annex A for more details on methodology.
Source: Authors' analysis from i) Platts WEPP (2017[1]) for oil and gas; ii) the Global Coal Plant Tracker (2017[2]) for coal; iii) IAEA (2017[3]) for nuclear; iv) IEA (2017[4]) for renewable energy.

The strong growth in renewable capacity is mostly driven by developments in China, which alone is responsible for 40% of global renewable capacity growth and represents half of global solar PV demand. Major solar power projects are being deployed in all continents of the world, including in countries that have historically relied on revenues derived from fossil fuels (World Energy Council, 2016[20]). In Dubai, for instance, a major solar park mixing PV technology and concentrated solar power is under development and is intended to deliver 1 GW of power by 2020 and 5 GWs by 2030 (Hill, 2017[21]).

When comparing the installed capacity to the capacity under construction, while renewables represent one third of the installed capacity in 2017, they account for almost two thirds of the plants under construction (Figure 2.3).

Figure 2.3. Global electricity generation capacity: installed and under construction, by technology

GW

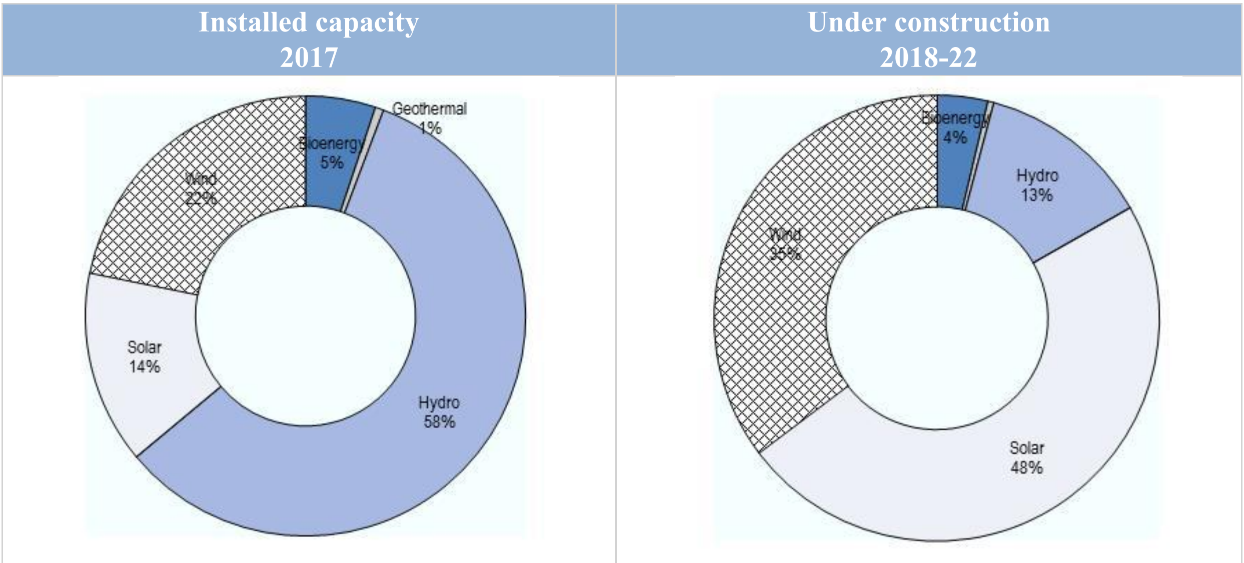


Note: See Annex A for more details on methodology.
Source: Authors' analysis from i) Platts WEPP (2017[1]) for oil and gas; ii) the Global Coal Plant Tracker (2017[2]) for coal; iii) IAEA (2017[3]) for nuclear; iv) IEA (2017[4]) for renewable energy.

Within the renewables category, the type of technology varies significantly between installed capacity and that under construction. Currently, hydropower accounts for 58% of the renewable generation capacity, while mostly solar and wind plants are being built (Figure 2.4).

Figure 2.4. Global renewable electricity capacity: installed and under construction, by technology

GW



Note: The category in grey refers to Geothermal, which accounts for less than 1% in both plants in operation and under construction.
Source: Authors' analysis from i) Platts WEPP (2017) for oil and gas; ii) the Global Coal Plant Tracker (2017) for coal; iii) IAEA (2016) for nuclear; iv) IEA (2017[4]) for renewable energy.

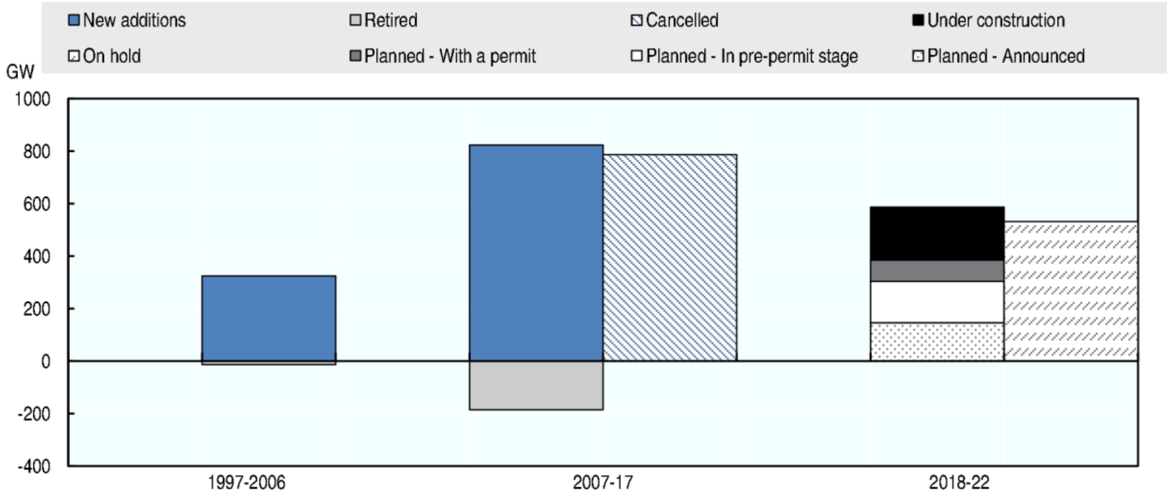
The share of coal in the plants under construction decreased compared to the installed capacity: currently representing 31% of total installed generation capacity, coal power represents 23% of electricity capacity under construction (Figure 2.3). This number could further decrease if the recent trend of coal plants put *on hold* and *cancelled* in the last 10 years continues.

Figure 2.5 describes the evolution of the coal power capacity in the last 20 years, and the "pipeline" of projects in G20 countries. Half of the GW to become operational were cancelled in the last 10 years, driven mainly by India (56 percent of the GW cancelled, followed by China with 26 percent of total). Plants *cancelled* include projects officially announced as cancelled by the plant sponsor, having disappeared from company documents (even if no announcement was made), and plants showing no activity over a period of four years. De facto, plants that have been *cancelled* have never been in operation, and have probably never been built, while plants *retired* are plants that have been decommissioned after having been operational.[7]

When looking at the "pipeline", an additional 200 GW of coal power plants are under construction and should be available by 2022 in G20 countries (amongst which 63% and 22% in China and India respectively). In addition to the plant*s under construction*, over 500 GW of plants ar*e on hold*. Plant*s on hold* represent projects where there is sufficient evidence to indicate that a project is no longer moving forward, but not enough evidence to declare it as definitively *cancelled*. 78 percent of the plants *on hold* (421 GW) are in China, who announced in its Thirteenth Five Year Plan that it would put on hold over 300 GW of planned coal power in the period 2016-2020 (Shearer et al., 2017[22]; Forsythe, 2017[23]).

[7] Data is not detailed enough to know whether plants have been retired earlier than their operational lifetime or not.

Figure 2.5. Evolution of coal power in G20 countries over 1997-2022: new additions, retired, cancelled, under construction, on hold and planned

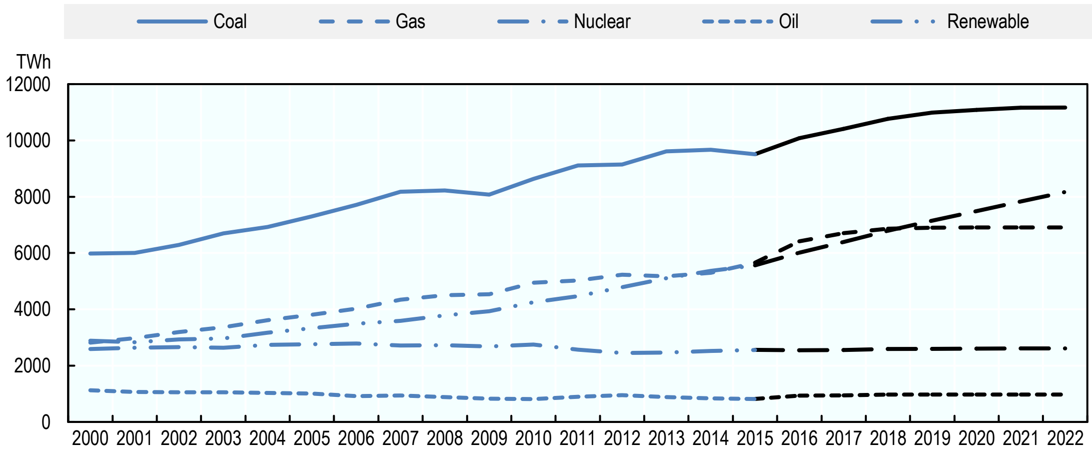


Source: Global Coal Plant Tracker (2017).

2.1.2. Looking at electricity output (GWh)

Whilst the analysis of electricity capacity being built provides some promising signs that the electricity sector is moving away from fossil fuel dependence, looking at the situation in terms of actual electricity output (GWh) paints a somewhat different picture. Figure 2.6 describes the global electricity output per technology. The dotted lines represent the estimates for the period 2016 to 2022, based on the capacity under construction and expected retirements (see Annex A for the methodology used).

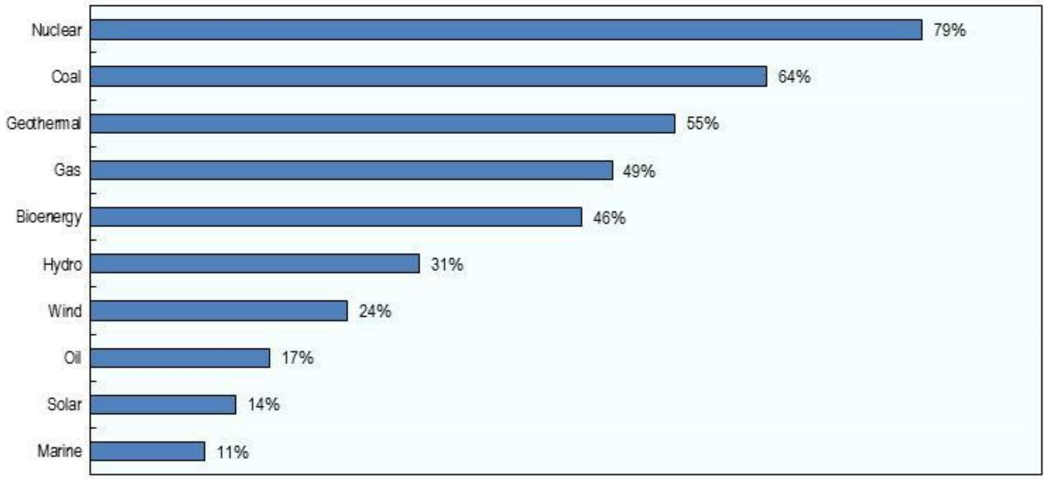
Figure 2.6. Global annual electricity output by technology
TWh, historical data and projections, 2000 to 2022



Note: The blue lines refer to historical data (2000 to 2015). The black lines are estimates based on the power plants under construction and on expected retirements (2016 to 2022). See Annex A for more details on methodology.
Source: IEA (2017[18]) for 2000 to 2015, 2016 to 2022 estimates based on i) Platts WEPP (2017) for oil and gas; ii) the Global Coal Plant Tracker (2017) for coal; iii) IAEA (2016) for nuclear; iv) IEA (2017[19]) for renewable energy; and v) historical capacity factor from IEA and author's calculations.

In spite of the remarkable growth in renewables in terms of installed capacity in recent years (as shown in Figure 2.2 above), data suggests that coal will still be the main source of electricity output by 2022. This seems to contradict Figure 2.2, but can be partly explained by a purely technical point: the electricity generated by 1 GW of a given plant - the "capacity factor" – varies according to the technology used. For example, a coal power plant with a total capacity of 1 GW typically generates more electricity than a solar plant of 1 GW over the same period: a coal power plant can operate day and night, whereas solar plants are dependent on sunlight hours and intensity. Figure 2.7 shows the average capacity factor of different technologies in G20 countries.

Figure 2.7. Average capacity factor by technology in G20 countries



Note: The capacity factor refers to the five-year average (2011-5) in G20 countries. Argentina and Saudi Arabia were excluded from the calculation due to data limitations. See Annex A for more details on methodology.
Source: Author's calculations based on IEA (2017[18]), Platts WEPP (2017); Global Coal Plant Tracker (2017); IAEA (2016); and (IEA, 2017[19]) for renewable energy.

2.2. Is the decarbonisation of electricity on track to meet the Paris Agreement mitigation objectives?

In order to understand the extent to which the "pipeline" is aligned to the low-carbon transition, this section compares the electricity output in the "pipeline" in 2020, to the electricity output in the IEA *Sustainable Development Scenario* (hereafter SDS). The main focus is on coal and renewables: coal accounts for more than 70% of the CO_2 emitted by the electricity sector in 2016, and renewables are expected to account for 36% of the energy sector emissions reduction needed in the SDS (IEA, 2017[16]).

The SDS is a new integrated scenario that shows how the three Sustainable Development Goals (SDGs) most closely related to energy can be achieved in parallel:

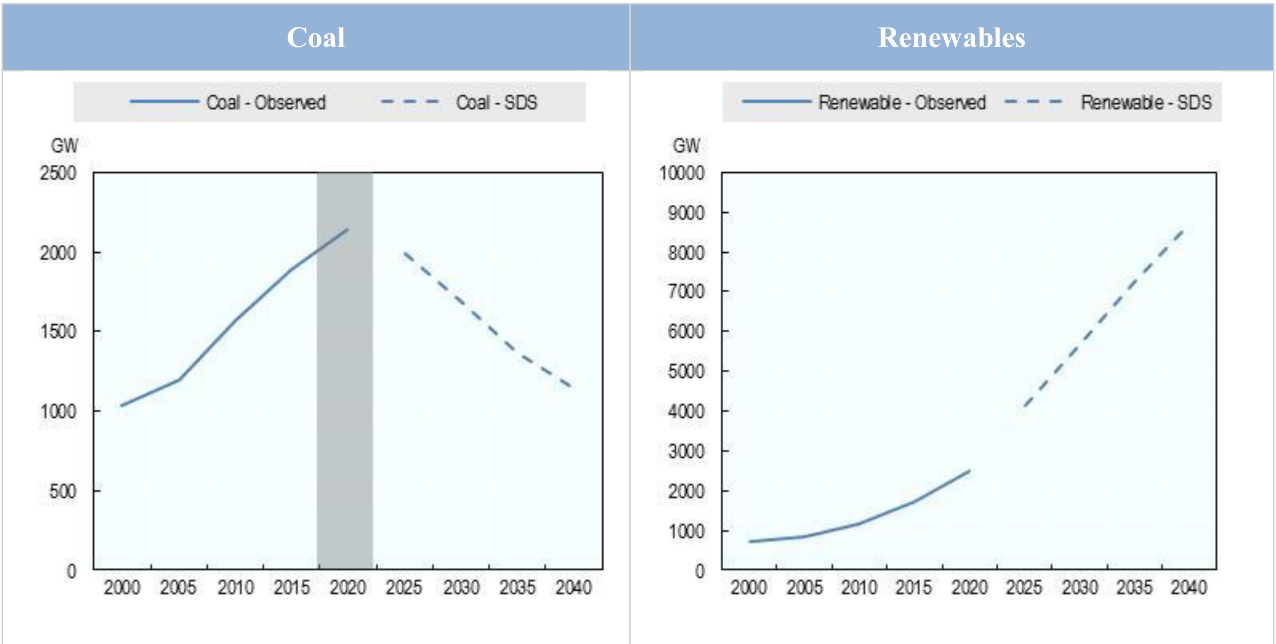
- it ensures universal and sustained access to affordable, reliable, sustainable and modern energy services by 2030 (SDG 7);
- it substantially reduces air pollution, preventing human death and illness (SDG 3.9); and
- it takes effective action to combat climate change (SDG 13) (IEA, 2017[16]).

In the SDS, global energy-related CO_2 emissions peak before 2020 and enter a steep decline, falling by more than 50% to around 18 Gt in 2040. This is at the lower end of the range of publicly available 2040 emission scenarios in the SSP database, all of which project long-term temperature outcomes of between 1.7 and 1.8°C. The long-term temperature outcome beyond the 2040 horizon of the SDS will depend on how quickly emissions fall to zero in the second half of the century, whether global emissions subsequently turn negative and how quickly other GHGs are reduced.[8]

Figure 2.8 compares the global estimates of installed capacity up to 2020 for coal and renewables, to the installed capacity compatible with the SDS scenario. Taking into consideration the plants currently under construction, coal capacity will have increased over the last ten years (2010-20) by 3% per year, to reach over 2,000 GW in 2020. Whilst this is similar to the levels of installed coal capacity under the SDS in 2020, the installed capacity of coal should decrease by 2% per year (to approx. 1700 GW in 2030 in the SDS) in the following 10 years (2020-30) to continue to be compatible with the IEA scenario. This suggests that the current 200 GW of coal capacity under construction over the next five years, and the over 500 GW of coal capacity planned in the future are not compatible with a scenario to stay below 2°C. Renewable energy deployment, on the contrary, appears to be going in the right direction. However, the renewable installed capacity should triple by 2040 to reach the levels of electricity output compatible with the SDS.

Figure 2.8. Coal and renewables: Global installed capacity

GW, observed and IEA projections, 2000 to 2050



Note: The shaded area on the graphs corresponds to the installed capacity taking into consideration the projects currently under construction and available by 2022. See Annex A for more details on methodology.
Source: Observed: Authors' analysis from i) Platts WEPP (2017) for oil and gas; ii) the Global Coal Plant Tracker (2017) for coal; iii) IAEA (2016) for nuclear; iv) IEA (2017[19]) for renewable energy. SDS: (IEA, 2017[16]).

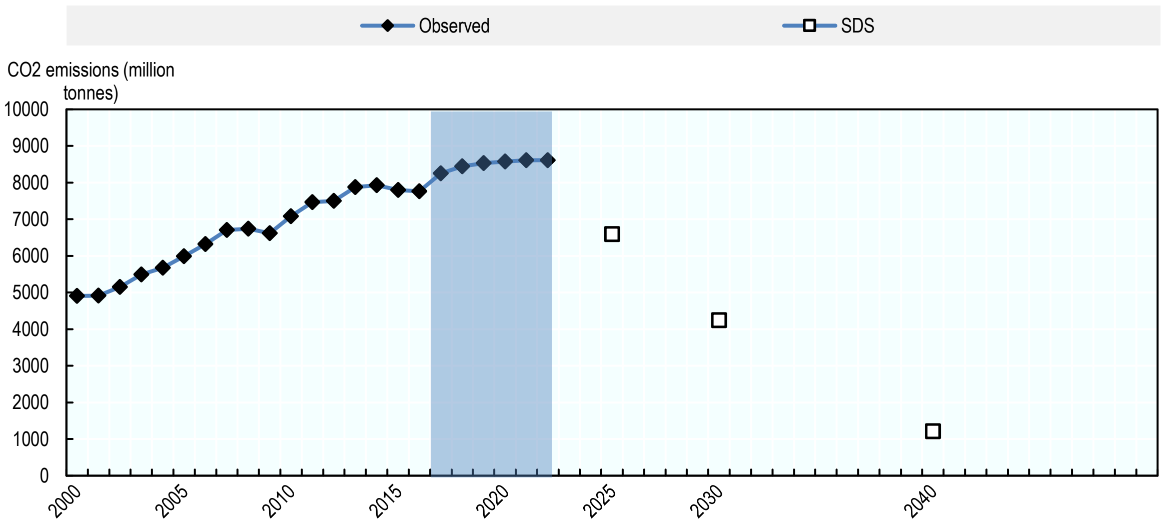
Figure 2.9 compares the annual CO_2 emitted (or expected to be emitted) from electricity generated between 2000 and 2022; with the level of emissions from coal electricity generation compatible with the SDS for the years 2025, 2030, and 2040. To be compatible with the SDS, a particularly sharp decline of emissions for coal power generation is needed: CO_2 emissions from coal power

[8] For further information regarding the SDS see IEA (2017[16]).

generation need to be almost 2 times lower in 2030, and over 6 times lower in 2040, compared to their level in 2015.

Figure 2.9. CO_2 emissions from coal: observed vs. IEA Sustainable Development Scenario

Million tCO_2, observed and IEA projections, 2000 to 2040



Note: The shaded area on the graphs corresponds to the installed capacity taking into consideration the projects currently under construction and available by 2022. See Annex A for more details on methodology.
Source: Observed: Authors' analysis from i) (IEA, 2017[12]) until 2015. From 2016 to 2022, the calculation is based on estimates of GWh and average CO2 intensity (2011-15) from (IEA, 2017[12]).

The analysis presented above indicates that a number of changes need to take place in the electricity sector if the Paris Agreement mitigation goals are to be met:

- Coal needs to be phased-out rapidly, particularly in those countries that currently have the largest electricity generation capacity (i.e. China, India and the United States). This translates into the need to halt new construction and push existing plants into early retirements;
- Renewable energy technology needs to be more widely deployed; coupled with energy efficiency improvements;
- Investment in electricity-demand management systems needs to be ramped up and redirected towards technologies that could help increase the capacity factor of renewable sources of energy. (IEA/IRENA, 2017[24]; OECD, 2017[7]; Sartor, 2017[25]; UN Environment, 2017[26]; Bertram et al., 2015[27]);

Technological advances providing a greater ability to store electricity could make a significant contribution to harnessing more effectively renewable sources of energy with a (currently) low capacity factor, such as solar and wind power. An additional 20 GW of energy storage capacity would be needed in 2025, above the 930 MW of installed capacity observed in 2016. If technology deployment continues at the current pace, this target is likely to be met (IEA, 2017[28]). The digitalisation of energy and the development of smart grids can also push the transition to new heights by making the electricity demand and supply interact more efficiently (IEA, 2017[29]).

Beyond action on coal, renewables and energy-demand management systems, the role of gas in accelerating the low-carbon transition in the power sector is a considerable source of debate (see Box 2.2).

Box 2.2. Can natural gas be a bridge fuel for a low-carbon world compatible with the Paris Agreement goals?

The low-carbon intensity of natural gas, combined with the efficiency of its new power plants, mean that natural gas is often perceived as having the potential to act as a “bridge fuel” capable of replacing more carbon-intensive and pollution-intensive fossil fuels in the short term whilst renewable energy infrastructure is more widely deployed (Hausfather, 2016[30]; Zhang et al., 2016[31]). The role of natural gas in the transition depends on both where and how the gas is used, and also on how it is produced and transported.

The IEA Sustainable Development Scenario, a global energy scenario in line with achieving the goals of the Paris Agreement, sees increasing demand for gas out to 2030, even as demand for the other fossil fuels declines sharply over the coming years. The continued growth of natural gas is driven primarily by industry, though the power sector also contributes, in particular in regions where natural gas displaces coal in the power mix. Natural gas also has a role to play in supporting increased renewables deployment by providing flexibility in the power grid, in the absence of large scale electricity storage. The potential of natural gas to act as a transition fuel is therefore very much dependent on country specificities. Its role could also be greater if coupled with CCS technologies.

The role of natural gas in the transition will also depend on minimising the environmental footprint of its production. Natural gas extraction and distribution is prone to the unintentional release of methane, a GHG close to 30 times more potent than CO_2 over a period of 100 years (IPCC, 2014[32]). The extent of these fugitive emissions is not a trivial affair, with some studies arguing that they could significantly counteract the climate benefits derived from switching from coal to gas in some circumstances (Howarth, Santoro and Ingraffea, 2011[33]; Friends of the Earth Europe, 2017[34]). However, a recent IEA study concluded that with reasonable estimates of methane leakage rates, life-cycle emissions from natural gas are likely to be lower than coal in most regions (IEA, 2017[16]).

Having lower emissions than coal is however an insufficient argument for retaining gas in the low-carbon transition. Further efforts to reduce methane emissions in gas infrastructure are important; IEA estimate that up to half of methane leakage could be eliminated at zero or negative cost, by capturing and selling the gas (IEA, 2017[16]). Secondly, certain forms of natural gas extraction generate significant environmental concerns beyond climate impacts. Fracking in particular is a water-intensive extraction method, and can generate risks of local groundwater contamination by chemicals involved in the process, if insufficiently regulated (Lieberman, 2016[35]). Effective regulation can go some way to minimising these risks (IEA, 2012[36]).

In short, natural gas need not be ruled out as incompatible with climate objectives: its further deployment should however be carefully considered in light of country circumstances, climate objectives and not hamper the deployment of renewable energies.

3. Accelerating the decarbonisation of electricity: challenges and opportunities

A varied set of challenges and opportunities will inevitably accompany the transition away from a fossil fuel centric electricity generation system. In the sections below we explore a few of these, including opportunities linked to improved air quality. Challenges associated to ensuring a just and inclusive transition, managing stranded assets, and compensating for the potential losses of government revenue are also discussed.

3.1. Synergies with the clean air agenda

The use of carbon-intensive sources of electricity, including coal power, not only exacerbates climate change; it also significantly deteriorates air quality. This in turn has dramatic consequences for human and ecosystem health alike, making it – against many preconceptions - one of the more costly forms of energy. In 2015, outdoor air pollution alone prematurely killed close to 4.5 million people (Roy and Braathen, 2017[37]); by 2060, this figure could increase by a factor of two to three (OECD, 2016[38]). The hardest hit regions will include those that are densely populated and have high concentrations of $PM_{2.5}$ and ozone (notably China and India) as well as those with an ageing population. By 2060, the market costs associated to air pollution[9] are likely to be as high as 1% of the global gross domestic product (OECD, 2016[38]). As for annual global welfare costs associated to premature deaths from outdoor air pollution these are estimated at 5 trillion USD in 2015 (Roy and Braathen, 2017[37]). OECD (2016[38]) projected these welfare costs to increase to 18-25 trillion USD by 2060.

A quick and drastic transition to a low-carbon economy will therefore not only increase our chances of limiting the impacts of climate change, it will also help countries protect the health of their populations. This point is an important one to emphasise as it makes the social and economic case for acting on climate change and can therefore increase the public's acceptability of climate action.

3.2. A just and inclusive transition

The foundations of most OECD and G20 economies rest on decades of investment in carbon-intensive fuels. The latter are integral to most of today's societies:

- many people's jobs and mobility revolve around carbon-intensive fuels directly or indirectly;
- people rely on them to gain access to electricity;
- companies rely on them to make their investments and activities profitable; and
- many governments rely on them as a source of revenue and to sustain or develop their country's growth.

Inevitably, such an economy-wide transformation is likely to generate tension among those that benefit from these changes and those that will – in the first instance – consider themselves worse off (OECD, 2017[7]). For that reason, the Paris Agreement highlights the imperative of a "*just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities*" (UNFCCC, 2015[6]). A successful transition will hinge on whether governments can ensure that the costs and benefits of the transition are distributed in an equitable and transparent manner across society.

With regards to the labour market, understanding which job categories will be positively and negatively affected is crucial to designing effective policies that will lead to a smooth and publicly-accepted transition (ILO, 2011[39]). As an order of magnitude, the UNFCCC estimates that close to 1.5 billion people globally are directly employed in sectors that are likely to affect the extent of climate change (Table 3.1). As a result of the low-carbon transition, the energy supply sector and energy-intensive industries are likely to experience the most job destructions across countries, albeit with some regional disparity (Chateau, Bibas and Lanzi, 2018[40]). Prematurely closing assets could cause 1 million job to be lost, or around 20% of the current coal mining employment (IEA/IRENA, 2017[24]). Conversely, the transition is likely to create numerous jobs in other sectors (Chateau, Bibas and Lanzi, 2018[40]), such as in the renewable energy sector which in 2016 employed 9.8 million people globally, a 1.1 % increase over 2015 figures (IRENA, 2017[41]). .

Because the skills of the workers having lost their jobs due to transition will not necessarily match those of the jobs created by the transition, there is a need to accompany and support these populations so that they can adapt to a changing labour market. Ensuring that the policy environment is conducive to developing new business plans which will open up new job opportunities for those previously engaged in fossil fuel intensive activities is key. Measures to help affected workforce build their resilience to the risks and shocks brought about by the transition include upgrading and diversifying workers' skillset to allow for greater job transfer. This is particularly important in countries with limited education opportunities and low-income households where opportunities to re-skill and relocate are limited (OECD, 2017[7]).

Table 3.1. Global direct employment in sectors that have an impact on climate

Sector	Employment (millions of people)
Agriculture	1,000
Forestry	44
Energy	30
Manufacturing (resource-intensive)	200
Buildings	110
Transport	88
TOTAL	1,472

Note: The figure for the energy sector includes employment in (i) construction and installation, (ii) manufacturing, (iii) operations and maintenance, (iv) fuel supply (domestic), and (v) coal and gas exports in North America, Latin America, Europe, Africa, Middle East Eastern Europe and Eurasia, and Asia.
Source: UNFCCC (2016[42]). Energy figures from Greenpeace International & Global Wind Energy Council (2015[43]).

Beyond affecting workers, the transition should not be a regressive process which entrenches structural and social inequalities as well as disproportionally affects lower income households. In this context, the decarbonisation of the electricity sector should not jeopardise the access or the affordability of electricity; to the contrary, opportunities to maximise them should be reaped. Overcoming public concerns that core climate policy instruments (such as carbon prices and the reform of fossil fuel subsidies) will translate into an increase in the cost of electricity is likely to ensure the population's ownership of – and hence buy-in to – the transition.

A number of countries are beginning to make the concept of social justice and inclusiveness an integral part of their climate strategies. One of the pillars of France's *Plan Climat*, for instance, focuses on improving the daily lives of all French people via measures targeting:

- The development of clean and accessible mobility for all;
- The eradication of energy poverty by 2027;
- The encouragement of a "prosumer" energy culture; and
- The development of a circular economy in the country (French government, 2017[44]).

The first concrete measures emanating from this plan were unveiled by the government in September 2017 and will be enacted in 2018. These include:

- direct payments to encourage car owners to switch old polluting cars for new, less polluting vehicles;
- an "energy check" provided to low-income households to help them pay their energy bills;
- a tax credit (converted in a direct payment as of 2019) for households wishing to improve the thermal isolation of their home; and
- green energy certificates of up to 3,000 EUR in the benefit of low-income households wishing to replace their boiler. (French government, 2017[45])

Canada's Just Transition Task Force is another illustration of a governments' will of making the transition to a low-carbon economy a fair and equitable shift. The Task Force was first convened in 2016 to provide expert advice to the government on how to best support coal workers and communities as Canada phases out coal power from its energy mix (Government of Canada, 2016[46]).

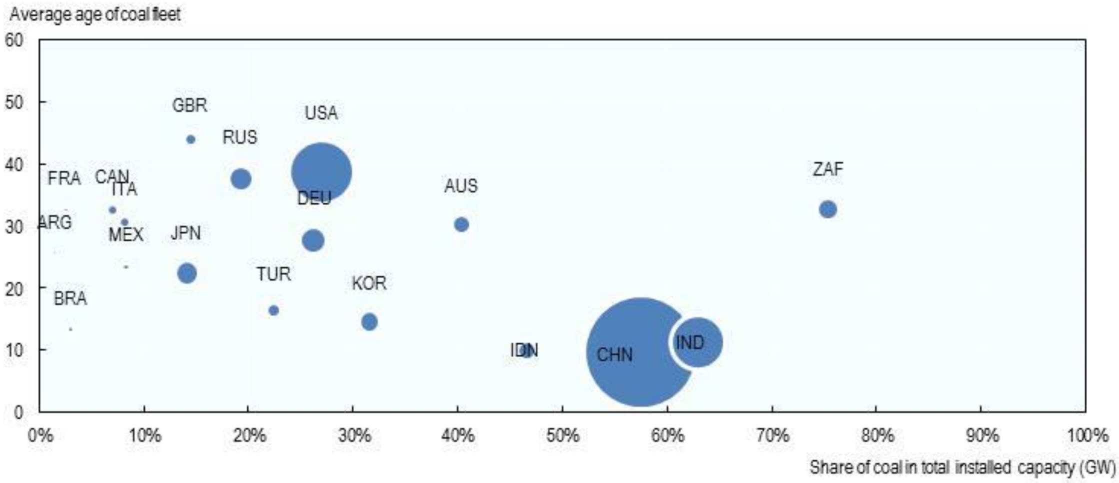
3.3. Stranded assets and government revenues

In addition to overshooting climate targets, building fossil fuel dependent infrastructure will result in stranded assets, defined as assets that are "unable to recover their investment cost as intended, with a loss of value for investors" (Baron & Fischer, 2015[71]). Locking in long-lived assets[10] that risk being stranded will lead to higher costs if the global carbon budget is still to be met, and is sub-optimal from a global welfare perspective (OECD, 2017[7]).

The exposure of a country to stranded assets depends on the amount of fossil-intensive infrastructure in its stocks, the capital intensiveness of assets (which relates to the time needed to recover investment costs), and the age of the infrastructure. Figure 3.1 shows the share of coal power plants in the country's generation capacity, the average age of the coal fleet, and the size of the coal generation capacity stock in G20 countries. Countries on the lower right-hand side of the chart are those more exposed to stranded assets, given the low age of the fleet and the high share of the generation capacity to be replaced by less emitting technologies.

[10] The technical lifetimes of power plants range between: 45 and 60 years for existing fossil-fuel plants and nuclear plants (unless otherwise specified by government policies), 50 years for hydropower projects, 25 years for bioenergy power plants, and between 20 and 30 years for wind and solar PV (IEA, 2017[36]).

Figure 3.1. Exposure to stranded assets in G20 countries: average age of coal fleet and share of coal in total installed capacity



Note: The size of the bubble represents the size of the coal generation capacity stock.
Source: Author's calculations based on the Global Coal Plant Tracker (2017).

Beyond stranded assets, the transition may also lead to a loss of revenue for governments that collect rents from fossil fuel use. Over the period 2011-2015, OECD countries reaped USD 130 billion in revenue from fossil fuel rents (OECD, 2017[7]). Phasing out carbon-intensive sources of energy from the economy in these countries will therefore translate in a loss of governmental revenue from that source.

However, new evidence is emerging concerning the potential for the transition to generate new government revenue streams. Approximately USD 28.3 billion is collected each year by governments of 40 countries and 16 states or provinces around the globe. 27% of this revenue is thought to feed back into the financing of the transition by subsidising spending in energy efficiency or the deployment of renewable technologies. 26% goes straight into governments' general budget, and 36% finance tax cuts and direct rebates (Carl and Fedor, 2016[47]).

The section above highlighted a few of the opportunities and risks associated to the low-carbon transition. These will vary according to a number of factors associated to national circumstances (including natural resources, population dynamics, education levels, level of development and policy priorities). What remains clear, however, is that governments have a key role to play in pushing forward the energy transition. The section below explores in greater detail how governments can play a key role in contributing to the decarbonisation of their country's economy.

4. The role of governments as infrastructure commissioners in the decarbonisation of the electricity sector

There are several policy levers that governments can use to accelerate the decarbonisation of the electricity sector. Firstly, developing strong coherent climate policies should be the heart of governmental strategies to move towards a low-carbon economy. These include: (i) putting a price on carbon, (ii) eliminating fossil fuel subsidies, (iii) introducing regulations in areas where carbon pricing would be less effective, and (iv) providing economic incentives for the deployment of low-carbon technologies at a large scale.

Beyond policy settings and their capacity as regulators, governments have an important role to play to foster the low carbon transition in its capacity as investor as well as planners.[11].

4.1. Governments as planners

The invitation under the UNFCCC to formulate NDCs and Long-term Strategies (LTS) provides an opportunity for governments to plan medium- and long-term pathways to decarbonise their economies and achieve the Paris Agreement goals. To date, commitments made under the countries' current NDCs are not sufficient to achieve the Paris Agreement climate goals (UN Environment, 2017[26]; OECD, 2015[48]), and only 6 countries[12] have formulated a LTS. Raising the ambition of these NDCs and pushing forward the formulation of LTSs is one powerful way of providing direction to investors of where the electricity sector – in terms of infrastructure – may be headed. This high-level planning could incentivise the private sector to move away from carbon-intensive forms of energy, above and beyond what certain actors have committed to undertaking (see Box 4.1).

Beyond the UNFCCC instruments themselves, governments can formulate long-term infrastructure plans to provide private investors with a clear vision of where the electricity sector is headed, and hence where future investments can or should be made (OECD, 2017[7]). The need to formulate such long-term infrastructure plans was identified during the 2014 G20 Summit in which leaders agreed that "*to help match investors with projects,* [they would] *address data gaps and improve information on* [infrastructure] *project pipelines*" (G20 Leaders, 2014[49]).

[11] Governments may also mobilise investment through providing incentives or instruments such as guarantees.

[12] Benin, Canada, France, Germany, Mexico, United States of America.

Box 4.1. Private sector commitments to move away from carbon-intensive forms of energy

Over the past few years, private stakeholders have divested from fossil-fuel intensive investments as a response to policy signals and the drop in renewable energy prices, in particular for solar photovoltaic.

The private sector's commitment to move away from carbon-intensive forms of energy is probably best epitomised by the recent One Planet Summit organised on 12 December 2017 by the President of France, Emmanuel Macron. This Summit triggered a new wave of commitments from the public and private sector alike to intensify efforts to implement the Paris Agreement. Among these, *Climate Action 100+* was launched. This initiative brings together 225 institutional investors, managing more than USD 26.3 trillion assets, the aim of which is to influence more than 100 large companies in ramping up efforts to reduce greenhouse gas emissions and strengthen climate-related financial disclosures (Climate Action 100+, 2017[50]).

In addition, under the *Powering Past Coal* alliance, launched by the United Kingdom and Canada at COP23, a number of larger corporations – including BT, Engie, and Unilever for instance – committed to "powering their operations without coal" as well as supporting clean power and "restricting their financing of coal power without CCS" (Powering Past Coal Alliance,(n.d.)[51]).

In parallel, many individual private sector actors have taken commitments to move away from fossil fuel use and investments. The insurance company AXA for instance committed to divesting EUR 2.4 billion from companies that derive more than 30% of their energy or revenues from coal as well as not to insure the construction of new coal plants or oil sand extractions (Thouet, 2017[52]).

However, to date, governments have made little progress in articulating and communicating clear infrastructure plans. Practical barriers, such as the difficulty of coordinating between different ministries and the distribution of responsibility across levels of government, go part of the way in explaining this lack of progress. More fundamentally, however, the concept of "infrastructure pipeline" is poorly understood – let alone the elements it should contain (see Box 4.2). Yet, if properly designed, they have the potential to serve as a powerful link between long-term objectives and short-term action. They can potentially connect top-down vision, planning, market creation and goal setting by governments to the bottom-up delivery and execution of project-level infrastructure assets by investors, project developers, and actors along the investment supply chain (OECD, 2018[53]).

Governments therefore have a key role to play in bringing clarity on which type of infrastructure is expected in the short, medium and long-term, where, and – importantly – which types of investment should not be made. Articulating electricity infrastructure plans which mainstream climate considerations alongside development goals is key to mobilising investments that can accelerate the decarbonisation of the electricity sector.

Some global initiatives are being developed to improve the transparency of infrastructure project pipelines across three main areas:

- Providing research and leadership to align infrastructure investment plans with sustainability targets (e.g. the OECD Centre on Green Finance and Investment[13], the New Climate Economy);
- Assisting i) governments in developing bankable projects and ii) investors in channelling funds into those projects (e.g. the Global Infrastructure Hub and SOURCE, a joint global initiative from Multilateral Development Banks); and
- Facilitating the integration of environmental and social components of infrastructure projects into investment decisions (e.g. IRENA Navigator and the World Bank's REFINe)

Mainstreaming climate considerations in these global initiatives is key. The Global Infrastructure Hub (GI Hub) launched by the G20 in 2014 is an example of a tool that could prove useful to increase transparency and strengthen the global pipeline of private and public infrastructure investment opportunities. It showcases investment-ready projects to multilateral banks and private investors. A major drawback of this platform is that it does not encourage potential infrastructure decision makers and investors to take into consideration sustainability aspects. An assessment of the types of technologies in the electricity sector similar to the one proposed in this analysis could be a way of mainstreaming climate considerations and analysing whether future infrastructure decisions are in line with the Paris Agreement goals.

[13] See www.oecd.org/cgfi/.

Box 4.2. – Understanding the nature of an infrastructure project pipeline.

Currently, an infrastructure project pipeline is commonly understood as a list of future infrastructure assets. However, to be a useful means to concretely translate nationally-determined contributions into tangible policies, regulations and investment opportunities for private sector actors, the pipeline must also be supported by an interface via which the government can effectively communicate with private actors.

The precise elements that should constitute the interface or its form is an emerging research question. In order for these pipelines to be useful in redirecting electricity infrastructure in the near future, identifying these elements quickly is vital. The following recommendations can facilitate the formulation of such pipelines at a national level:

- The process of drafting infrastructure pipelines should include local governments (including cities) given their practical know-how in developing infrastructure projects.
- Infrastructure pipelines should take into account the political, institutional and economic factors that are inherent to a given country and affect infrastructure investment and planning priorities (e.g. level of development, level of co-operation with government, previous infrastructure investment and expected future needs, etc.).
- The infrastructure pipeline should build on a strong policy framework of core climate policies.
- Governments should make use of a number of policy levers to articulate the pipelines, including by: (i) using public budgets to fund large capital infrastructure projects; (ii) leading public-private partnerships; (iii) supporting research into innovative technologies; and (iv) shaping a domestic enabling environment.
- Infrastructure pipelines should include timings, capacity needs and locations, as well as relevant policy support for specific projects.

Source: OECD (2018[53]).

4.2. Governments as investors

Beyond stimulating investments from the private sector, governments also invest in companies in key economic sectors, including electricity. State-owned enterprises (SOEs) can take many forms: ranging from a company that is fully state-owned, to one that is owned in majority by the State, or to one in which the State owns a minority of shares (Prag, Röttgers and Scherrer, 2018[54]).

In the electricity generation sector, these SOEs occupy a central role. Worldwide, they account for 61% of total global electricity capacity installed in 2016 and approximately 52% of capacity planned or under construction (Prag, Röttgers and Scherrer, 2018[54])[14]. They serve a range of purposes by allowing the government to:

- better guarantee electricity supply throughout the country, including in remote areas which would not necessarily attract the interest of private stakeholders. This

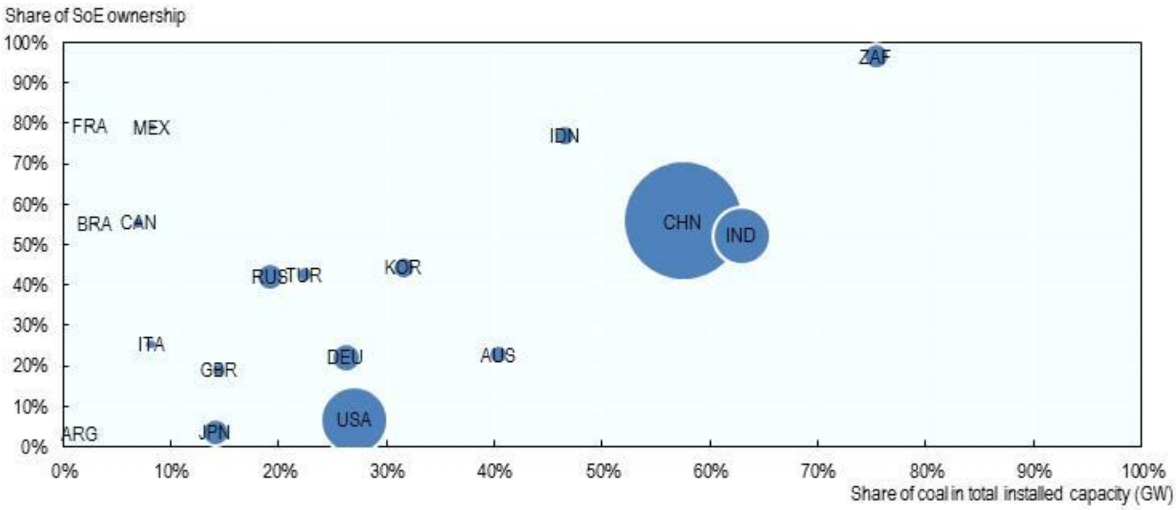
[14] As of data available in Q3 2017.

is particularly important in countries where universal access to electricity has not yet been achieved;

- control strategically sensitive energy supply chains;
- generate state revenue; and
- gain access to foreign technologies.

Undoubtedly, SOEs are some of the entities with the most to lose from the transition in terms of stranded assets. Owning about 70% of oil and gas production assets and 60% of coal mines and power plants worldwide (Climate Policy Initiative, 2014[55]), they are heavily involved with the fossil fuels industries that countries should strive to move away from as soon as possible. Figure 4.1 shows for G20 countries the share of coal from total capacity generation, and the share of ownership of the total (not only coal) generation capacity by SOEs. While the share of SOE ownership vary significantly, most countries dependent on coal for their electricity supply have a high share of SOE ownership of the power generation fleet (right-hand side of Figure 4.1). In these countries, governments will bear a large part of the costs associated to the stranded assets brought about by the transition.

Figure 4.1. Share of SoE ownership and the importance of coal in total installed capacity in G20 countries



Note: The size of the bubble represents the size of the coal generation capacity stock. The share of SoE ownership is an estimate based on publicly available SoE ownership data.
Source: Author's calculations based on IEA (2017[18]) (2015 data) and (Prag, Röttgers and Scherrer, 2018[54]).

The transition to a low-carbon economy generates risks and provides opportunities for SOEs and governments. As SOEs have a strong foothold in electricity markets, they represent an opportunity for governments to redirect electricity-related activities towards more sustainable sources of electricity. Yet, recent evidence suggest that SOEs are still continuing to invest in coal power, to a greater extent than their private counterparts, thereby increasing the risk of stranding assets (Prag, Röttgers and Scherrer, 2018[54]). There is therefore further scope for governments to use their power of influence in these SOEs to further accelerate the uptake of low-carbon sources of energy as well as the phase-out of coal.

5. Conclusion

The findings of this paper illustrate that the known "pipeline" of electricity generating infrastructure projects in the next five years is not in line with what is needed to reach the long-term Paris Agreement temperature goals. In particular, the phase-out of coal and the deployment of renewable energy need to be drastically accelerated. Beyond that, investing in technologies capable of increasing the capacity factor for renewables and storing the electricity produced in peak hours as well as energy efficient improvements are key to allow countries to reap the full benefits of renewable power in an efficient manner while maintaining energy security.

The decarbonisation of the electricity sector must involve all actors, ranging from public and private economic actors as well as civil society. Governments however have a leading role to play in sending strong signals that a shift is underway and should be accelerated. Sending such signals begins with implementing strong climate policies, at the heart of which is putting a price on carbon by implementing measures such as taxes on carbon or emission trading schemes. Such carbon-focused policies could prove to be a suitable alternative transitional source of revenue for governments currently reliant on fossil fuels rents, thereby making the transition more affordable. Policies focused on carbon can also help internalise the economic, social and human health costs associated to the air pollution caused by CO_2 emissions, thereby tackling two policy goals simultaneously.

Beyond traditional climate policies, infrastructure planning is central to the transition. The articulation of clear, short and long-term electricity infrastructure plans which mainstream climate considerations alongside development goals is also crucial to further enable the transition. These plans can serve the dual purpose of redirecting the activity of SOEs involved in carbon-intensive electricity infrastructure (such as coal power plants) towards low-carbon sources of electricity, as well as providing strong investment signals to the private sector.

Finally, governments have the power to ensure that the transition to a low-carbon economy is (i) just, by opening up new opportunities for people whose jobs are likely to be affected by the shift away from carbon-intensive electricity generation, as well as (ii) socially inclusive, by benefitting populations as a whole.

The 2018 Talanoa (Facilitative) Dialogue and the taking stock at COP24 provide an opportunity for countries to review the adequacy of collective efforts and to inform the preparation of revised NDCs. Given the scale of challenges, it is also an opportunity to increase the ambition of their near-term action to 2020, formulate long-term strategies under the UNFCCC process, and revise their NDCs covering the period after 2020. Firming up plans to further decarbonise the electricity sector fits particularly well in this agenda.

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Annex A. Methodology

This paper focuses on power plants *under construction* in the period 2017-22, and briefly describes coal power plants *planned*, *on hold* and *cancelled* from 2010 to 2017. The coverage of the analysis is global.

Power plants *under construction* refer to projects where physical construction is proceeding. Plants *planned* are plants that have appeared in corporate or governmental planning, have applied for environmental permits or were granted permission to construct, but have not started physical construction yet. Plants *on hold* represent projects where sufficient evidence is found to indicate that a project is no longer moving forward (sponsor announcement or no activity over a period of two years), but not enough to declare it definitively *cancelled*. Plants *cancelled* include projects officially announced as cancelled by the plant sponsor, having disappeared from company documents (even if no announcement is made), and plants showing no activity over a period of four years, unless there is evidence to the contrary.

The analysis is presented in terms of the generation capacity (expressed in GW) in operation and under construction by 2022, the electricity output (expressed in GWh) and the tonnes of CO_2 (tCO_2) emitted or expected to be emitted by 2022.

Capacity (GWs)

Different data sources specialise in specific technologies. Data from the data sources below have been merged to ensure the best possible coverage per technology (Table A A.1). Data from national sources were not included in this analysis due to time constraints

Table A A.1. Capacity generation data

Technology	Source	Date of reference	Level of data disaggregation
Coal	(Global coal plant tracker, 2017[2])	July 2017	Power plant
Oil	(Platts WEPP, 2017[1])	March 2017	Power plant
Gas	(Platts WEPP, 2017[1])	March 2017	Power plant
Nuclear	(IAEA, 2017[3])	May 2017	Power plant
Renewables	(IEA, 2017[19])	October 2017	Country level

Source: Authors.

The level of disaggregation of data varies between sources. The Global Coal Tracker (GCT), Platts and IAEA provide data for coal, oil, gas and nuclear at the plant level (i.e., each row in the database refers to an individual power plant). Data is categorized by the status of the plant, namely: *in operation* (in 2017), *under construction*, *planned*, *shelved (on hold)*, and *decommissioned/retired*. Renewables data is based on IEA (2017[19]), and is provided aggregated at the country-level per year (i.e., a row refers to the GWs in operation in a specific country in a specific year), for the period 2000 to 2015.

Using the information on the status of the plant, together with the date in which the power plant was built or retired, a time series of generation capacity in operation has been (retroactively) constructed from 2000 to 2017 for coal, gas, nuclear and oil. Whenever information on the built or retired date is missing, dates are estimated. The following steps are carried out:

(1) Estimates of missing dates

For gas and oil, a large part of the sample missed retirement dates (see table below). An average lifetime estimate is calculated based the observed retirement dates of power plants, while accounting for country-, year and technology idiosyncrasies. Based on these estimations, retirement dates are estimated for power plants without an observed retirement date. The same methodology is used to estimate the power plants “in operation” in 2017 that will be retired by 2022 (see item 3).

Table A A.2. Share of generation capacity data with built and retired dates

	In operation with date built	Retired with both dates
Coal	100%	95%
Gas	99%	55%
Oil	97%	58%
Nuclear	100%	99%

Source: Authors.

(2) Construction of time series – 2000 to 2017

Using built and retirement dates for each plant, it is possible to reconstruct a time series from 2000 to 2017, as follows:

$$\textbf{Plants in operation in year}_i = \\ \text{plants in operation in 2017 built after or at year}_i + \\ \text{plants marked decommissioned in 2017, but decommissioned after year}_i$$

(3) Construction of time series – 2018 to 2022

Based on the plants “in operation” in 2017 as the starting point, the time series of GWs from 2018 to 2022 ($year_j$) are calculated as follows:

$$\text{Plants in operation in year}_j \\ = \text{plants in operation in 2017 expected to be decommissioned afteryear}_j \\ + \text{plants under construction expected to be built before or at year}_j$$

Generation (GWh)

The electricity output (GWh) is based on the IEA World Energy Balances database. Data are available for all technologies per country from 2000 to 2015. Electricity output from renewable generation for the period 2016 to 2022 are based on IEA (2017[19]). Electricity output of coal, oil, gas and nuclear for the period 2016 to 2022 are estimated by multiplying the generation capacity in a specific year, by the observed capacity factor (expressed in hours, i.e. multiplied by 8760) per technology and country in 2015:

$$\text{Electricity output for technology}_i\text{, country }_j\text{and year}_j \\ = \text{plants (GWs)in operation in year}_j \\ * \text{capacity factor (expressed in total hours)}$$

The capacity factor is based on IEA estimations and estimated by dividing the average GWh in 2014 and 2015 from (IEA, 2017[18]) by the generation capacity estimated in those years for countries for which IEA data were not available. The implicit assumption is that the running hours observed in the past will be constant in the future. Recently observed reductions in running hours for coal in particular are not taken into account, and imply that the estimates presented may overestimate the electricity output produced by coal power plants.

Emissions for coal (million tonnes of CO_2)

CO2 emissions from coal are based on IEA data on CO2 from fuel combustion, available until 2015. From 2016 to 2022, the calculation is based on estimates of GWh (see section above) and the average CO2 intensity between 2011 and 2015 from (IEA, 2017[12]). Data relates to emissions from electricity including combined heat and power (CHP).

Age of fleet

The age of fleet for the period 2000 to 2017 was estimated for coal, oil and gas, which are the technologies for which data are available at the power plant level (see Table A A.1). Starting from the time series of generation capacity - estimated as explained in section “Capacity (GWs)” above - a weighted average is used to calculate the age of the fleet per country (c) and technology (t):

$$\frac{\sum_{c,t,i} Age_{\ i} * MW_i}{\sum_{c,t,i} MWi}$$

Where i= power plants in country c and technology t.