International comparison of fossil power efficiency and CO_2 intensity - Update 2018

FINAL REPORT

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By: Sam Nierop and Simon Humperdinck
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Summary

The purpose of this study is to compare the power generating efficiency and CO_2-intensity of fossil-fired power plants for Australia, China, France, Germany, India, Japan, Nordic countries (Denmark, Finland, Sweden and Norway aggregated), South Korea, United Kingdom and Ireland (aggregated), and the United States. This is done by calculating separate benchmark indicators for the generating efficiency of gas-, oil- and coal-fired power plants. Additionally, an overall benchmark for fossil-fired power generation is determined. The benchmark indicators are based on deviations from average generating efficiencies. The study is based on data from the IEA Energy Balances (2018 edition).

Trends in power generation

Total power generation in 2016 is largest in China with 5,936 TWh, with the United States following as second (4,119 TWh), and India (1,226 TWh) and Japan (873 TWh) as third and fourth respectively. Total power generation is smallest in Australia (232 TWh), United Kingdom and Ireland (312 TWh) and the Nordic countries (383 TWh). The countries included in the study generated 64% of public power generation worldwide in 2016, while the share of fossil power used in the public power production mix was 67%. Total fossil power generation is largest in China with roughly 4,323 TWh, exceeding the United States (2,683 TWh). India is the country ranked third with 994 TWh. From the fossil fuels, coal is most frequently used in all countries except Japan, France and UK & Ireland. Figure 1 shows the breakdown of public power generation per country.

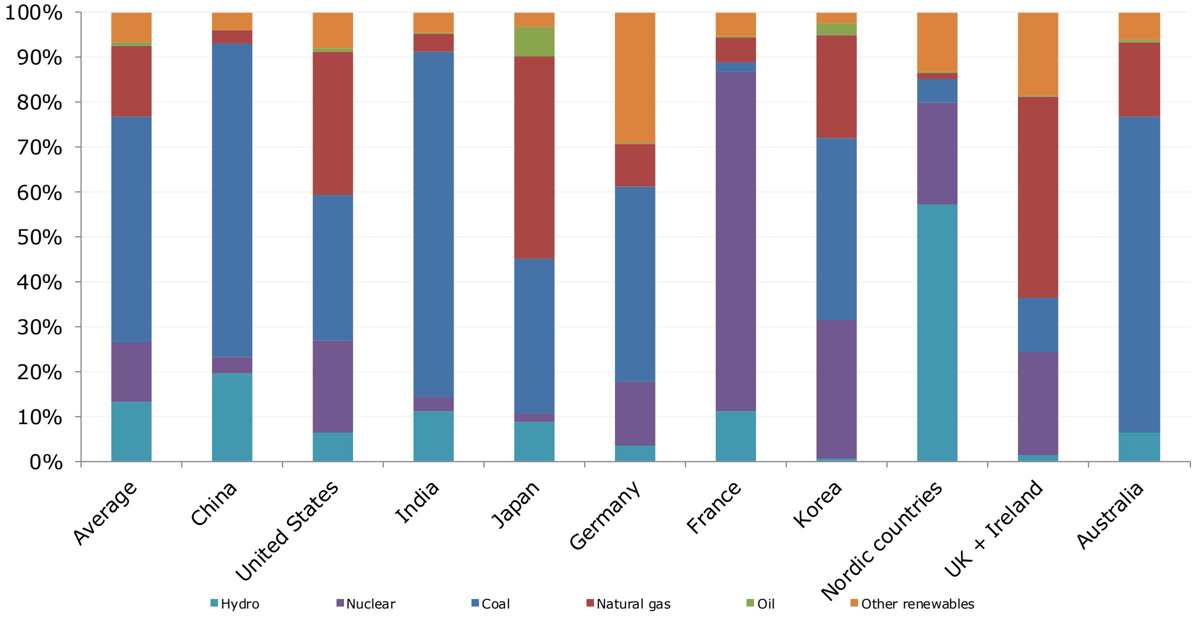

Figure 1 Public power generation by fuel source in 2016.

Total coal-fired power generation in all countries in this study is unchanged in 2016 compared to 2015 from 7,426 to 7,436 TWh (+0%), after the first major decrease from 2014 to 2015 reported in last year's report. The United States still saw a major decrease of 8% compared to 2015 driven by relative low natural gas prices due to shale gas development.

Total gas-fired power generation in all countries in this study increased significantly from 2,147 in 2015 to 2,316 TWh in 2016 (+8%). The United States especially shows a strong absolute growth from 1,273 to 1,316 TWh (+3%), due to the abovementioned shale gas development.

Oil-fired power generation played a marginal role in 2016 with only 107 TWh (around 1% of overall fossil-fired power generation). Japan and the United States were the largest oil-fired power producers and generated 79% of all oil-fired power production in the countries under consideration in this study. The general trend is that power production from oil has been declining over 1990 – 2016, although some temporary peaks can still be observed (e.g. Japan almost tripled power production from oil in 2012 compared to 2010 after the Fukushima incident).

Generating efficiency

Figure 2 shows the generating efficiency per country and fuel source according to the statistics used. Because the uncertainty in the efficiency for a single year can be high, we show the average efficiencies for the last three years available: 2014 – 2016. The following results can be highlighted:

- Coal-fired power efficiencies range from 35% (Australia & India) to 42% (Japan).
- Gas-fired power efficiencies range from 38% (Australia) to 57% (Korea).
- Oil-fired power efficiencies range from 28% (India) to 42% (Japan).
- Fossil-fired power efficiencies range from 35% (India) to 46% (UK + Ireland).

The weighted average generating efficiency[1] for all countries together in 2016 is 37% for coal, 49% for natural gas, 40% for oil-fired power generation and 40% for fossil power in general.

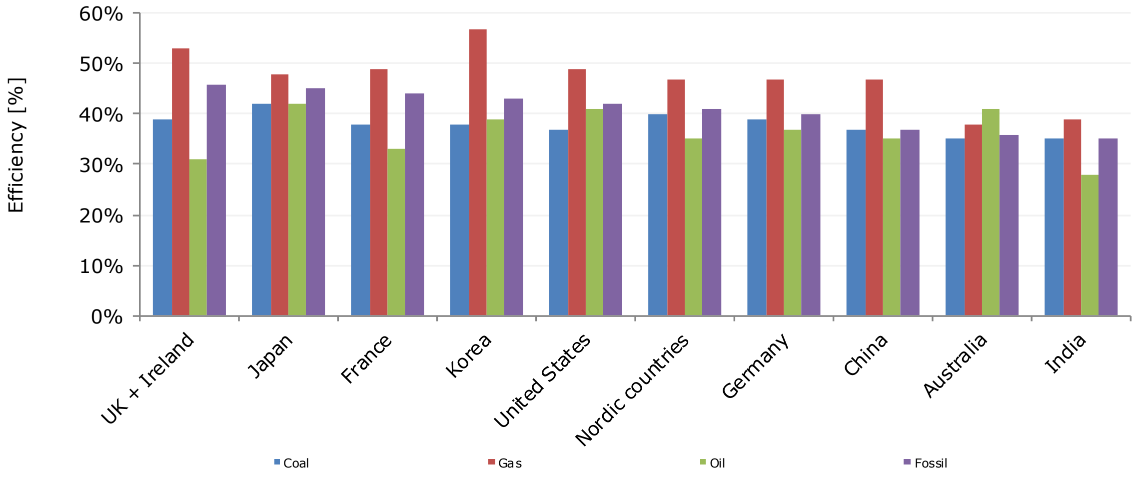

Figure 2 Generating efficiency per fuel source (average 2014 – 2016).

[1] See section 2 for details on definitions and calculations.

The weighted average efficiency for gas-fired power generation shows a strong increase from 38% in 1990 to 49% in 2016 for the considered countries (see Figure 3). This is caused by a strong increase in modern gas-based capacity: gas-based production more than quadrupled. However, while coal-fired power generation more than doubled in the period 1990 - 2016, the weighted average efficiency only increased slightly from 35% to 37%. The reason for this is that best available technology is not applied widely, as the efficiency that can be achieved by applying best available technology (super-critical units) is as high as 47%. In particular in India, where a significant part of the growth in coal-fired power generation took place, generating efficiencies of coal remain below average. The weighted average efficiency for oil-fired power generation shows a negative peak from 1997 to 2001 due to a negative peak of the oil-fired generation efficiency in the United States, which is likely caused by data inconsistencies.

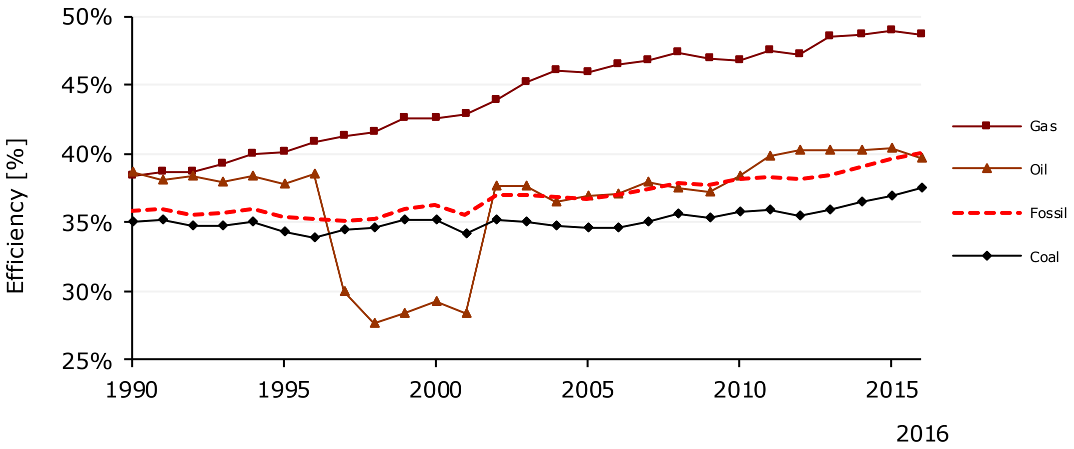

Figure 3 Weighted average generating efficiency for included countries.

Figure 4 shows the benchmark for the weighted efficiency of fossil-fired power generation for 2014-2016. Countries with benchmark indicators above 100% perform better than average and countries below 100% perform worse than the average. As can be seen, in order of performance, United Kingdom and Ireland, South Korea, Japan, Germany, the Nordic countries, France and United States all perform better than the benchmark fossil-fired generating efficiency. China, India and Australia perform below the average generating efficiency for fossil power.

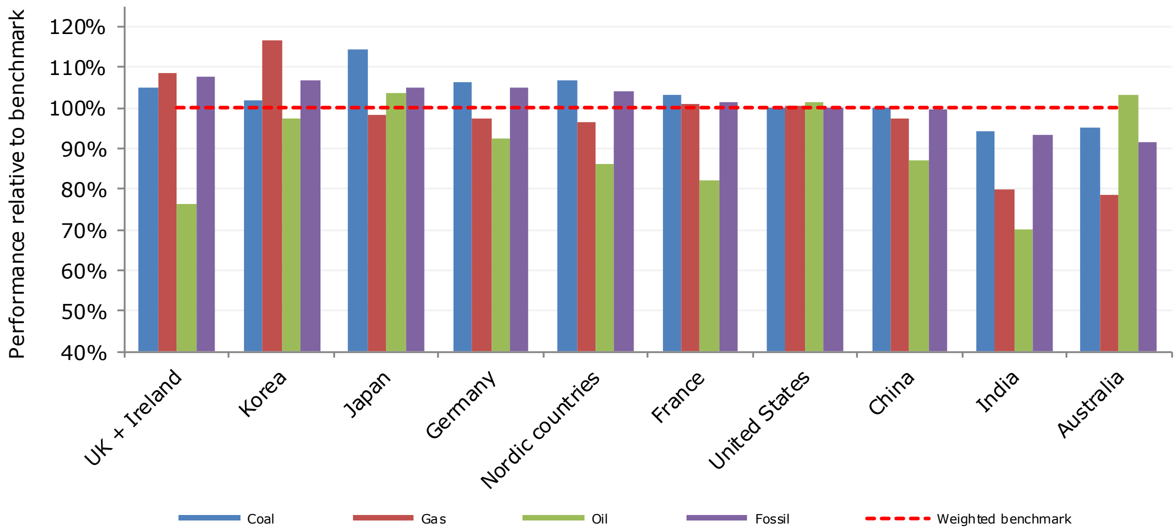

Figure 4 Benchmark for weighted generating efficiency of fossil-fired power plants for period 2014-2016 (100% is average).

CO_2-intensity and reduction potential

Figure 5 shows the CO_2-intensity for fossil-fired power generation for the years 2014 – 2016 per country. The CO_2 intensity for fossil-fired power generation ranges from 581 g/kWh for United Kingdom and Ireland to 962 g/kWh for India. The CO_2 intensity for fossil-fired power generation depends largely on the share of coal in fossil power generation and on the efficiency of power production.

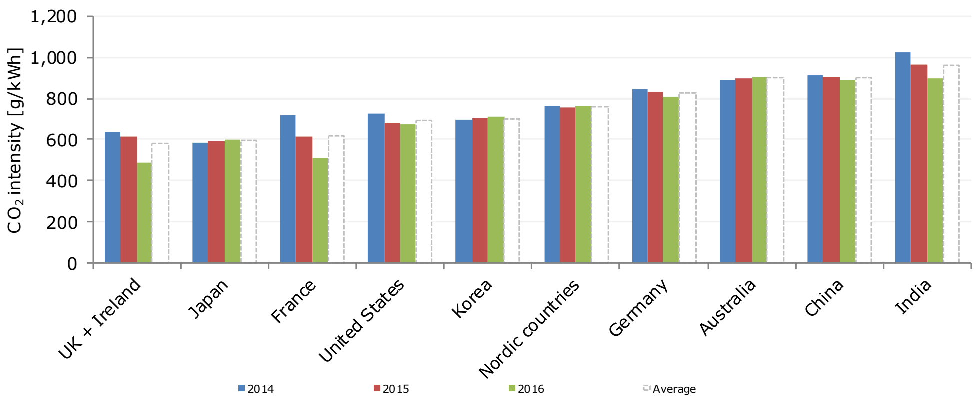

Figure 5 CO_2-intensity for fossil-fired power generation for period 2014-2016.

If the best available technologies (BAT)[2] would have been applied for all fossil power generation in the countries of this study in 2016, absolute emissions would have been, on average, 20% lower. Figure 6 shows how much lower CO_2 emissions would be for all individual countries as a share of emissions from fossil-fired power generation. The emission reduction potential per country ranges from 14% for United Kingdom and Ireland to 27% for Australia.

[2] Installations operating according to the present highest existing conversion efficiencies.

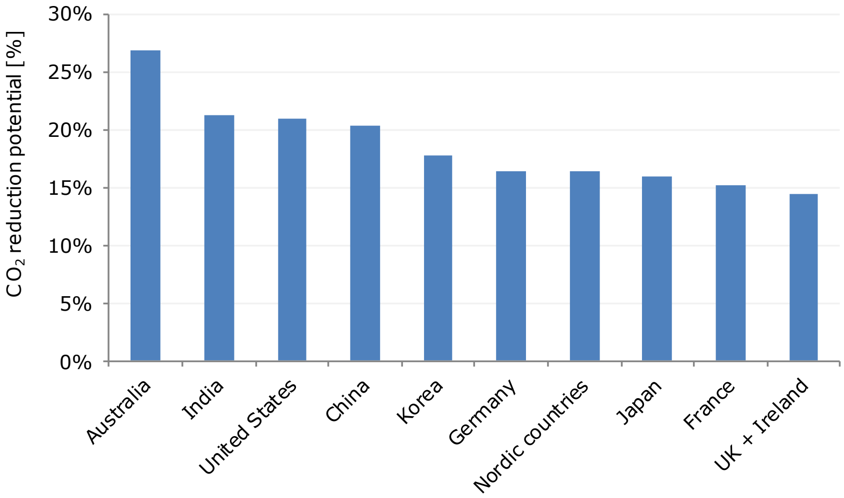

Figure 6 Relative CO_2 emission reduction potential for fossil power generation by efficiency improvement by replacing all fossil public power production by BAT for the corresponding fuel type in 2016.

Figure 7 shows the emission reduction potential in absolute amounts that could be achieved by replacing existing capacity with BAT. China, United States and India show very high absolute emission reduction potentials of 785, 380 and 189 Mt CO_2, respectively. This is mainly due to large amounts of coal-fired power generation at relatively low efficiency.

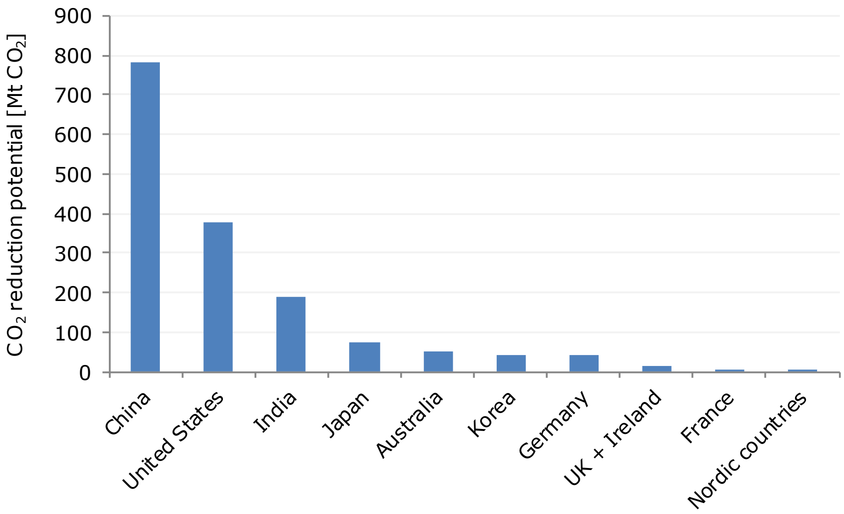

Figure 7 Absolute CO_2 emission reduction potential for fossil power generation by efficiency improvement by replacing all fossil public power production by BAT for the corresponding fuel type in 2016.

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1 Introduction

This study is an update of the analysis “International comparison of fossil power generation and CO_2 intensity” (Ecofys, 2017). This analysis aims to compare fossil-fired power generating efficiency and CO_2-intensity (coal, oil and gas) for Australia, People's Republic of China, France, Germany, India, Japan, South Korea, Nordic countries (Denmark, Finland, Sweden and Norway aggregated), United Kingdom and Ireland, and the United States. This selection of countries and regions is based on discussions with the client. United Kingdom and Ireland, and the Nordic countries are aggregated, because of the interconnection between their electricity grids. Although the electricity grids in Europe are highly interconnected, there are a number of markets that operate fairly independently. These include the Nordic market (Denmark, Finland, Sweden and Norway), the Iberian market (Spain and Portugal) and United Kingdom and Ireland (European Commission, 2016).

The analysis is based on the methodologies described in Phylipsen et al. (1998) and applied in Phylipsen et al. (2003). Only public power plants are taken into account, including public CHP plants. For the latter a correction for the (district) heat supply has been applied.

This chapter gives an overview of the fuel mix for power generation for the included countries and of the amount of fossil-fired power generation. The methodology for this study is described in Chapter 2. Chapter 3 gives an overview of the efficiency and CO_2 intensity of fossil-fired power generation by fuel source and addresses the development of the share of renewables in public power generation over time. Chapter 4 outlines the main conclusions. Chapter 5 discusses uncertainties in data and analysis, and provides recommendations for detailed follow-up actions.

1.1 Power generation by fossil-fuel sources

Fossil-fired power generation is a major source of greenhouse gas emissions. Worldwide, electricity and heat generation accounted for 42% of total greenhouse gas emissions from fuel combustion in 2015 (IEA Emissions, 2017). The countries included in the study generated 64% of public power generation worldwide in 2015 (IEA, 2018).

In 2016, the total power generation (incl. renewables and nuclear power) was largest in China with roughly 5,936 TWh, exceeding the United States (4,119 TWh), see Figure 8. Japan generated 873 TWh. The share of fossil fuels in the overall fuel mix for electricity generation was 67%. France, which has a large share of nuclear power (76%) and the Nordic countries with a large share of hydropower (57%) in 2016 are exceptions. It is also notable that the share of other renewables is at 28% in Germany.

When comparing the fossil fuel sources, Figure 8 shows that coal is most frequently used in all countries except for Japan, France and UK & Ireland where natural gas is more abundantly used. Australia, China and India show a very high share of coal in their overall fuel mix for power generation of around 70-

77% in 2016. The share of oil-fired power generation is typically limited; only Japan, Korea and the United States have larger amounts, in absolute sense.

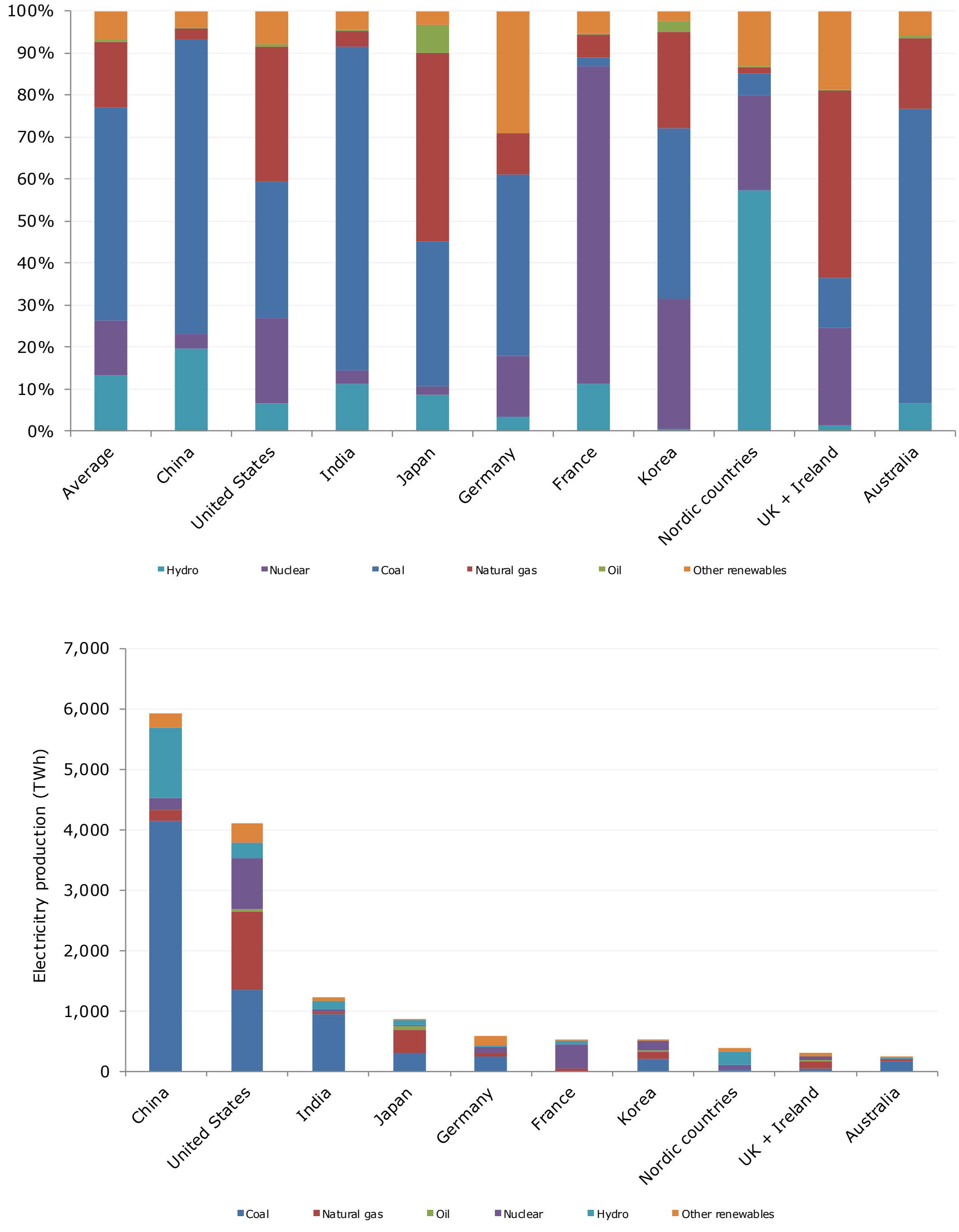

Figure 8 Absolute (top) and relative (bottom) public power generation by source in 2016.

Figure 9 - Figure 12 show the amount of coal-, gas-, oil- and total fossil-fired power generation respectively in the period 1990 - 2016, from public power plants and public CHP plants together.

The total coal-fired power generation in all countries increased from 3,043 to a peak of 7,644 TWh (+151%) during the period 1990 – 2014, but declined to 7,436 TWh in 2016 (-3% compared to 2014). The US saw its share of coal-fired power production shrink with 8% compared to 2015, mainly driven by national and regional regulations promoting (shale) gas and renewable technologies at the expense of coal-fired generation.

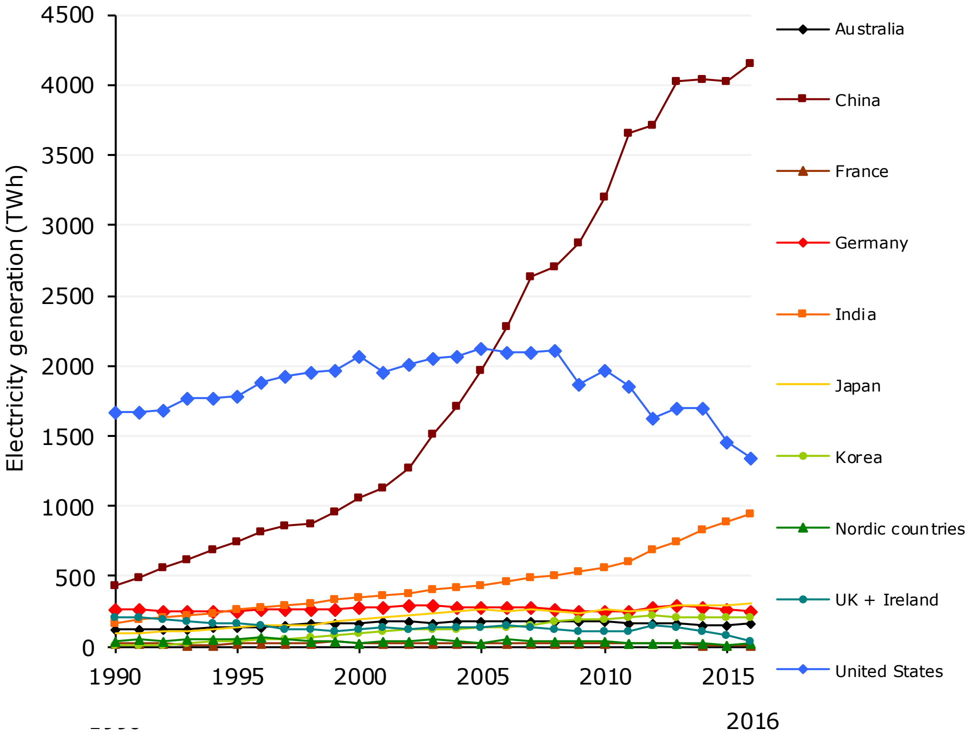

Figure 9 Coal-fired power generation from 1990 to 2016 for analysed countries

Gas-fired power generation in all countries combined increased from 514 to 2,316 TWh in 1990 – 2016 (+451%), with an 8% increase in 2016 compared to 2015. Figure 10 shows that the United States had a further growth from 1,273 TWh to 1,316 TWh (+3%) in 2016 compared to 2015, which was fuelled by shale gas development. In Japan, gas-fired power generation increased significantly post-Fukushima (from 285 TWh in 2010 to 380 TWh in 2012).

Oil-fired power generation plays a limited role and its importance has further diminished over time, especially in the case of the three leading oil-fired power producing countries (USA, Japan and South Korea). However, Figure 11 shows that Japan almost tripled power production from oil in 2012 compared to 2010 – most likely due to the need for deploying reserve capacity as nuclear power plants were shut down after the Fukushima accident.

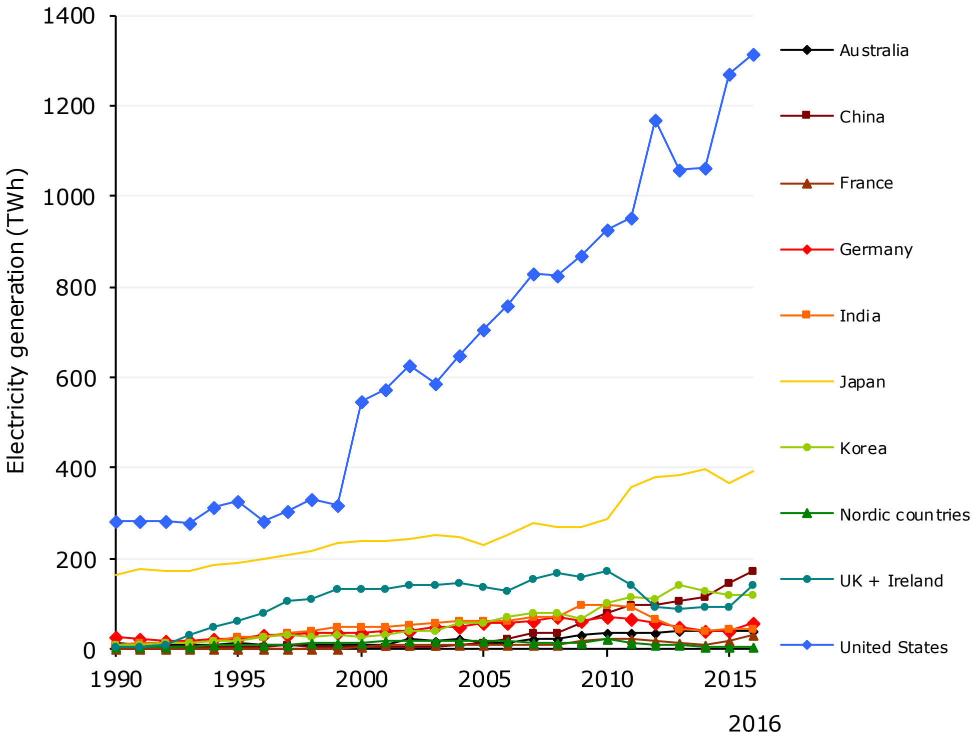

Figure 10 Gas-fired power generation from 1990 to 2016 for analysed countries

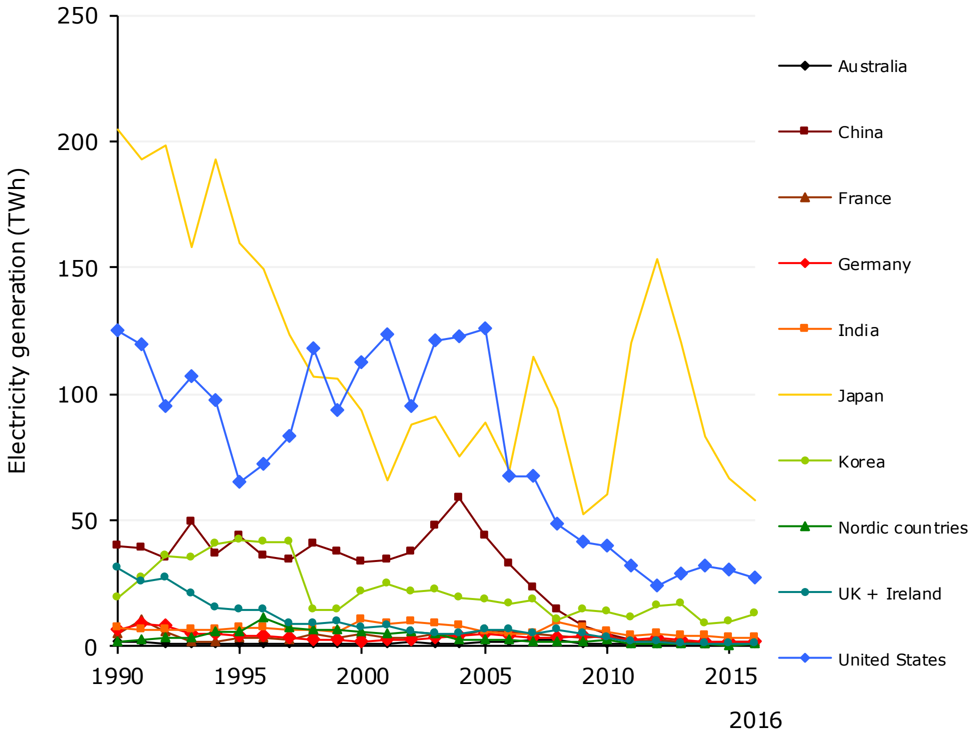

Figure 11 Oil-fired power generation from 1990 to 2016 for analysed countries

Figure 12 indicates that China, US and India had the strongest absolute growth in fossil-fired power production from 1990 to 2016. The total fossil-fired power generation increased steadily from 3,998 in 1990 to 9,860 TWh (+147%) in 2016. Of the countries in this study only China and India have significantly increased its fossil-fired power production from 2013 to 2016. Most European countries have decreased their fossil-fired power production over this three-year period (-7% for Germany, -34% for Nordic countries and -22% for UK & Ireland). Japan decreased its fossil-fired power production in the same period from 803 TWh to 751 TWh (-6%).

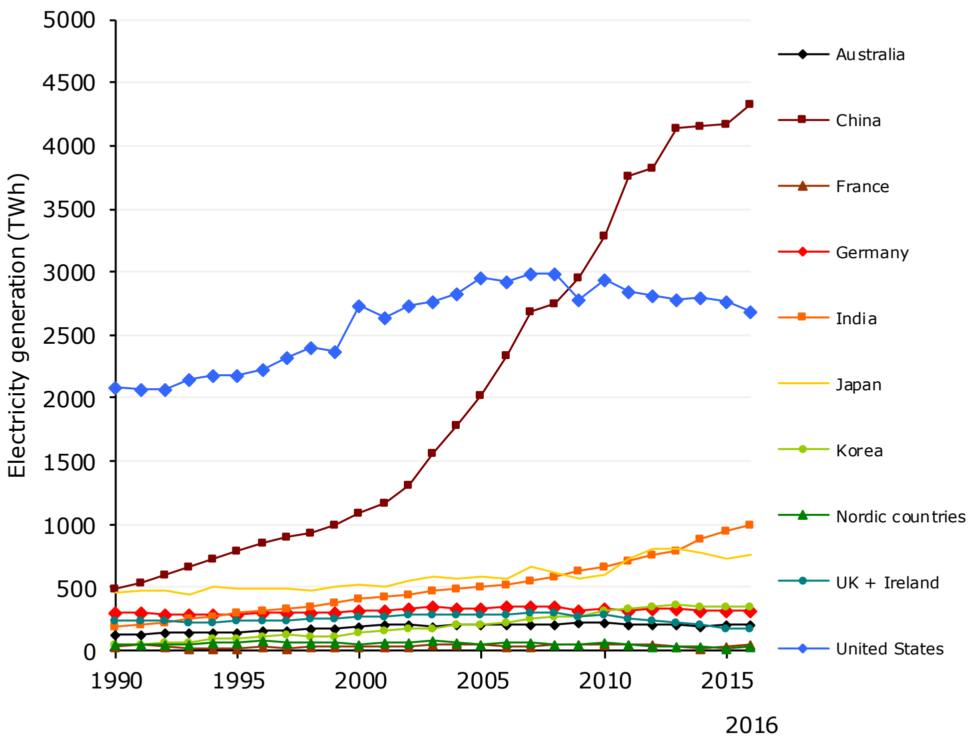

Figure 12 Fossil-fired power production from 1990 to 2016 for analysed countries

2 Methodology

This chapter discusses the methodology used to derive the generating efficiency indicators as well as the input data used to determine the indicators.

This study is based on data from IEA World Energy Balances edition 2018 (IEA, 2018). The advantage of using IEA Energy Balances is its consistency on a number of points:

- Energy inputs for power plants are based on net calorific value (NCV)[3];
- The output of the electricity plants is measured as gross production of electricity and heat. This is defined as the "*electricity production including the auxiliary electricity consumption and losses in transformers at the power station*";
- A distinction is made between electricity production from industrial power plants and public power plants and public combined heat and power (CHP) plants.

In this study we take into account public power plants and public CHP plants. We distinguish three types of fossil fuel sources: (1) coal and coal products, (2) crude oil and petroleum products and (3) natural gas. In the remainder of this report, we will refer to these fuel sources as coal, oil and gas, respectively. For a more extensive definition of public power production and these fuel types, refer to Appendix III: IEA Definitions.

2.1 Efficiency of power generation

The formula for calculating the efficiency of power generation is:
$E = (P + H*s) / I$.

Where:

E	Efficiency of power generation
P	Power production from public power plants and public CHP plants
H	Heat output from public CHP plants
s	Correction factor between heat and electricity, defined as the theoretical reduction in electricity production per unit of heat produced
I	Fuel input for public power plants and public CHP plants

Heat extraction causes the efficiency of electricity generation to decrease although the overall efficiency for heat and electricity production is higher than when the two are generated separately. Therefore, a correction for heat extraction is applied. This correction reflects the amount of electricity production lost per unit of heat extracted from the power plant(s). For district heating

[3] The Net Calorific Value (NCV) or Lower Heating Value (LHV) refers to the quantity of heat liberated by the complete combustion of a unit of fuel when the water produced is assumed to remain as a vapour and the heat is not recovered.

systems, the substitution factors vary between 0.15 and 0.2. In our analysis we have used a value of 0.175. It must be noted that when heat is delivered at higher temperatures (e.g. to industrial processes), the substitution factor can be higher. However, at the moment, the amount of high-temperature heat delivered to industry by public utilities is small in most countries. We estimate that the effect on the average efficiency is not more than an increase of 0.5 percent point[4].

No corrections are applied for air temperature and cooling method. The efficiency of power plants is influenced by the temperature of the air or cooling water. In general surface water-cooling leads to higher plant efficiency than the use of cooling towers. The cooling methods that can be applied depend on local circumstances, like the availability of abundant surface water and existing regulations. The effect of cooling method on efficiency may be up to 1-2 percent points. Furthermore the efficiency of the power plant is affected by the temperature of the cooling medium. The sensitivity to temperature can be in the order of 0.1-0.2 percent point per degree (Phylipsen et al, 1998).

In order to determine the efficiency for power production for a region, we calculate the weighted average efficiency of the countries included in the region.

2.2 Benchmark for generating efficiency of fossil-fired power plants

In this analysis we compare the generating efficiency of fossil-fired power plants across countries and regions. Instead of simply aggregating the efficiencies for different fuel types to a single efficiency indicator, we determine separate benchmark indicators per fuel source. This is because the efficiency for natural gas-fired power generation is generally higher than the efficiency for coal-fired power generation. In general, choices for fuel types are often outside the realm of the industry and therefore a structural factor. Choices for fuel diversification have in the past often been made at the government level for strategic purposes, e.g. fuel diversification and fuel costs.

The most widely used power plants for coal-fired power generation are conventional boiler plants based on the Rankine cycle. Fuel is combusted in a boiler and with the generated heat, pressurized water is heated to steam. The steam drives a turbine and generates electricity. In principle any fuel can be used in this kind of plant.

An alternative for the steam cycle is the gas turbine, where combusted gas expands through a turbine and drives a generator. The hot exit gas from the turbine still has significant amounts of energy which can be used to raise steam to drive a steam-turbine and another generator. This combination of gas and steam cycle is called 'combined cycle gas turbine' (CCGT) plant. A CCGT plant is generally fired with natural gas. Also coal firing and biomass firing is possible by gasification, e.g. in integrated coal gasification combined cycle plants (IGCC). These technologies

[4] A change of 1 percent point in efficiency here means a change of e.g. 40% to 41%.

are not widely used. The generating efficiency of a single steam cycle is at most 47%, while the generating efficiency of a combined cycle can be over 61% (Siemens. 2012; GE 2014[5]). Open cycle gas turbine plants (only gas turbine, no steam cycle) are also still widely applied.

Several possible indicators exist for benchmarking efficiency of power generation. One possible indicator is the comparison of individual countries' efficiencies to predefined best practice efficiency. The difficulty in this method is the definition of best practice efficiency. Best practice efficiency could e.g. be based on:

- The best performing country in the world or in a region;
- The best performing plant in the world or in a region;
- The best practical efficiency possible, by best available technology (BAT).

The best practice efficiency differs yearly, which means that back-casting is required to determine best practice efficiencies for historic years.

A different method for benchmarking generating efficiency is the comparison of countries' efficiencies against average efficiencies. An advantage of this method is the visibility of a countries' performance against average efficiency. In this study we choose to use this indicator. We compare the efficiency of countries and regions to the average efficiency of the selected countries.

The average efficiency is calculated per fuel source and per year and can be either weighted or non-weighted. In the first case the weighted-average efficiency represents the overall generating efficiency of the included countries. A disadvantage of this method is that countries with a large installed generating capacity heavily influence the average efficiency while small countries have hardly any influence at all on the average efficiency. On the other hand, when applying non-weighted benchmark indicators, one efficient power plant in a country could influence the average efficiency if absolute power generation in the country is small. In this research we included both methods, to verify if this leads to different results.

The formula for the non-weighted average efficiency for coal (BC_1) is given below as an example. The formulas for oil and gas are similar.

[5] https://powergen.gepower.com/plan-build/products/gas-turbines/9ha-gas-turbine.html

$BC_1 = \sum EC_i / n$

Where:

BC_1	Benchmark efficiency coal (1). This is the average efficiency of coal-fired power generation for the selected countries.
EC_i	Efficiency coal for country or region i (i = 1,…n)
n	The number of countries and regions

The formula for the weighted average efficiency for coal (BC_2) is given below as an example:

$BC_2 = \sum (PC_i + HC_i *s)/ \sum IC_i$

Where:

BC_2	Benchmark efficiency coal (2). This is the weighted average efficiency of coal-fired power generation for the selected countries.
PC_i	Coal-fired power production for country or region i (i = 1,…n)
HC_i	Heat output for country or region i (i = 1,…n)
s	Correction factor between heat and electricity, defined as the reduction in electricity production per unit of heat extracted
IC_i	Fuel input for coal-fired power plants for country or region i (i = 1,…n)

To determine the performance of a country relative to the benchmark efficiency we divide the efficiency of a country for a certain year by the benchmark efficiency in the same year. The formula of the indicator for the efficiency of coal-fired power is given below as an example:

$BC_i = EC_i / BC_1$ or $BC_i = EC_i / BC_2$

Where:

BC_i	Benchmark indicator of coal-fired generating efficiency for country or region i

Countries that perform better than average for a certain year show numbers above 100% and vice versa. To come to an overall comparison for fossil-fired power efficiency we calculate the output-weighted average of the three indicators, as is shown in the formula below:

$BF_i = (BC_i * PC_i + BG_i * PG_i + BO_i * PO_i) / (PC_i + PG_i + PO_i)$

Where:

BF_i, BC_i, BG_i and BO_i	Benchmark indicator for the efficiency of fossil-fired, coal-fired, gas-fired and oil-fired power generation for country or region i
PC_i, PG_i and PO_i	Coal-fired, gas-fired and oil-fired power production for country or region i

2.3 CO_2 intensity power generation

In this study we also calculate CO_2 emissions intensities per country:

- Per fossil fuel source (coal, oil, gas);
- For total fossil power generation and
- For total power generation.

There are several ways of calculating CO_2-intensities (g CO_2/kWh) for power generation, depending on the way combined heat and power generation is taken into account. In this study we use the same method as for calculating overall generating efficiency and correct for heat generation by the correction factor of 0.175 (see Section 2.1).

The formula for calculating CO_2 intensity is:

$$CO_2\text{-intensity} = \Sigma(3.6 * C_i * P_i / E_i) / \Sigma P_i$$

Where:

i	Fuel source 1 ... n
E_i	Efficiency power generation per fuel source (see Section 2.1)
C_i	CO_2 emission factor per fuel source (see table below) (tonne CO_2/TJ)
P_i	Power production from public power and CHP plants per fuel source (GWh)

The table below gives the CO_2 emission factors per fuel source.

Table 1 Fossil CO_2 emission factor (IEA, 2005)

Fuel type	Tonne CO_2/TJ_{ncv}
Hard coal	94.6
Lignite	101.2
Natural gas	56.1
Oil	74.1
Other fuels (biomass, nuclear, etc.)	0

2.4 Share of renewable and nuclear power generation

This report also gives an insight into the development of the share of renewable and nuclear power production in total public power production. For the period 2000 - 2016, annual developments for all geographical regions as stated above are included.

The IEA classifies a number of different energy sources that are used for power production as renewables (see Table 2). Ecofys has mapped (i.e. aggregated) these into various different categories:

- Bio;
- Geothermal;
- Hydro;
- Solar;
- Ocean;
- Waste;
- Wind.

Table 2 Mapping of different renewable energy categories of IEA

Renewable energy sources as defined by IEA	Ecofys mapping
Municipal waste (renewable)	Waste
Primary solid biofuels	Bio
Biogases	Bio
Bio-gasoline	Bio
Biodiesels	Bio
Other liquid biofuels	Bio
Non-specified primary biofuels and waste	Bio
Charcoal	Bio
Bio jet kerosene	Bio
Hydro	Hydro
Geothermal	Geothermal
Solar photovoltaics	Solar
Solar thermal	Solar
Tide, wave and ocean	Ocean
Wind	Wind

Data input for calculating the shares originates from IEA, 2018. To be consistent with the rest of this study, only the share in public power production is considered, omitting the installed capacity in the private sector (i.e. energy production for own use).

3 Results

Table 3 gives an overview of the content of the different sections of Chapter 3.

Table 3 What can be found in which section in this chapter

Section	Content
3.1	Efficiencies for coal,- gas- and oil-fired power production, including a simple aggregation of fossil-fired power efficiency
3.2	Results of the benchmark analysis based on non-weighted average efficiencies
3.3	Results of the benchmark analysis, based on weighted average efficiencies
3.4	CO_2 intensities per fuel source and for total power generation per country
3.5	CO_2 abatement potentials per country when replacing current installed generating capacity by best available technology (BAT)
3.6	Development of the share of renewable and nuclear power production over the last decade

The underlying data for the figures in this chapter can be found in Appendix II: Input data, which gives the input for the analysis in terms of power generation, fuel input, heat output, benchmark efficiencies and CO_2-intensity.

3.1 Efficiency of coal-, gas- and oil-fired power generation

Figure 13 - Figure 15 show the efficiency trend for coal-, gas- and oil-fired power production, respectively, for the period 1990 - 2016. Figure 16 shows the efficiency of fossil-fired power generation by the weighted-average efficiency of gas, oil- and coal-fired power generation.

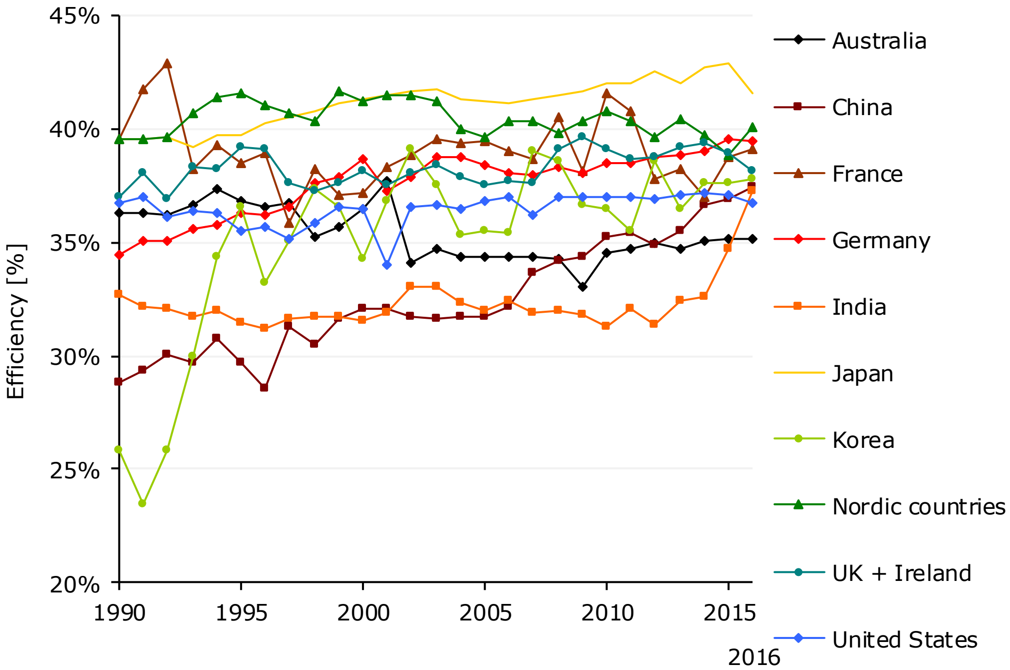

Figure 13 Average efficiency of coal-fired power production from 1990 to 2016 for analysed countries

The efficiencies for coal-fired power generation in 2016 range from 35% for Australia to 42% for Japan. Note that over the last five years China and India, two of the largest coal-fired power producers, have continued to improve the efficiency of their coal-fired power generation. Most of the other countries have experienced very limited improvement or efficiency decreases.

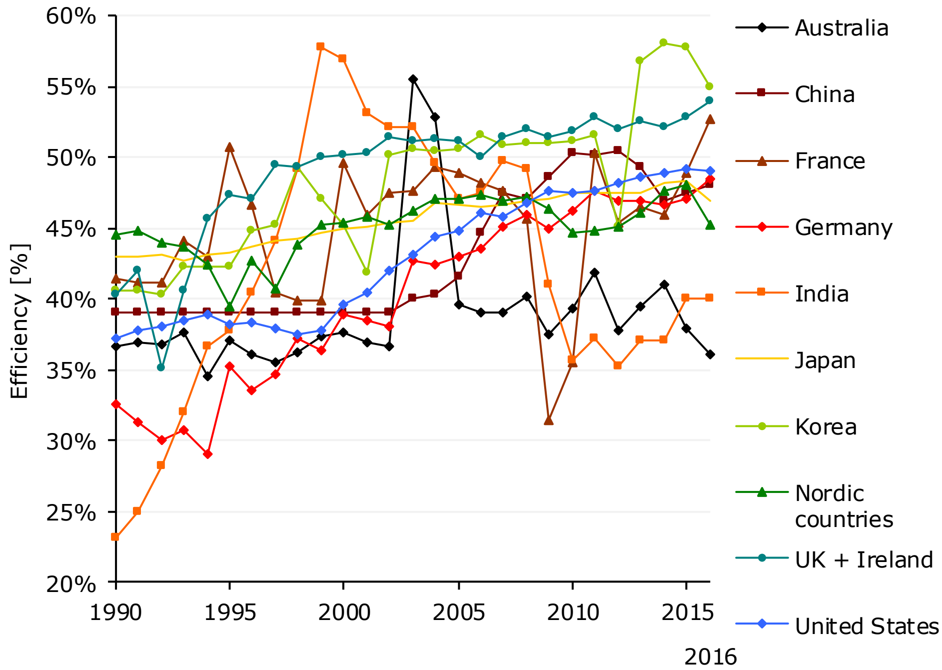

Figure 14 Average efficiency of gas-fired power production from 1990 to 2016 for analysed countries

In contrast to other fuels, the efficiency of gas-fired power generation has improved substantially over the last two decades. The largest efficiency improvements in 1990 - 2016 are observed for India[6], Germany and South Korea. In 2016, efficiencies range from 36% for Australia to 55% for South Korea. The increase in efficiency for South Korea in the last years might be because of the recent construction of some highly efficient combined cycle power plants.

Generating efficiencies for gas power plants in India appear to have some inconsistencies in the years 1999 and 2000, as average efficiencies of around 57% are close to BAT and thus can be considered unrealistic for India at that time. The sudden peak for Australia in 2003 and 2004 is also noteworthy and might indicate inconsistencies in the statistics.

For some countries, such as France, efficiencies fluctuate heavily over time. This may be explained by gas-fired power plants significantly varying operating hours from year to year. Four-fifths of the French public power originates from nuclear plants, with natural gas only responsible for 6% in 2016. Natural gas capacity is deployed as a peak load capacity together with oil fired capacity. This provides explanation for the fluctuating and relatively low efficiencies.

[6] Although the early figures for India are deemed unreliable with efficiencies approaching a BAT efficiency of 61% in 1999.

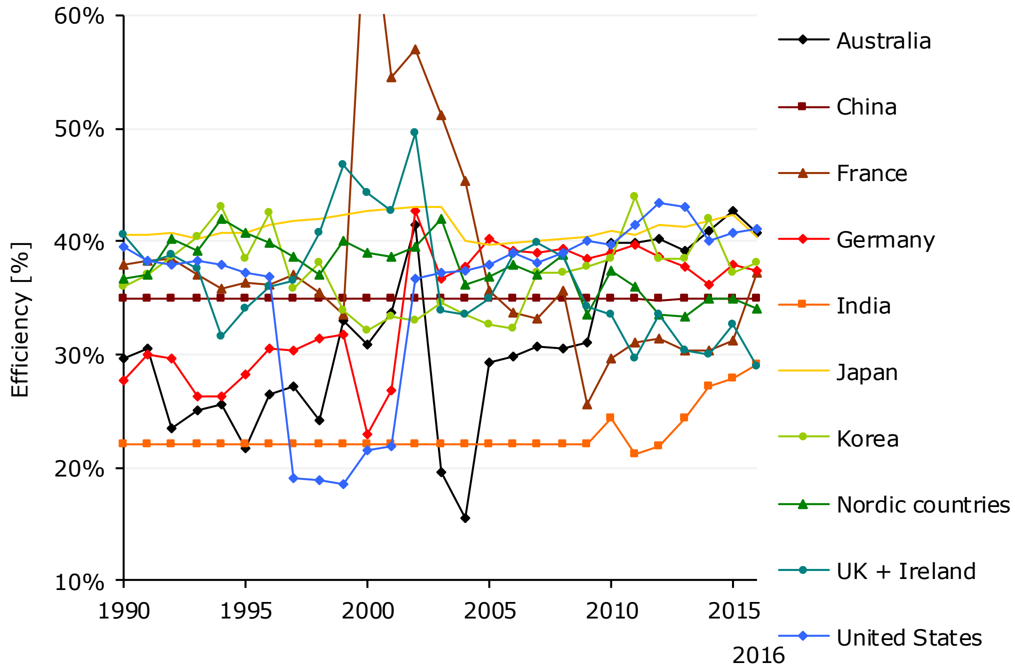

Figure 15 Average efficiency of oil-fired power production from 1990 to 2016 for analysed countries

In 2016, the efficiencies for oil-fired power generation range from 29% for India and United Kingdom and Ireland to 41% for the United States and Australia. The graph shows large fluctuations in efficiency for oil-fired power generation, e.g. for France efficiencies peak above BAT levels. The explanation for the variance could be partly the fluctuation of yearly operating hours, as running at significantly lower operating hours typically lowers efficiencies, or another explanation could be data uncertainty in the case of unrealistically large changes. It should be noted that oil-fired power generation is relatively small (below 3 TWh in 2016) in all countries but Japan, South Korea and the USA. Therefore, the overall impact on the average fossil-fired generating efficiency is limited.

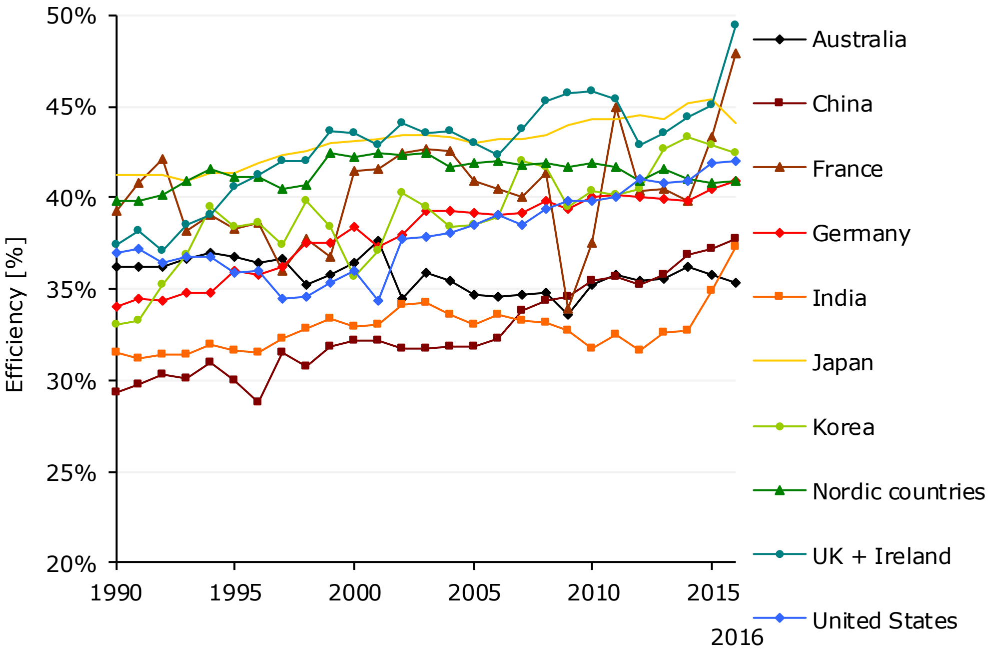

Figure 16 Average efficiency of fossil-fired power production from 1990 to 2016 for analysed countries

For overall fossil-fired power generation, the efficiencies range from 35% for Australia to 49% for United Kingdom and Ireland in 2016.

Below is a discussion of the results organised by country. Note that all data refers to the year 2016, unless stated otherwise.

Australia

Total fossil-fired power generation in Australia is 203 TWh, of which 80% is generated from coal. Gas-fired power generation represents most the remainder of fossil-fired power generation (19%), with oil-fired power generation in Australia only accounting for 1%.

The efficiency of gas-fired power generation in Australia was very low at 36% in 2016. This makes Australia the lowest performer in gas-fired power generation efficiencies. The efficiency for coal-fired power generation of Australia also ranks at the bottom at 35.2%, now behind India (at 37.2%) which was the lowest performer in 2015 (at 34.7%). However, Australia is one of the top performers for oil-fired power generation efficiencies together with the United States at 41%.

China

China is the largest fossil-fired power generator, generating 4,323 TWh in 2016. China relies almost entirely on coal (96% of fossil power production). Gas-fired power generation increased significantly from 145 TWh in 2015 to 170 TWh in 2016 (+17%) and now comprises 4% of fossil-fired power generation. Oil-fired power generation is negligible in China in 2016 (roughly 1 TWh).

The efficiency of coal-fired power generation is 37.4%. It has increased steadily in the period 1990 - 2016 coming from 28.8%. Coal-based electricity production increased substantially from 440 TWh in 1990 to 4,025 TWh in 2013, corresponding to about a tenfold increase. However, the last three years coal-based electricity production has stabilized at this level (4,040 TWh in 2014, 4,032 TWh in 2015 and 4,151 TWh in 2016). This is an important reason that global coal-fired power production in 2015 decreased significantly compared to 2014, which is the first major decrease since decades.

France

Fossil-fired power generation in France was relatively small at only 42 TWh in 2016. Besides the dominant contribution of nuclear capacity, France fossil fuel use is mainly coal and gas-fired power generation. In general, fossil power generation is used to absorb electricity demand peaks in winter due to electric heating, which means that the capacity factor of coal- and gas-fired power plants can vary strongly year-by-year. Due to the relatively small amount of fossil-fired power generation this results in stronger fluctuations for the efficiency of fossil-fired power generation in comparison to other countries.

The generating efficiency for coal-fired power plants in France was 39.1% in 2016. Coal-fired power generation in France shows strong fluctuations ranging from about 10 to 30 TWh per year in the past two decades, which can be explained by the existence of power production that has lower marginal production costs, i.e. hydro and nuclear plants.

Public gas-fired power generation increased from practically zero in 1990 to roughly 24 TWh in 2011, decreased to 9 TWh in 2014, but has picked up again to 30 TWh in 2016. The generating efficiency of natural gas is increasing recently (from 45% in 2012 to 53% in 2016), mainly because of the commissioning of highly efficient combined cycle plants.

The average efficiency of fossil-fired power production increased in France in 2016 compared to 2015. This is a result of significantly more gas-fired power generation compared to 2015, which is relatively more efficient than other fossil fuel sources. In France gas-fired power generation increased from 16 TWh in 2015 to 30 TWh in 2016. Higher usage of gas plants might also contribute to the increasing efficiency of gas-fired power generation in 2016 compared to 2015.

Germany

Fossil-fired power generation in Germany totalled 313 TWh in 2016, of which 81% is produced by coal. After the reunification of West and East Germany several inefficient lignite power plants were closed. This led to a higher efficiency of coal-fired power generation, which increased gradually from 34.4% in 1990 to 39.5% in 2016.

In the mid '90s the natural gas market was liberalised in Germany, leading to more competition and lower gas prices. This resulted in more gas use and a large increase of CHP capacity. This led to a strong increase of efficiency of gas-based power generation from 32.6% in 1990 to 48.4%

in 2016. Gas-fired power generation increased from 25 TWh in 1990 to 72 TWh in 2008, but has been gradually decreasing since 2008, standing at 39 TWh in 2015 with a new peak at 57 TWh in 2016.

India

Fossil-fired power generation in India is 994 TWh, of which 95% is produced from coal. Gas-fired power generation increased from 8 TWh in 1990 to 98 TWh in 2010, but recently decreased significantly, standing at 47 TWh in 2016. Oil-fired power generation was 3 TWh in 2016.

The efficiency for coal-fired power generation is constantly quite low around 31-33% over the whole period of 1990 - 2014. Some reasons for this may be (IEA, 2003):

- The coal is unwashed;
- Indian coal has a high ash content of 30% to 55%;
- Coal-fired capacity is used for peak load power generation as well as base load power generation.

However, in recent years since 2014 the efficiency for coal-fired power generation has been steadily increasing significantly, and with an efficiency of 37.2% India is now only the third-lowest performer (in front of Australia at 35.2% and the United States at 36.7%).

The efficiency for gas-fired power generation increased from 23.2% in 1990 to 40.0% in 2016, suggesting strong efficiency developments. However, it should be noted that the efficiency is highly fluctuating (e.g. 57.7% in 1999 to 35.2% in in 2012). Although efficiencies in India have significantly improved because of the installation of modern combined cycle plants (IEA, 2003), the statistics should be taken with care because of inconsistencies in the early 2000's where the efficiency seems unrealistically high.

The average efficiency of fossil-fired power production increased in India in 2016 compared to 2015, which can mainly be attributed to an increasing efficiency of coal-fired power production from 2015 to 2016. This is likely because coal-fired power production is still expanding in India and newer plants tend to have better efficiencies.

Japan

Japan is the fourth largest fossil-fired power producer of the countries studies with 751 TWh, starting at 464 TWh in 1990. Fossil-fired power production increased significantly in 2011 to 725 TWh (from 606 TWh in 2010, +20%) to compensate for the shutdown of nuclear power plants following the Fukushima incident. After peaking at 803 TWh in 2013, fossil-fired power generation has been decreasing the to 751 TWh in 2016. The largest part of this decrease comes from a diminishing oil-based production (from 120 TWh in 2013 to 58 TWh in 2016).

The efficiency for coal-fired power generation slowly increased from 39.6% in 1990 to 42.8% in 2015, but decreased to 41.6% in 2016. Similarly, the efficiency for oil-fired power generation slowly increased from 40.6% in 1990 to 42.4% in 2015, but decreased to 40.5% in 2016. The gas-fired generating efficiency also increased from 43% in 1990 to 48.4% in 2015, but decreased to 47.0% in 2016. The Japanese Central Research Institute of the Electric Power Industry (CRIEPI) describes the development of gas-fired power plants in Japan as follows:

> Japanese general electric utilities started to implement gas-fired power plants ahead of time in response to the oil crises of the 1970s. In those times gas turbines were not yet implemented on a large scale. As a result, utilities implemented conventional steam turbines based on active electricity demand, as they remain now. In the 1990s however, utilities implemented combined cycle power plants. Furthermore, utilities will implement More Advanced Combined Cycle (MACC) with 59% (LHV) thermal efficiency, among the world's highest. The first MACC began its commercial operation in June 2007.

The average efficiency of fossil-fired power production decreased in Japan in 2016 compared to 2015. This is a result of decreasing efficiencies for coal-, gas- and oil-fired power production. One possible explanation might be that the nuclear and renewable power production (especially solar and wind) has increased in 2016, so that the fossil-fired power plants were used less which makes power generation less efficient. Another explanation might be that many electric power producers have started supplying power to the public due to the liberalization of the power market in 2016. These fossil-fired power plants will then be reclassified in the IEA statistics from autoproducer power plants to public power plants, so that they are included in this analysis. This could explain the decreased efficiency of fossil-fired power production in case the reclassified power plants are less efficient than the previous average.

Nordic countries

Total fossil-fired power generation in the Nordic countries was 26 TWh in 2016. Finland and Denmark comprise the majority of this generation with 51% and 42% respectively. Sweden accounts for only 6% and Norway for 1%.

All types of fossil-fired power generation in the Nordic countries have been decreasing in recent years. Coal-fired power generation reached its lowest point since 1990 at 16 TWh in 2015 (slightly increasing to 20 TWh in 2016). The efficiency for coal-fired power generation in the Nordic countries has been between 39.5% and 41.7% in 1990 – 2016, except for 2015 where it decreased below this range with 38.8%, likely because of lower operating hours. Gas-fired power generation (with a large share consisting of CHP plants) in the Nordic countries is 6 TWh, generated at an efficiency of 45.3%.

South Korea

Total fossil-fired power generation in South Korea was 346 TWh in 2016, of which 62% is generated by coal and 35% by gas. South Korea has also significant oil-fired power production at 13 TWh in 2016.

The efficiency for coal-fired power generation increased strongly from 25.8% in 1990 to 36.5% in 1995 and has fluctuated significantly since then between 33% and 39%. The efficiency of gas-fired power generation increased from 40.5% in 1990 to 50% in 2002 and remaining at these levels until 2011. Recently, the efficiency of gas-fired power generation increased significantly to 58% in 2014, although showing a slight decrease to 55% in 2016. This increase might be because of the recent construction of some highly efficient combined cycle power plants.

United Kingdom and Ireland

Total fossil-fired power generation in the United Kingdom and Ireland was 178 TWh, of which 21% is generated from coal and 78% from gas. As gas prices decreased during the liberalization in the 90's, gas-fired power generation capacity increased significantly from 1992 onwards, from only 4 TWh in 1990 to 171 TWh in 2010. However, gas-fired power generation has dropped significantly in recent years falling to 94 TWh in 2015, but increased to 140 TWh again in 2016. Coal-fired power generation has decreased significantly from 147 TWh in 2012 to 38 TWh in 2016. This shift from coal-fired power generation to gas-fired power generation might be explained by the carbon price floor, which taxes fossil fuels used to generate electricity and is specifically aimed at the phase-out of unabated coal use.

The generating efficiency for coal-fired power plants has remained relatively constant over the past 20 years around 37-39%, it was 38.1% in 2016. This relative constant efficiency can be explained by the fact that no renewal of the coal-based stock has occurred. For natural gas the trend is different: the large addition of new capacity has resulted in a strong increase of the average efficiency of gas-fired power plants, from 40.4% in 1990 to 53.9% in 2016.

The average efficiency of fossil-fired power production increased in 2016 compared to 2015. This is a result of significantly more gas-fired power generation compared to 2015, which is relatively more efficient than other fossil fuel sources. Gas-fired power generation increased from 94 TWh to 140 TWh while coal-fired power production reduced from 83 TWh in 2015 to 38 TWh in 2016. This shift from coal-fired power generation to gas-fired power generation might be explained by the carbon price floor, which taxes fossil fuels used to generate electricity and is specifically aimed at the phase-out of unabated coal use.

United States

The United States is the second largest fossil-fired power generating country in the world with 2,683 TWh in 2016, of which 50% is generated by coal and 49% by gas. Coal-fired power generation decreased significantly from 1,455 TWh in 2015 to 1,340 in 2016 (-8%), which is the lowest point ever since 1990. Conversely, electricity generation by gas-fired power plants increased strongly in the past years from 1,065 TWh in 2014 to 1,316 TWh in 2016 driven by the availability and relative low prices of natural gas.

The generating efficiency of coal-fired power generation remained to a high degree constant since 2002 at around 37%. The efficiency of gas-fired power generation has been gradually increasing from 37.2% in 1990 to 49.0% in 2016.

3.2 Benchmark based on non-weighted average efficiency

In this section, a benchmark indicator for fossil-fired power generating efficiency is calculated. This is done by comparing the efficiency of countries and regions to the average efficiency of the selected countries. Separate benchmark indicators per fuel for coal, oil, gas and for total fossil-fired power generation are calculated to compare the efficiencies. The formula for calculating the benchmark indicators can be found in Chapter 2. The benchmark indicator is based on the country efficiency per fuel source divided by the average efficiency per fuel source. The separate benchmark indicators are weighted by power generation to get to an overall indicator for fossil-fired power generation.

Figure 17 shows the average efficiencies for all countries and regions considered in this study. Because these efficiencies are not weighted, they do not represent the total overall generating efficiency of power production in the included countries; one efficient power plant in a country could influence the average efficiency if absolute power generation in the country is small (see Section 2.2).

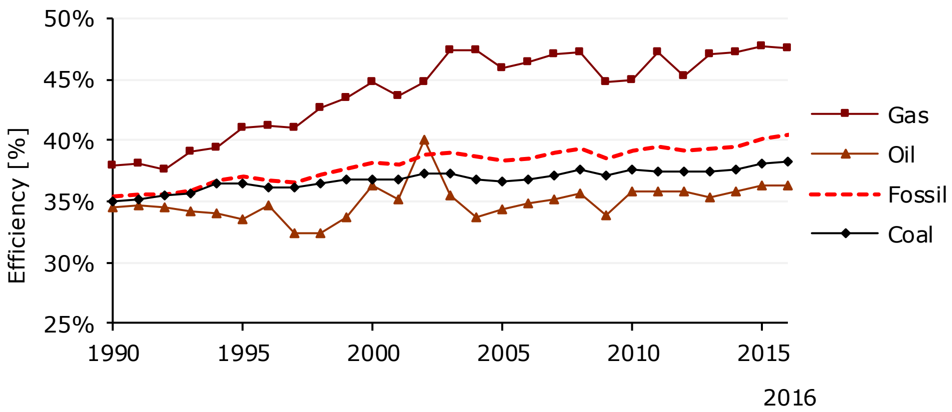

Figure 17 Average non-weighted efficiencies

With regard to average non-weighted efficiencies, the efficiency for gas-fired power generation shows a strong increase from 38% in 1990 to 48% in 2016 (average annual improvement of 0.9%). The reason for this improvement is mainly the large amount of new, more efficient generating capacity; gas-fired power generation more than quadrupled over the period 1990 - 2016. The increase in efficiency for coal-fired power generation was more limited, from 35% to 38% (average annual improvement of 0.3%). This is because coal-fired power generation increased relatively less (twofold increase over the period 1990 – 2016) and a significant part of the growth in coal-fired power generation took place in India, where generating efficiency by coal is still significantly below BAT levels.

Figure 18 shows the generating efficiencies of the countries divided by the non-weighted average of efficiency. The data is averaged over the period 2014 – 2016 as uncertainty in the data of an individual year can be high. A benchmark indicator of 110% for gas means that the efficiency for gas-fired power generation in a country is 10% higher than the average (non-weighted) efficiency of the considered countries. The fossil benchmark indicator is based on the average benchmark indicators for coal, gas and oil, and is weighted by power generation output.

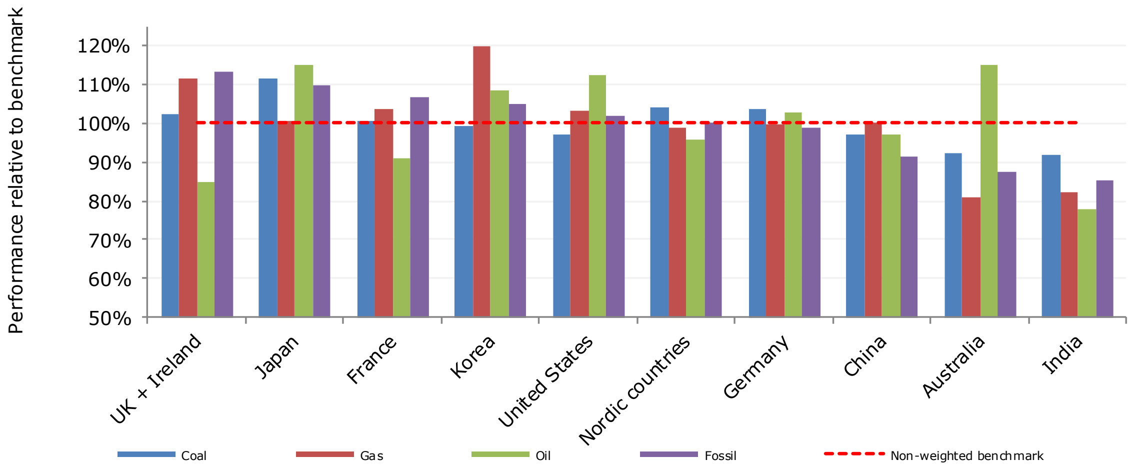

Figure 18 Average 2014 – 2016 performance for coal, gas, oil and fossil for countries relative to respective non-weighted average benchmark efficiencies. Countries are sorted on the basis of performance relative to the non-weighted benchmark for fossil fuel-fired power generation.

As can be seen, the UK & Ireland, Japan and France perform best in terms of fossil-fired power generating efficiency with 13%, 10% and 7% above average efficiency respectively, followed by Korea with 5% above average. India and Australia are the most prominent underperformers with generating efficiencies at 15% and 12% below the benchmark respectively.

Figure 19 shows the time development of the benchmark indicator for fossil-fired power generation. Note that a decrease of the benchmark indicator for a country might mean that the efficiency of the power production in the country has decreased or that the non-weighted average efficiency has increased.

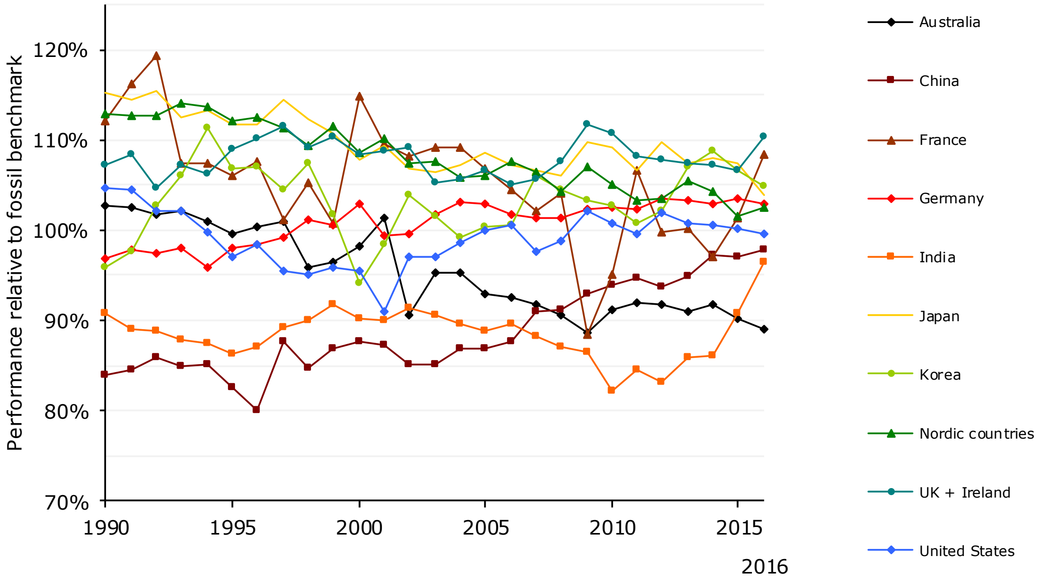

Figure 19 Output-weighted average benchmark for generating efficiency of fossil-fired power plants (based on non-weighted average efficiencies).

3.3 Benchmark based on weighted average efficiency

In this section, we calculate a second benchmark indicator for fossil-fired power generating efficiency. This is done by comparing the efficiency of countries and regions to the weighted average efficiencies of the selected countries. The formula for calculating the benchmark indicators can be found in Section 2.2. The benchmark indicator is based on the country efficiency per fuel source divided by the weighted average efficiency per fuel source. The separate benchmark indicators are weighted by power generation to get to an overall indicator for fossil-fired power generation.

Figure 20 shows the weighted average efficiencies for all countries and regions considered in this study. The weighted average generating efficiency for all countries and regions together in 2016 is 37% for coal, 49% for natural gas, 40% for oil-fired power generation and 40% for fossil power in general.

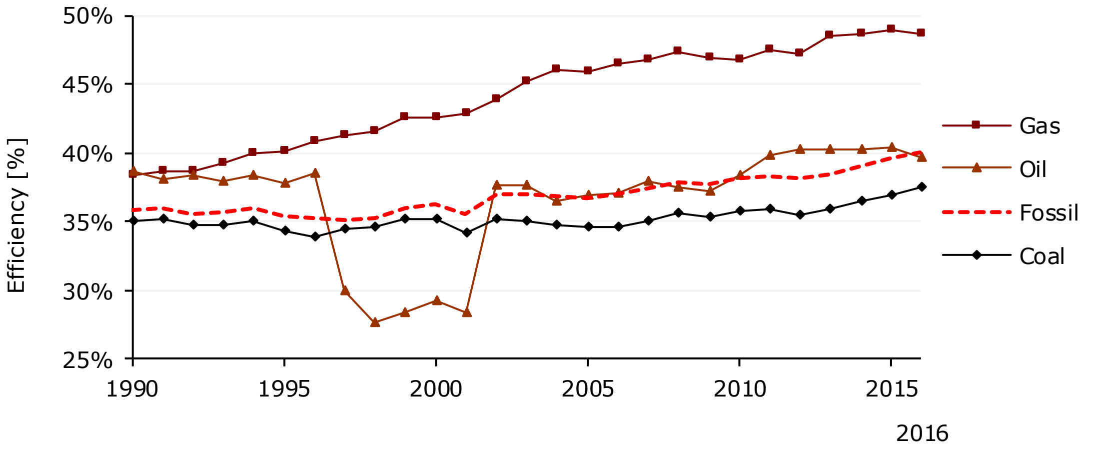

Figure 20 Average weighted efficiencies of all countries and regions at the scope of this study (%).

For the weighted average efficiencies, the efficiency for gas-fired power generation shows a strong increase from 38% in 1990 to 49% in 2016 (average annual improvement of 1.0%). The reason for this improvement is mainly the large amount of (more efficient) new generating capacity (see previous section).

The efficiency for oil fired generation decreased in 2016 compared to years before. This can be explained by a decrease in efficiency for the largest oil-fired power generators, the United States and Japan. The negative peak from 1997 to 2001 for the oil-based generation efficiency is due to negative efficiency peaks for the United States in these years, which is likely due to data inconsistencies.

Coal-fired power generation increased more than twofold over the period 1990 - 2016. However, only a limited increase in efficiency is seen of 35% to 37% (average annual improvement of 0.3%). The reason for this is that a significant part of the growth in coal-fired power generation took place in India, where generating efficiency by coal is still significantly below BAT levels.

The differences with the non-weighted average approach (Figure 17) are significant. In general these can be explained by the fact that the impact of countries with large power production output is diminished by the non-weighted approach whereas the impact of small countries is magnified. For instance, Korea and the United States are among the largest producers from gas-fired power and also among the most efficient. In the non-weighted average approach their impact on the average is lower than in the weighted average approach, resulting in a lower overall average efficiency for all countries combined.

Figure 21 shows the generating efficiencies of the countries divided by the weighted average efficiency. Again, the data is based on the average over the period 2014 – 2016 as uncertainty in the data for an individual year can be high. A benchmark indicator of 110% for gas means that the efficiency for gas-fired power generation in a country is 10% higher than the weighted average efficiency of the considered countries. The fossil benchmark indicator is based on the average benchmark indicators for coal, gas and oil, and is weighted by power generation output.

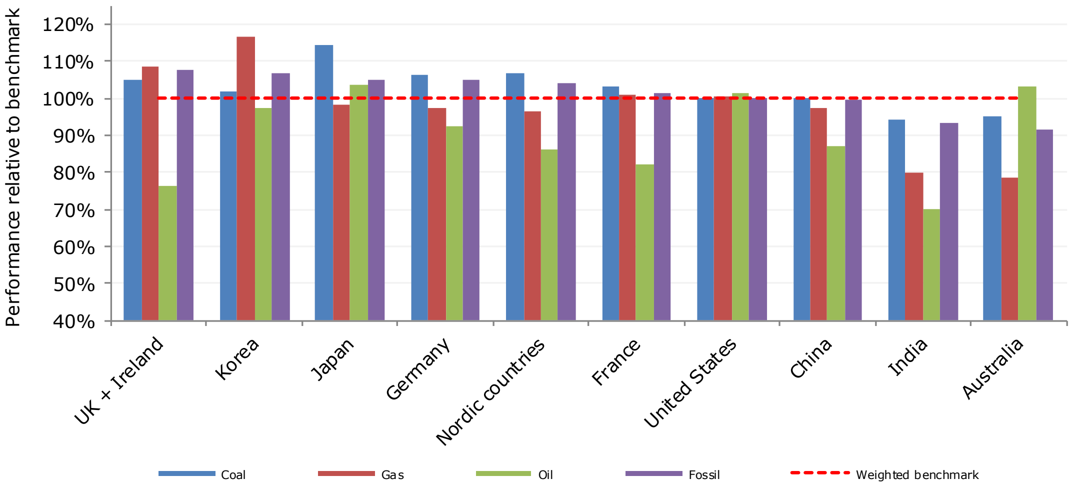

Figure 21 Average 2014 – 2016 performance for coal, gas, oil and fossil for countries relative to respective weighted average benchmark efficiencies. Countries are sorted on the basis of performance relative to the weighted benchmark for fossil fuel-fired power generation.

On average in the period 2014-2016, United Kingdom and Ireland had a 8% higher weighted fossil efficiency, followed by South Korea (+7%), Japan (+5%) and Germany (+5%), the Nordic countries (+3%), France (1%) and the United States (+0%). China is slightly below the benchmark (-0.1%), while India and Australia are the most prominent underperformers with generating efficiencies at 7% and 8% below the benchmark respectively.

As the exact numbers for the two benchmark approaches (1) non-weighted and (2) weighted average efficiency differ, the results also differ in terms of which countries are most efficient. Only UK & Ireland and China are at the same positions (first and eighth) for both approaches (Figure 18), while the order of other countries (2-7 and 9-10) is changed.

It should be remarked that most countries are above the benchmark value (100%), because Australia and India significantly pull down the average efficiency on which the benchmark is based. This means that the benchmark value is lowered and more countries seem to be relatively efficient.

Figure 22 shows the development in time of the benchmark indicators for fossil-fired power generation.

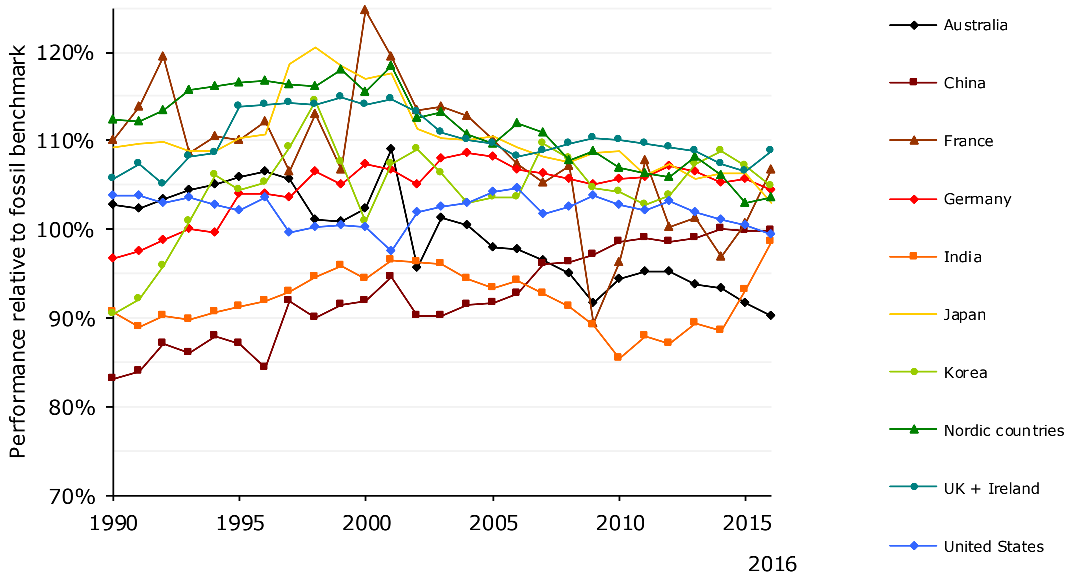

Figure 22 Output-weighted benchmark for generating efficiency of fossil-fired power plants (based on weighted average efficiencies).

3.4 CO_2-intensities

In this section we compare the CO_2-intensity per country for the different fuel sources (coal, oil, gas), for fossil-fired power generation and for total power generation. The average CO_2 intensities for the period 2014 - 2016 and the corresponding individual years are included. The underlying data for the figures can be found in Appendix II: Input data.

On average over the period 2014 - 2016, CO_2 intensities for coal-fired power generation range from 804 g/kWh for Japan to 995 g/kWh for Australia (Figure 23). Since last year's report, Australia has taken over from India as the country with the highest CO_2 intensities for coal-fired power generation.

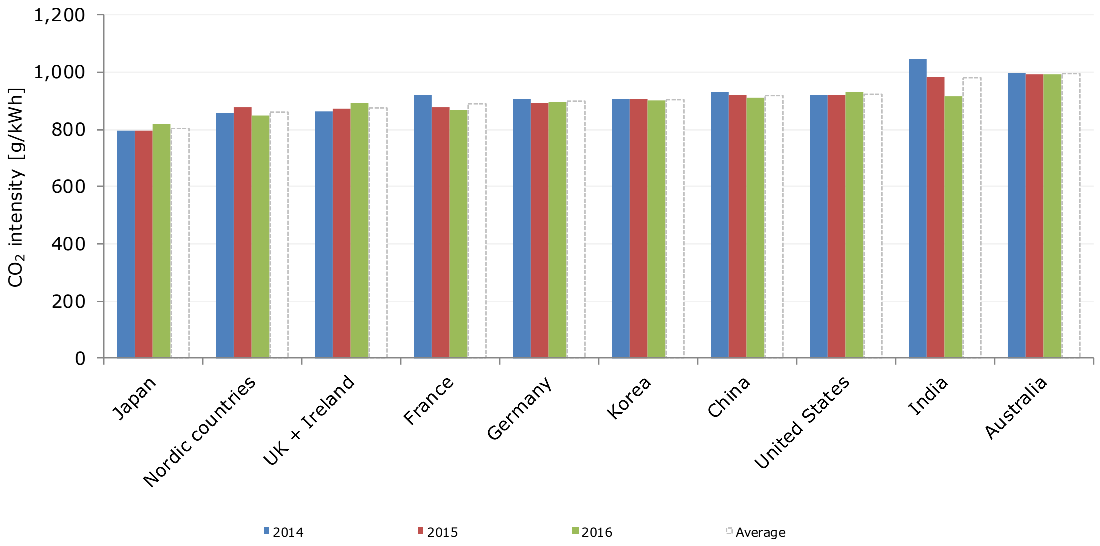

Figure 23 CO_2-intensity for coal-fired power generation. Countries are sorted based on average CO_2-intensity in 2014 - 2016

On average over the period 2014 – 2016, CO_2 intensities for gas-fired power generation range from 355 g/kWh for South Korea to 528 g/kWh for Australia (Figure 24). This is a difference of +49% in emissions per unit of power generation. Compared to last year's report, Australia has taken over from India as the country with the highest CO_2 intensity for gas-fired power generation.

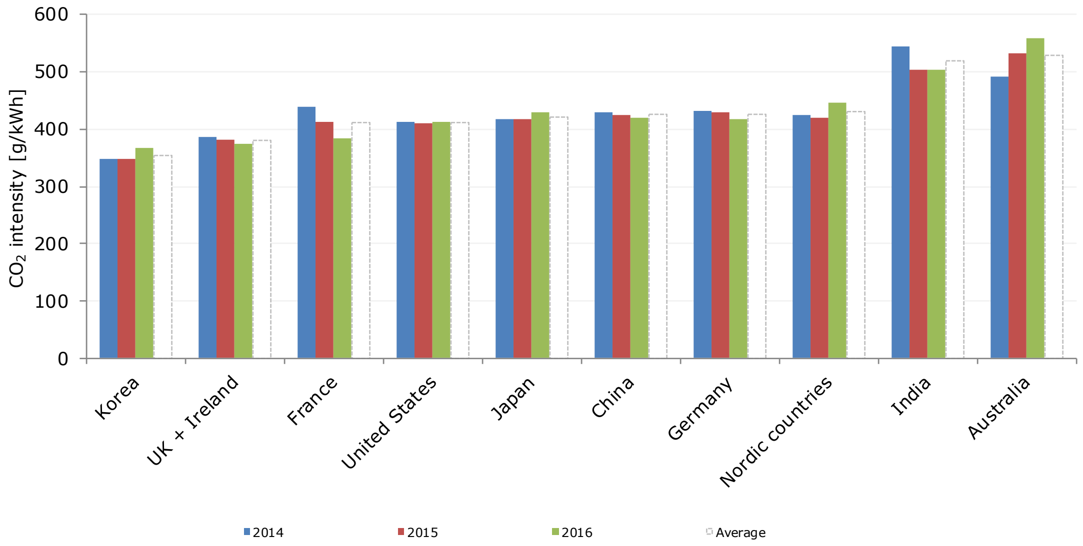

Figure 24 CO_2-intensity for gas-fired power generation. Countries are sorted based on average CO_2-intensity in 2014 - 2016

On average over the period 2014 - 2016, CO_2 intensities for oil-fired power generation range from 642 g/kWh for Japan to 951 g/kWh for India (Figure 25). This is a difference in emissions of +48% per unit of oil-fired power generated.

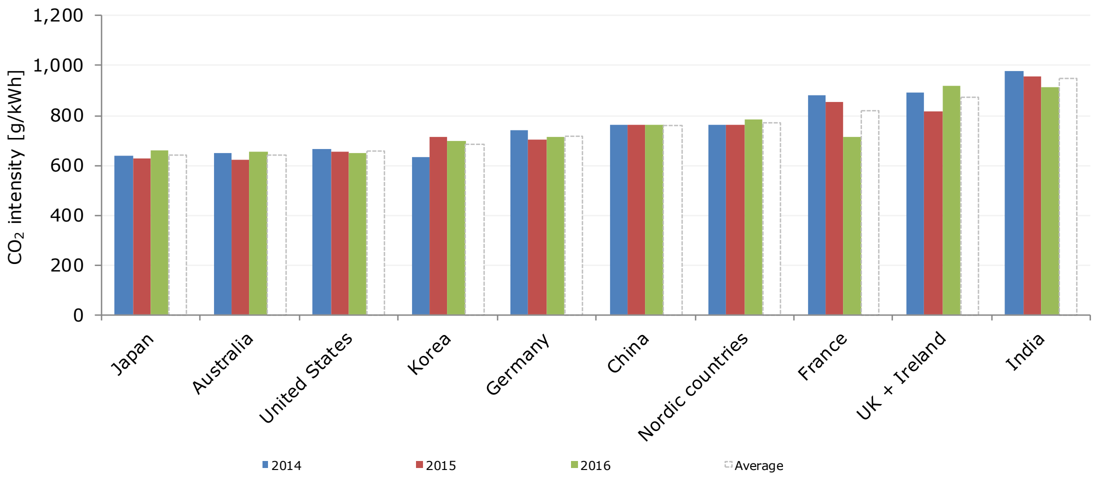

Figure 25 CO_2-intensity for oil-fired power generation. Countries are sorted based on average CO_2-intensity in 2014 - 2016

On average, over the period 2014 - 2016, CO_2 intensities for fossil-fired power generation range from 581 g/kWh for United Kingdom and Ireland to 962 g/kWh for India (Figure 26). This is a difference in emissions of 66% per unit of fossil-fired power generation. Compared to last year's report, United Kingdom and Ireland has taken over from Japan as the country with the lowest CO_2 intensity for fossil-fired power generation. The CO_2 intensity for fossil-fired power generation depends largely on the share of coal in fossil power generation and on the efficiency of power production.

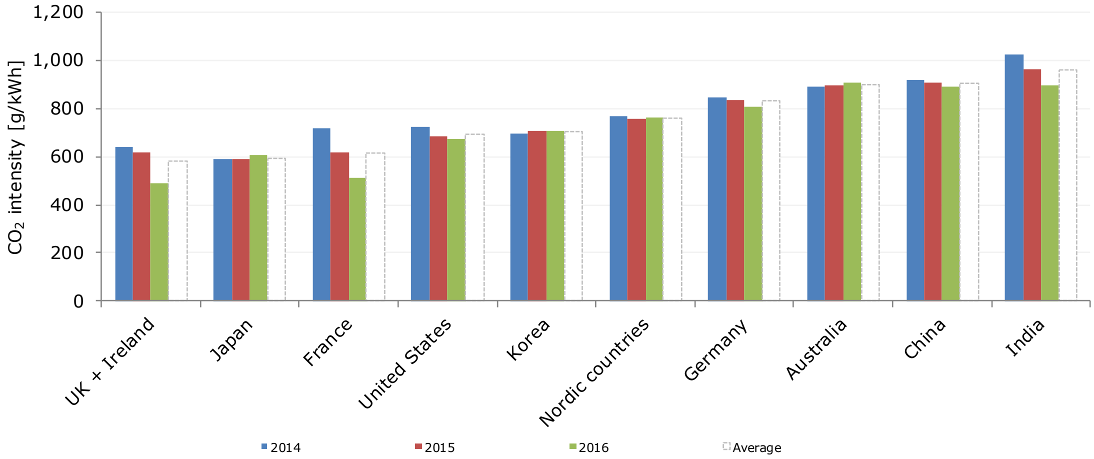

Figure 26 CO_2-intensity for fossil fuel-fired power generation. Countries are sorted based on average CO_2-intensity in 2014 - 2016

On average over the period 2014 - 2016, CO_2 intensities for total power generation ranges from 33 g/kWh for France to 786 g/kWh for Australia (Figure 27). The CO_2-intensity for total power generation depends mostly on the share of decarbonised electricity in the mix. In 2016 for example, about 76% of electricity generated in France comes from nuclear power and in the Nordic Countries 57% comes from hydro and 23% from nuclear power. Meanwhile, in China, Australia and India around 70-80% of public power originates from coal. At present, nuclear and hydropower generally remain the dominant sources of decarbonised power, although the share of renewables other than hydropower has experienced a very fast uptake in the past decade.

The development of renewables and nuclear power production over time is addressed in more detail in Chapter 3.6.

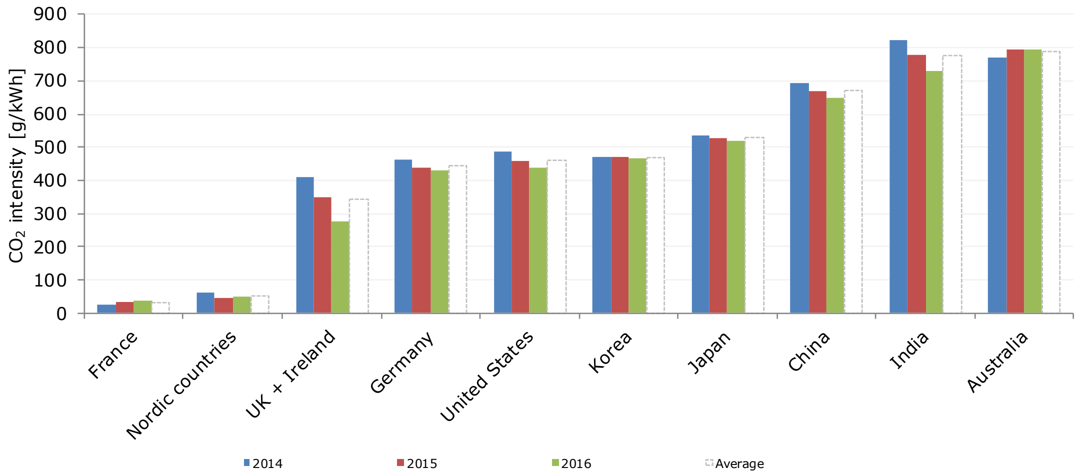

Figure 27 CO_2-intensity for total (i.e. including fossil, nuclear and renewable) power generation. Countries are sorted based on average CO_2-intensity in 2014 - 2016.

3.5 Emission reduction potential

A large potential for emission reduction is present by improving the generating efficiency of fossil-fired power plants.

The figures below show the specific (g CO_2/kWh), absolute (Mtonne CO_2) and relative (%) emission abatement potential per country that would occur if the best available technologies (BAT) for the respective fuels was applied for all power produced in 2016. Hence, it is assessed how much CO_2 emissions would be avoided if all power producing installations would be replaced by an installation that operates according to the best available conversion efficiency for the fuel combusted.

CO_2 emissions reductions from fuel switches are not incorporated in this analysis. It should be kept in mind that the abatement potential depends on the fuels combusted. This means that, for example, equally inefficient power production in a country with only gas use versus a country with only coal use would result in a larger CO_2 reduction potential for the coal-based country.

The efficiencies used for BAT are 47% for coal, 61% for natural gas and 47% for oil-fired power generation[7,8]. No changes are assumed for the fuel mix for fossil-fired power generation per country.

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[7] These values originate from the European Commission (2006), Siemens/TÜV (2012) and VGB (2004) respectively and refer to operational efficiencies based on gross power output and net calorific value for fuel input. Note that BAT efficiencies given by the relevant Best Reference document for Large Combustion Plants (European Commission, 2013) are lower. This can be explained by the fact that BREF documents do not always show the most up-to-date values as there is a time delay in adopting such values.

[8] It should be noted that fuels can be of different quality and may not be suitable to be converted at BAT efficiency levels. The analysis should therefore be considered as a higher estimate of the improvement potential.

It should be noted that the chart with specific potential (Figure 28) gives an indication for the GHG inefficiency of public power production, or the amount of specific GHG emissions above the BAT level. The chart with absolute potential (Figure 29) indicates the absolute amount of reduction possible thus taking into account the total amount of power production occurring in a country. Finally, the chart with relative potential (Figure 30) illustrates how large the absolute potential is in comparison with the total emissions.

India, Australia and China have the largest specific abatement potentials as these have, relatively, the highest shares of coal and the lowest conversion efficiencies. Even though the United States is with regard to coal-based power production among the lesser efficient countries, this is offset by the fact that for the past twenty years, the declining share of coal-based power was mostly replaced by power production from gas-fired power plants which are at present among the most efficient.

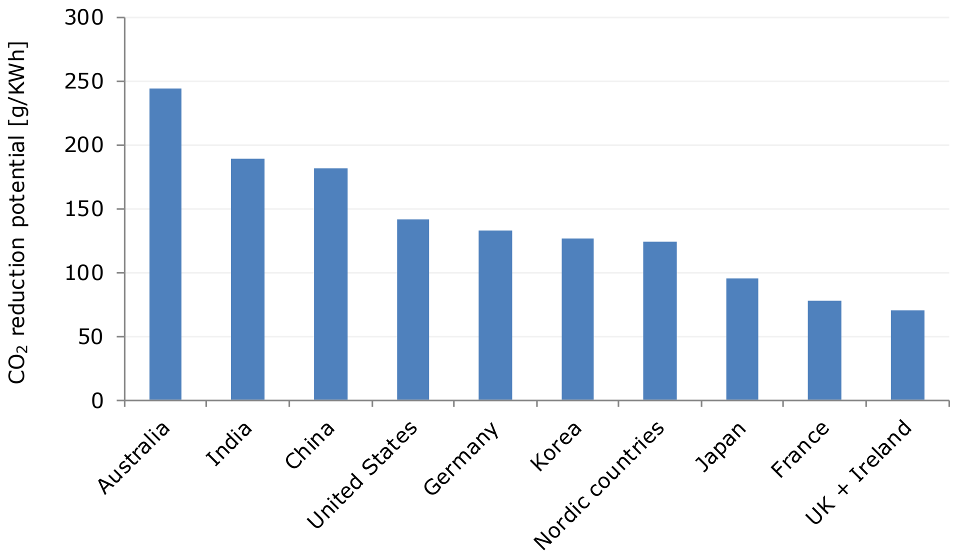

Figure 28 Specific CO_2 emission reduction potential for fossil power generation by replacing all fossil public power production by BAT for the corresponding fuel type.

If the best available technologies would have been applied for all fossil power generation in the countries of this study in 2016, absolute emissions would have been 20% lower. China, United States and India show very high absolute emission reduction potentials of 785, 380 and 189 Mt per year, respectively. The absolute abatement potential is very much dictated by the total amount of power produced in the country and the extent to which this occurs by making use of inefficient technologies combusting CO_2-intensive fuels. That explains why large countries with relatively inefficient power production, often predominantly from coal, have the largest absolute CO_2 abatement potentials.

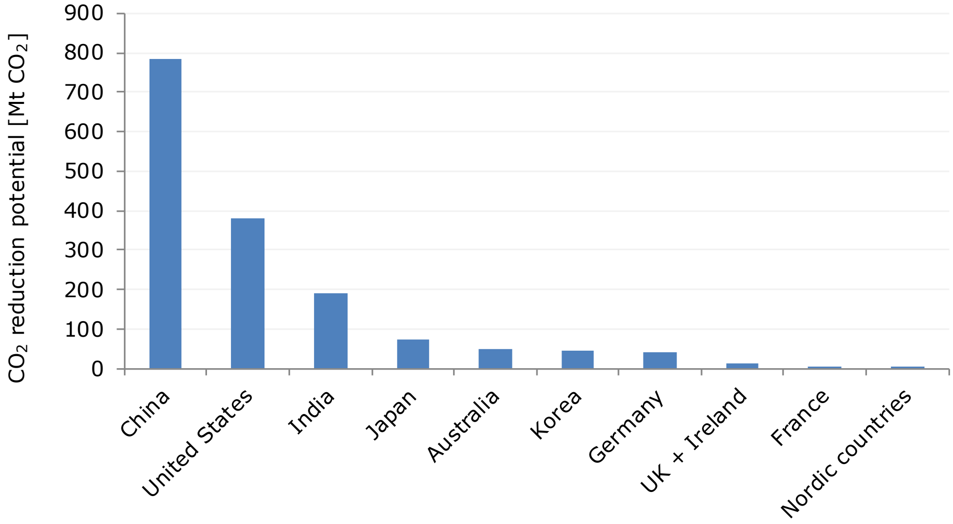

Figure 29 Absolute CO_2 emission reduction potential for fossil power generation by replacing all fossil public power production by BAT for the corresponding fuel type.

Relative CO_2 emission reduction potentials range from 14% for United Kingdom and Ireland to 27% for Australia.

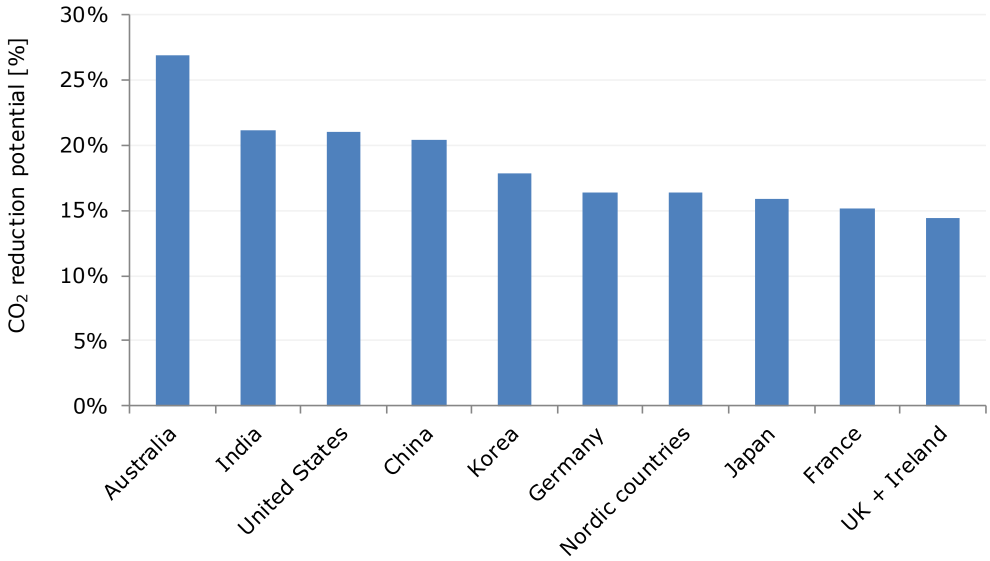

Figure 30 Relative CO_2 emission reduction potential for fossil power generation by replacing all fossil public power production by BAT for the corresponding fuel type.

3.6 Renewable and nuclear power production

In this section for each of the regions in the scope of this study, the development in the share of renewable and nuclear power production is graphically depicted. In addition, observations of the main trend(s) and an interpretation from a renewable energy expert - aiming at explaining the underlying reasons - are provided.

Note that for an accurate interpretation of the development of the share of nuclear or renewable power production this always has to be considered in relation with the overall developments in total power production. Therefore, the development of total public power production, relative to the year 1990, is also provided in the charts.

The methodology for determination of the results given in this section can be found in Section 2.4.

The years 2014 and 2015 were record years in terms of renewable energy investments globally. In 2016 there was a fall in investments in renewables due to two reasons. One was lower costs, due to a reduction of average dollar capital expenditure per MW by more than 10% for solar as well as onshore and offshore wind. The other was less investments in China, Japan and some emerging markets. However, due to the lower costs 2016 was still a record year in terms of installation of renewable power capacity. In 2016 139 GW of renewables excluding large hydro were installed, up from 128 GW in 2015 (Frankfurt School-UNEP Centre/BNEF, 2017). Overall, renewables excluding large hydro constituted 55% of all installed generating capacity in 2016.

Australia

Despite its significant uranium deposits, there are no nuclear power facilities in Australia. Hydro power has remained the main renewable power source in the period 2000 – 2016; the share of hydropower has been constant between 5.1 and 8.2%. The share of wind energy increased steadily in the last decade to 5.3% of total public power production in 2016, while the growth of bioenergy (mainly primary solid biofuels and biogases) has slightly increased to 0.6% in 2016 compared to 0.5% in 2014. 2016 was also the first year that there was a noticeable power production from solar energy at 0.2%.

The Clean Energy Future plan of 2012 reaffirmed the commitment to 20% renewable electricity production by 2020 (41,000 GWh) and provided support to increase renewable energy production in the future. However, in 2015 the Large-scale Renewable Energy Target was reduced from 41,000 GWh to 33,000 GWh by 2020 after long discussions. Renewable energy production was 29,015 GWh in 2016 according to the IEA data. Nonetheless, accompanying regulatory changes have also increased the financial certainty for renewable investments (Clean Energy Council, 2015). In addition to national policies, various states have introduced their own renewable energy support policies (usually feed-in tariffs) and individual renewable energy targets. South Australia for example is aiming for 50% renewable electricity production by 2025 and Northern Territory as well as Queensland set the same target for 2030. The Australian Capital Territory and Tasmania committed to 100% renewable electricity production by 2020 and 2022 respectively (Climate Council, 2017).

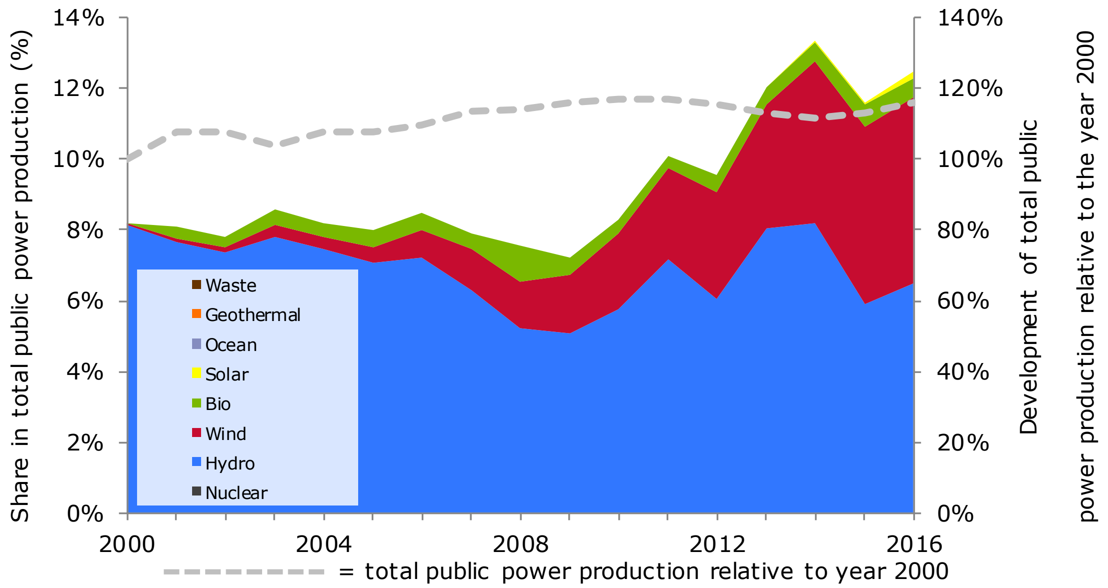

Figure 31 Share of renewable and nuclear power production during 2000 – 2016 in Australia.

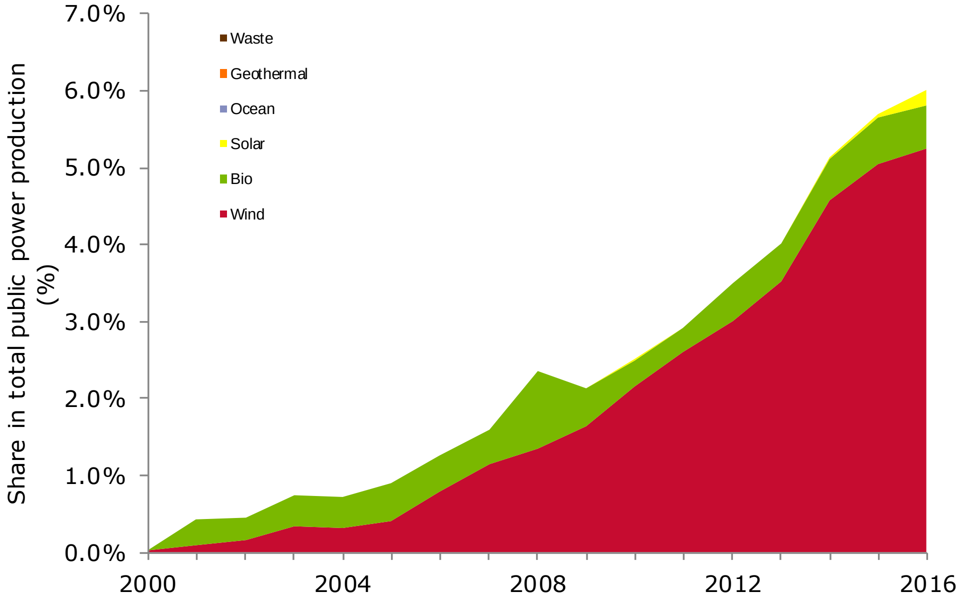

Figure 32 Share of renewable power production (excluding hydropower) during 2000 - 2016 in Australia.

China

The share of power production from non-fossil sources has been steadily increasing in China for the last years. Public power production from nuclear power reached its highest point since 2000 with 3.6% in 2016 and hydropower was at 19.6%, roughly the same level as the previous year (19.7%). In addition, in absolute terms public power production increased by a factor three in the last decade, which means renewable energy production (hydro & wind) increased significantly in absolute terms from 223 TWh in the year 2000 to 1,400 TWh in 2016. Wind power production has been steadily increasing in the last decade from 0% in 2000 (1 TWh) to 4.0% (237 TWh) in 2016.

Deployment of renewable energy forms a strong element in the overall energy and industrial policy. The 11th Five-Year Plan (2006 - 2010) resulted in the establishment of renewable energy markets, the completion of renewable resource evaluations, and construction of many renewable projects. The 12th Five-Year Plan aimed for 11.4% of non-fossil resources in primary energy consumption by 2015. In its 2014 National Action Plan on Climate Change, China set the goal to achieve 700 GW renewable energy capacity by 2020. The 13th Five-Year Plan was published in March 2016 and reaffirmed the previous targets of increasing non-fossil energy to 15% by 2020 and to 20% by 2030. The focus in the 13th Five-Year Plan is especially on expanding wind and solar power generation.

Policy support has consisted among others of feed-in tariffs, preferential taxes and access to cheap credit. Legislation has also facilitated guaranteed grid access and priority dispatch for renewable projects. One point of attention has been that not all installed capacity could be connected to the grid, for example only 75% of wind capacity was connected in 2011. The Renewable Energy Law was therefore amended in 2009 to improve grid access. Wind energy rejection, however, remains a big problem with up to 47% energy rejection rates in certain areas in China in the first half of 2016 (Yuning Zhang et al., 2016).

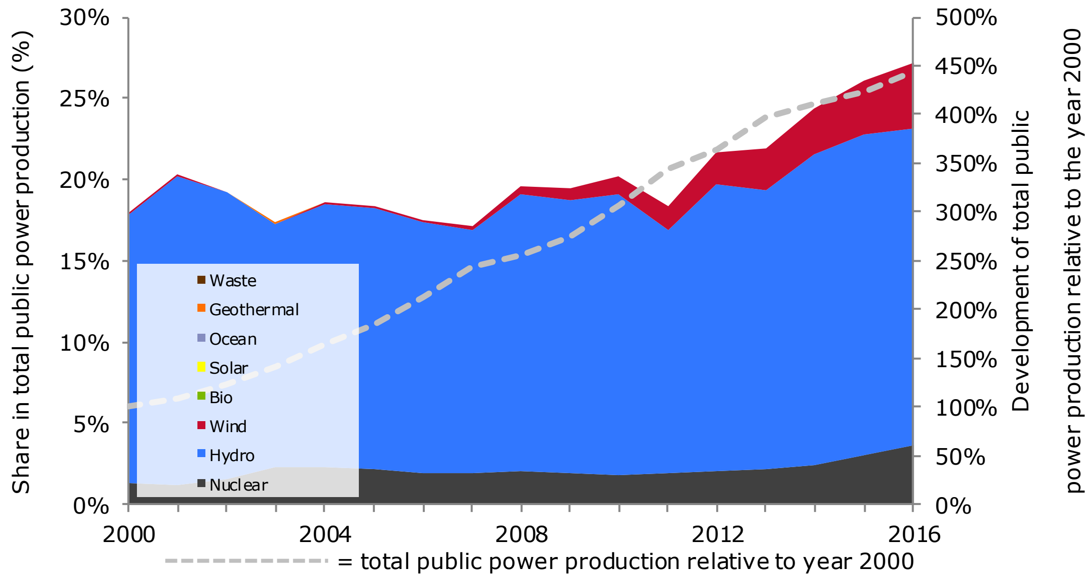

Figure 33 Share of renewable and nuclear power production during 2000 - 2016 in China.

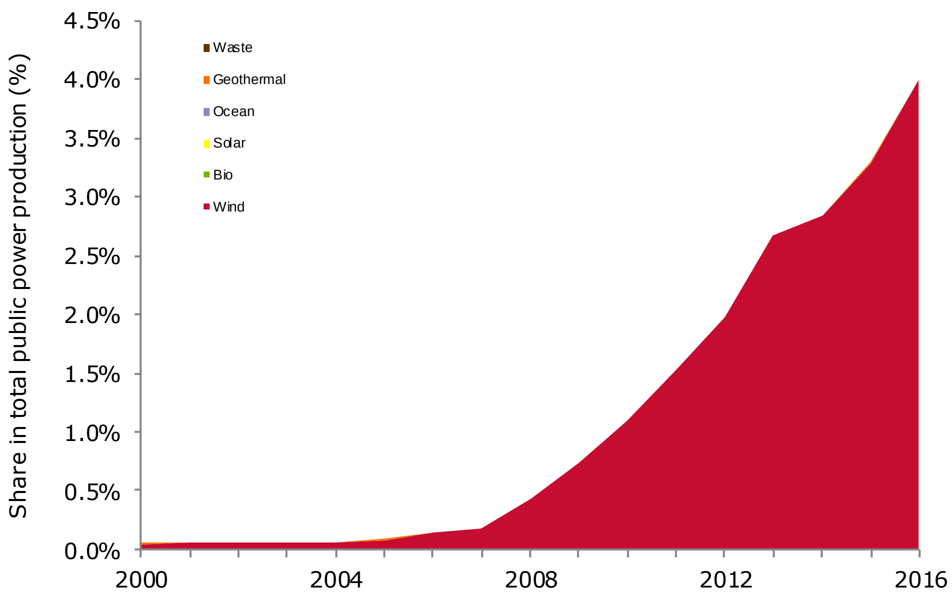

Figure 34 Share of renewable power production (excluding hydropower) during 2000 - 2016 in China.

France

France traditionally has an extremely high share of nuclear power of about 80%, although it reached its lowest point in 2016 at 75.8% This, combined with the a share of hydropower around 10% makes power from fossil fuels only marginal. There has been an increase in wind power production from 0% in 2002 to 3.8% in 2016, partly due to the feed-in tariff provided by the Government. In recent years, public power production based on solar energy is increasing from 0% in 2010 to 0.8% in 2016.

France is the only country besides South Korea within the scope of this study that generates any notable (albeit still very limited with 0.1%) amounts of electricity by means of tidal energy. One of the largest facilities is the Rance Tidal Power station that has been operating for more than 40 years.

France has committed in 2015 to a 40% share of renewable electricity in supply by 2030 in the Energy Transition for Green Growth Act (in 2016, the renewable share is 16.3% of total public power production). Additionally, France's nuclear share in electricity production should decrease to 50% by 2025. Feed-in tariffs are used for most renewable energy sources and tender schemes are applied to offshore wind, solar PV (>100 kW), bioenergy (>12 MW) and hydropower. France also introduced the Nitrogen Autonomy Plan in 2013 with the aim to commission 1,000 biogas plants until 2020.

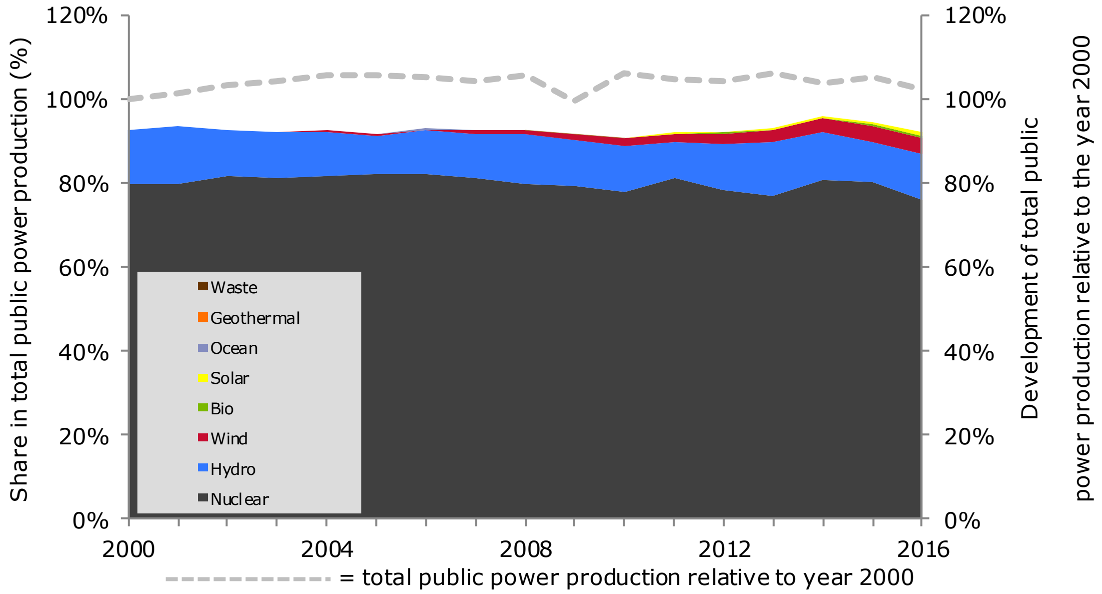

Figure 35 Share of renewable and nuclear power production during 2000 - 2016 in France.

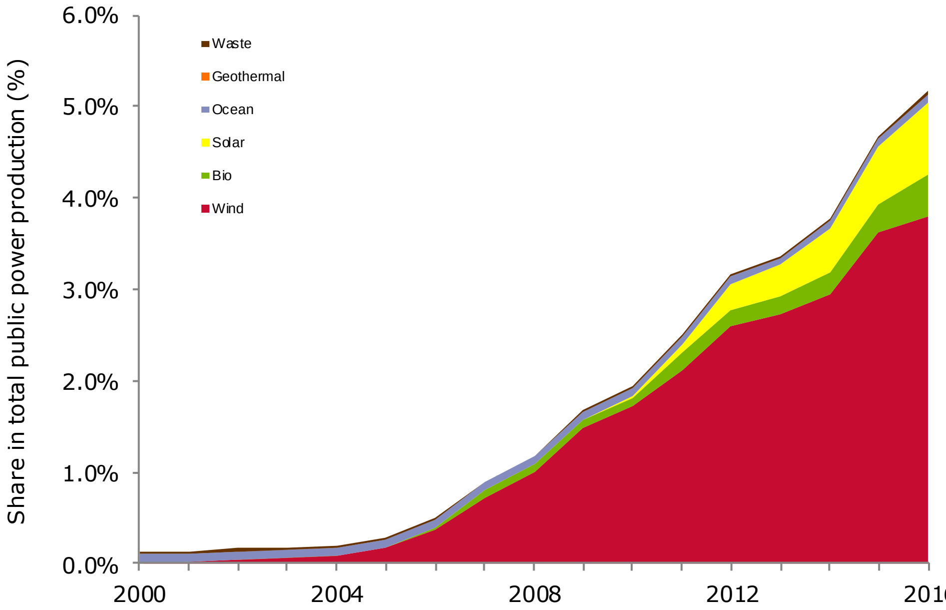

Figure 36 Share of renewable power production (excluding hydropower) during 2000 - 2016 in France.

Germany

Germany has a relatively diverse portfolio of renewable power production technologies that steadily increased from 6.6% in 2000 up to 30.9% in 2015. In 2015, large quantities of wind power (13.4%), hydropower (3.2%), bioenergy (6.8%) and solar power (6.6%) were generated. Wind power has been especially rising, from 9.9% in 2014 to 13.4% in 2015. However, there seems to be a stagnation of the renewable energy development in 2016. This can be explained by changes in the incentive structure, especially for solar energy, and a relatively low output for wind energy, even though the installed capacity of wind energy increased.

This increase has been brought about by strong support from Government policies such as a feed-in tariff and several finance programmes of the KfW bank. In addition, further measures for accelerated grid expansion were implemented, as the installment of offshore wind has partially been slowed by inadequate grid connection. A pilot auction scheme was introduced for ground-mounted PV plants (first auctions took place in 2015) and by 2017 an auction scheme for other renewable power technologies was introduced through an amendment of legislation. Germany is also actively promoting cooperation with support schemes of neighbouring states, having agreed on a joint PV auction with Denmark.

The deployment of nuclear power facilities has slowly declined from 32.4% in 2000 to 14.4% in 2016. In 2011, after the Fukushima accident, the decision was taken to phase out nuclear power stations by 2022.

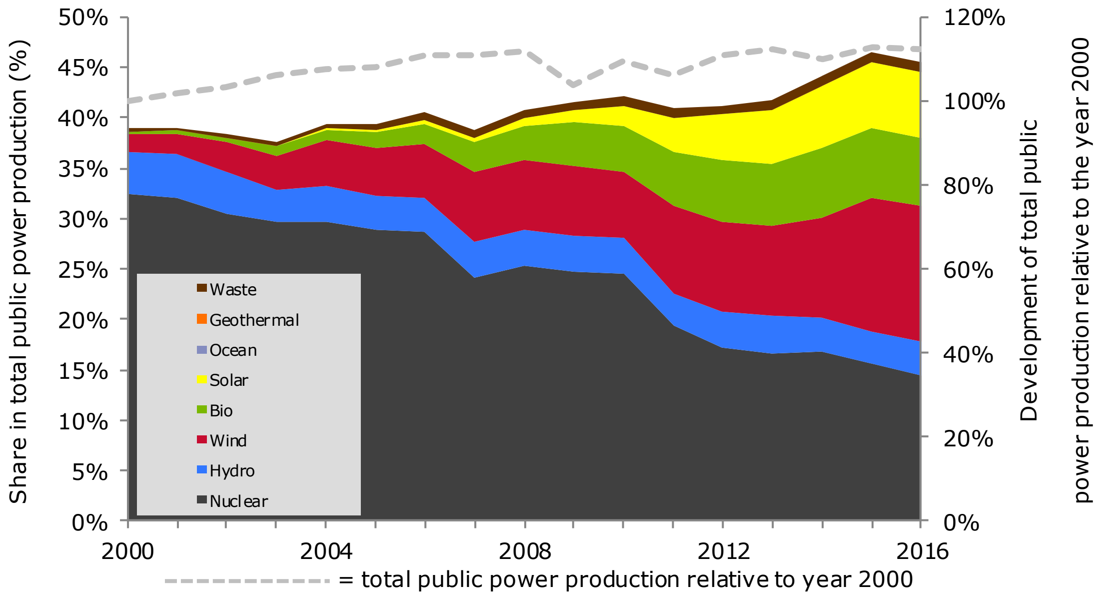

Figure 37 Share of renewable and nuclear power production during 2000 - 2016 in Germany.

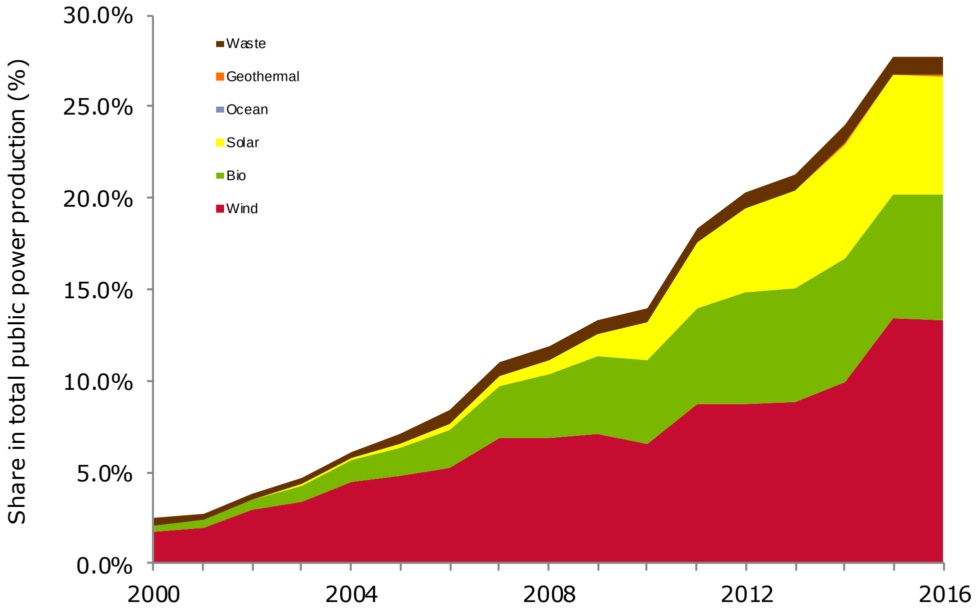

Figure 38 Share of renewable power production (excluding hydropower) during 2000 - 2016 in Germany.

India

Over the last five years, the shares of hydropower and nuclear power in India have been decreasing, for nuclear from 3.6% in 2011 to 3.1% in 2016 and for hydro from 15.6% in 2011 to 11.2% in 2016. In the years before, the nuclear share was between 2.0 and 3.8% and the hydro share between 12.7% and 17.8%. This means in absolute terms that nuclear and hydro power production has increased significantly (from 17 TWh in 2000 to 38 TWh in 2016 for nuclear, from 74 TWh in 2000 to 137 TWh in 2016 for hydro) because total public power production more than doubled from 2000 to 2016. There has also been a steady increase in wind power from 0.3% in 2000 to 3.5% in 2016, as well as recently in solar power from 0.1% in 2011 to 1.1% in 2016. However, the development of electricity transmission infrastructure has been relatively slow and in August 2012 there were wide-scale black outs. This could become an issue for further development of some renewables although there are opportunities for local power provision.

In 2013, the government pledged to increase its renewable power capacity from 25 GW in 2012 to 55 GW in 2017. This goal was reached and exceeded with India having an overall renewable energy capacity of 57.5 GW as of 14 June 2017. India has also set targets of 175 GW of renewable capacity in 2022, which includes 100 GW solar, 60 GW wind, 10 GW from biomass and 5 GW from small hydro. This is part of the pledge to establish a 40% share of non-fossil fuel power capacity by 2030. In 2040, renewables and nuclear are to present the majority of new generation capacity.

Feed-in tariffs and auction schemes are used at state level for different technologies. There is also a renewable power purchase obligation for utilities that can be fulfilled through renewable energy certificates. However, the certificates market has been highly unstable and crashed in the summer of 2013.

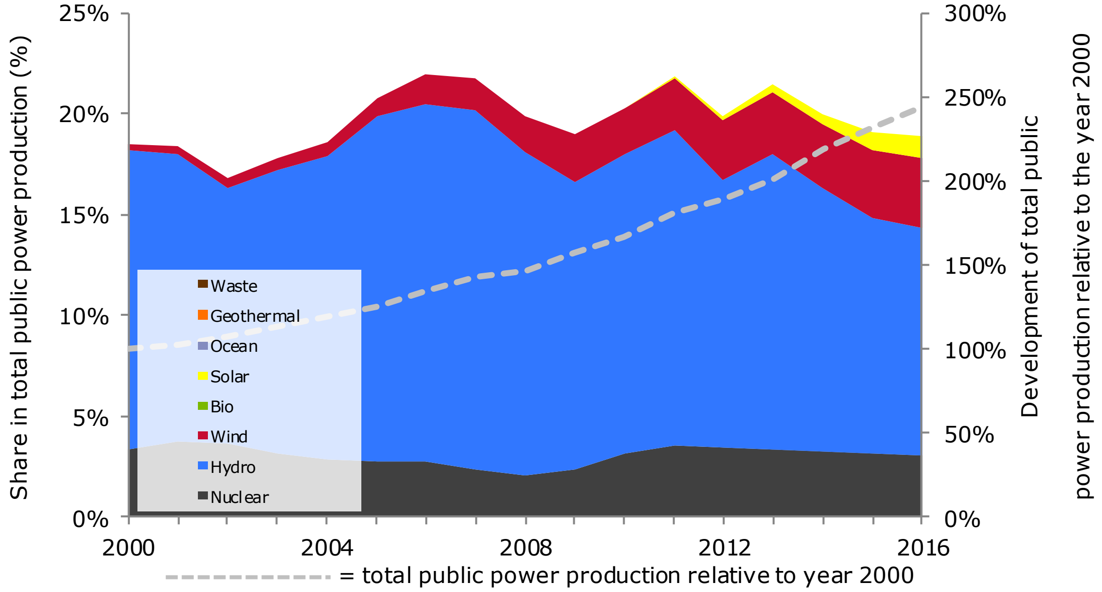

Figure 39 Share of renewable and nuclear power production during 2000 - 2016 in India.

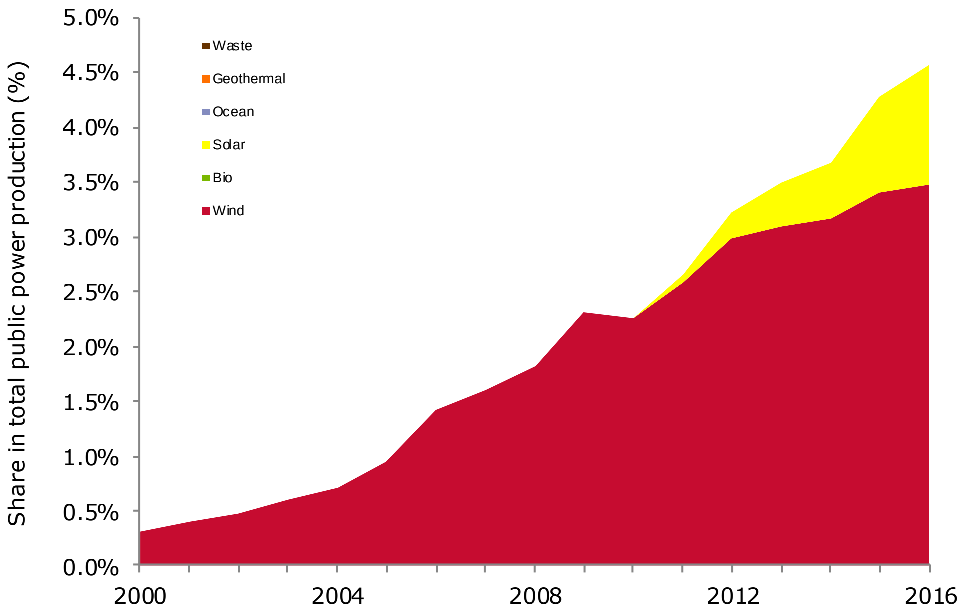

Figure 40 Share of renewable power production (excluding hydropower) during 2000 - 2016 in India.

Japan

Japan's share of nuclear power production fluctuated between 26.4% and 35.1% between 2000 and 2010. Following the Fukushima accident in 2011 the nuclear share rapidly decreased to 1.8% in 2012 and 0% in 2014, but it increased slightly again to 2.1% in 2016. Hydropower has the highest share of renewable energy production in Japan. Since 2000 it has fluctuated between 6.7% and 9.4%, showing a slight increase in the past four years, from 6.8% in 2012 to 8.7% in 2016.

A constant 0.3% of the total public power production originates from geothermal sources. Until 2004 this was practically the only source of renewable power production apart from hydro. In 2005, a single year increase of primary solid biofuels is observed (from 0 to 0.3%), which increased towards 0.6% in 2016. In 2016, 0.7% of total public power production originates from solar, which is the first noticeable amount since 2000.

The Renewable Energy Act of August 2011 and the feed-in tariff scheme introduced in 2012 aim to increase renewable power production. It obliges electricity utilities to purchase power from renewable energy sources at fixed prices. The feed-in tariff led to 87 GW of approved (not built) capacity until March 2015 of which over 90% was PV. In addition, about 2.3 GW of wind power and about 2 GW of biomass power have been approved (Institute for Sustainable Energy Policies, 2015). However, in recent years the feed-in tariff (FIT) has been further reduced and in April 2017 a range of changes were applied to the FIT regime. The new amendments include a new certification scheme under which each renewable project needs to be certified by the METI (Ministry of Economy, Trade and Industry) in order to be eligible for the FIT. In addition, a competitive reverse auctioning process for larger solar projects (>2MW) was introduced.

With the strategic energy plan of 2014 Japan set a target of a renewable power production of 237-252 TWh (22-24% of total power generation) by 2030. This is translated to a share of 7% solar, 1.7% wind, 3.7-4.6% biomass, 1.0-1.1% geothermal and 8.8-9.2% hydro power production. This target did not change with the 5th strategic energy plan which was approved by the Cabinet on the 3rd of July 2018.

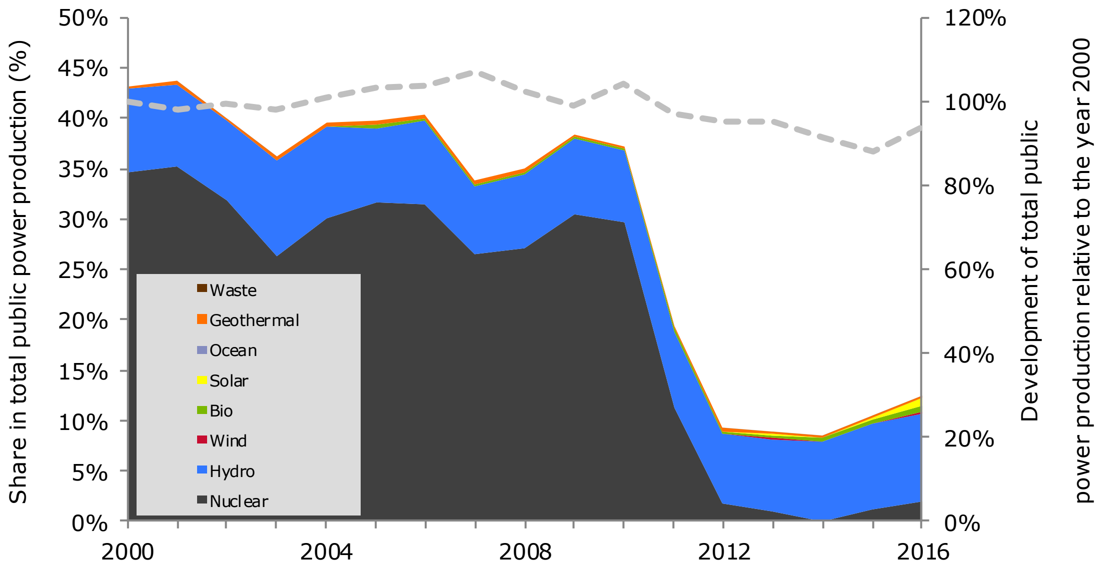

Figure 41 Share of renewable and nuclear power production during 2000 - 2016 in Japan.

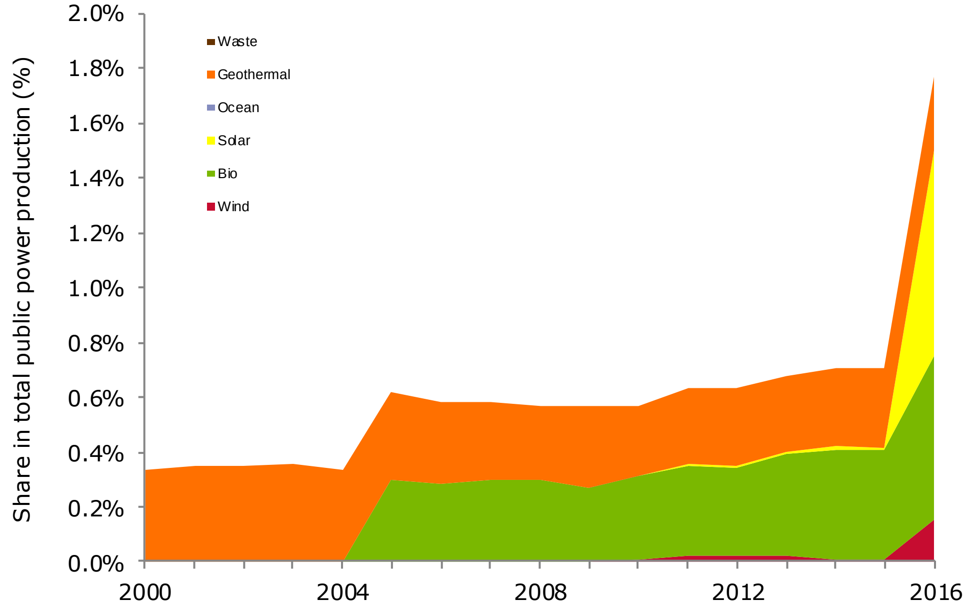

Figure 42 Share of renewable power production (excluding hydropower) during 2000 – 2016 in Japan.

South Korea

The share of nuclear power production was slowly decreasing from 41.8% in 2000 to 27.2% in 2013, but it has recently increased again to 30.9% in 2016. The share of hydropower is also slowly diminishing from 1.5% in 2000 to 0.5% in 2016. However, given that the total public power production has doubled from 2000 to 2016, the absolute power production for nuclear in 2016 is significantly larger (162 TWh) than in 2000 (109 TWh). Other renewable energy sources only have small shares, but their shares have been slowly increasing: wind and bio were at 0.3% and 0.9% respectively in 2016 and significant ocean-based energy production also came online in recent years (Sihwa Lake Tidal Power Station). Solar power also increased from 0.4% in 2014 to 0.9% in 2016.

The Korean government previously focused its energy policy on building up nuclear energy. However, especially after the Fukushima incident, this policy came under pressure. In the National Energy Master Plan, which was first established in 2008 and updated in 2014, the Korean government outlines its energy policies towards the long-term future. It includes a specific target for renewable energy, namely to achieve a share of 11% renewable energy in total energy consumption in 2035. The 8th Basic Plan for Long-term Electricity Supply and Demand from 2017 aims for 20% of renewable power generation by 2030. In particular, it aims for a strong growth of solar and wind power.

A renewable portfolio standard system operates in Korea to promote renewable energy, replacing a feed-in-tariff system which was in place until 2011. In the last National Energy Master Plan, some changes were made to the Renewable Portfolio Standard system in order to achieve the renewable energy goals. In addition, South Korea has an Emission Trading Scheme in place to reduce CO_2-emissions.

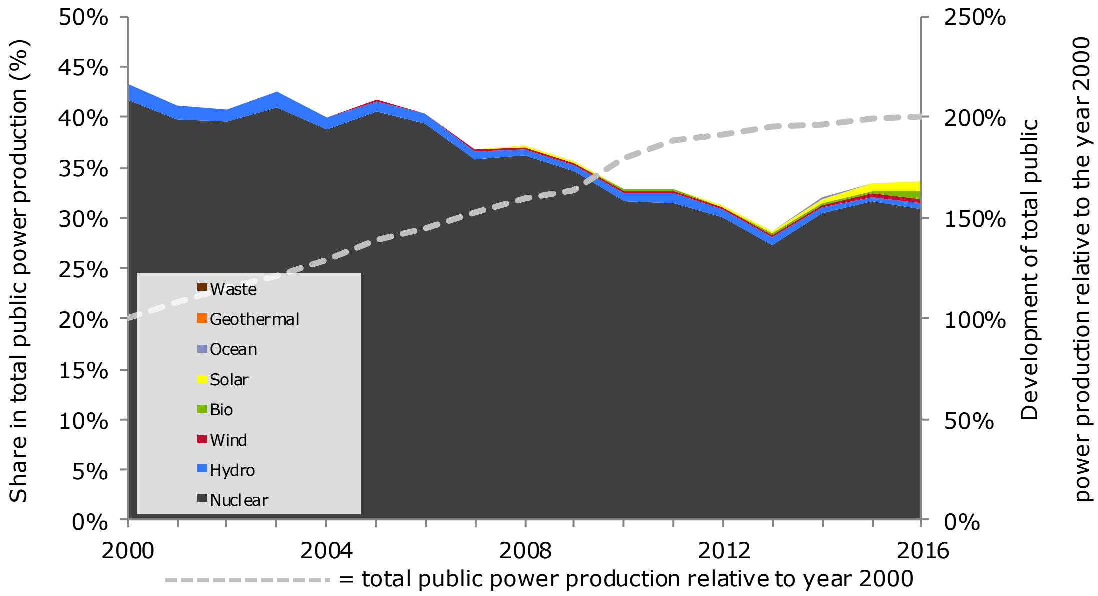

Figure 43 Share of renewable and nuclear power production during 2000 - 2016 in South Korea.

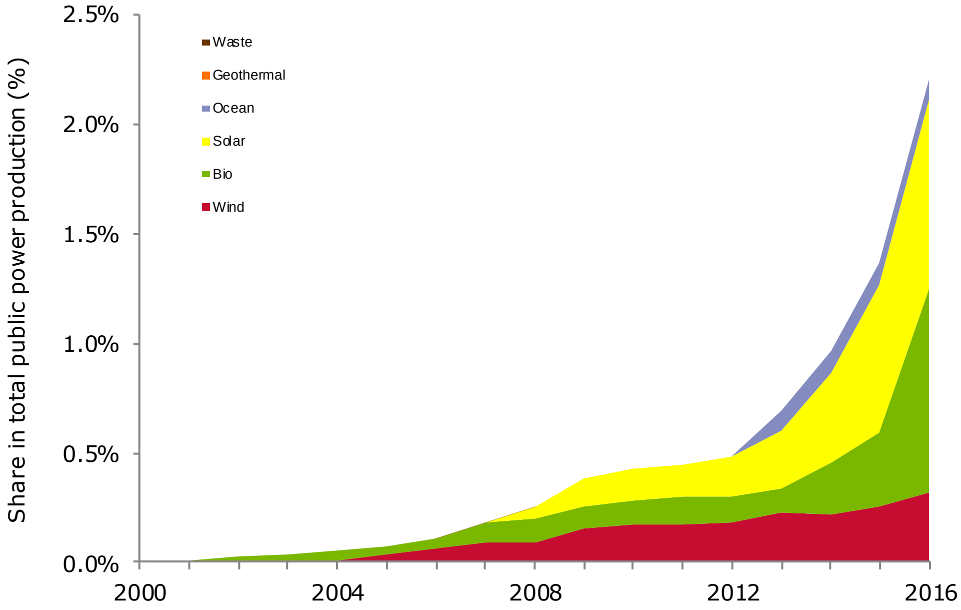

Figure 44 Share of renewable power production (excluding hydropower) during 2000 – 2016 in South Korea

Nordic countries (interconnected grid of Denmark, Sweden, Norway and Finland)

The region traditionally has a low dependence on fossil fuels. From 2010 to 2015, renewable energy generation has been increasing from 60.5% to 72.6%, but in 2016 it dropped a bit to 70.0%. In Norway, Sweden and Finland, the main source of renewable electricity is hydropower, which accounted for 57.3% of the total public power production in the Nordic countries in 2016. In Finland and Sweden, nuclear power also has an important role. However, the deployment of new wind farms (especially Denmark) has increased significantly in the past decade to respectively 8.7% in 2016 (2.2% in 2006). The power production portfolio differs significantly among the different countries of the region:

- Norway is almost completely hydro-powered. In the last decade the share of hydropower has marginally decreased as wind power is slowly increasing to produce 1.4% of the public power in 2016. Since Norway has a joint Tradable Green Certificates Scheme with Sweden, the renewables support policy can be found below.

- Denmark is now producing a majority of its public power production from wind (45.8% in 2016) and biomass energy (13.8% in 2016). Denmark has a diversified support system for renewable power and has been successful in integrating a high share of wind in the electricity grid. The long term policy goal for Denmark is to be fully independent of fossil fuels by 2050 and this is supported by the Energy Agreement reached in March 2012. Denmark is ahead of its schedule to meet the 30% RES target for 2020. Renewable power installations are supported through feed-in tariffs with the exception of auctions for offshore wind.

- Finland has 39.2% nuclear power, 24.9% hydropower, and about 6.9% power from biogenic sources in 2016. In recent years, wind energy has also been also significantly increasing from 0.4% in 2010 to 5.2% in 2016. In 2015, Finland started a debate on a revision of the wind quota and the new certificate scheme, as the earlier quota was already utilized to a large extent, but no changes are adopted to date. The aim is to support future wind power projects via an auctioning system.

- In the past decade, Swedish power has been nuclear and hydro-based, together responsible for more than 83.3% every year during 2000 – 2016. The share of wind power remained stable at 10.3% in 2016 compared to 10.4% the previous year, while nuclear increased from 36.1% in 2015 to 42.0% in 2016. There is a mix of instruments to promote renewable energy including a technology-neutral tradable green certificates scheme. Since the beginning of 2012, this has expanded to create a common market with Norway for these certificates. In 2013 quota levels have been increased and tax exemptions have been introduced for wind energy. In 2017 the two governments announced that the subsidy scheme originally set to expire in 2020 will be extended to 2030. The joint market will permit trading in both Norwegian and Swedish certificates until April 2046.

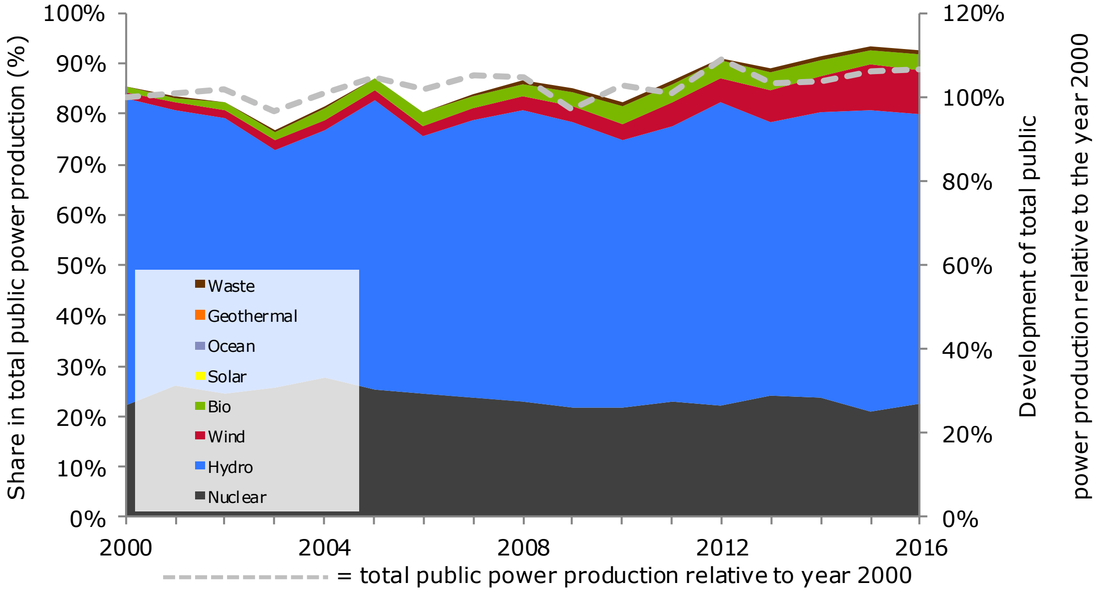

Figure 45 Share of renewable and nuclear power production during 2000 - 2016 in the Nordic Countries.

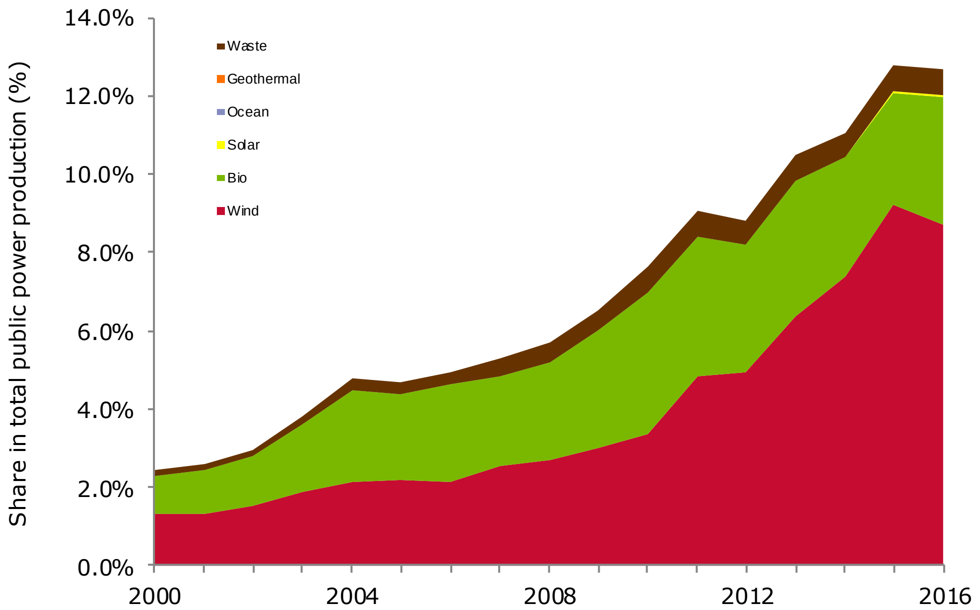

Figure 46 Share of renewable power production (excluding hydropower) during 2000 - 2016 in the Nordic Countries.

United Kingdom and Ireland (interconnected grid of the United Kingdom and Ireland)

The majority of power generation in the UK & Ireland is in the United Kingdom, with more than 90% of the total power generation (including fossil power) produced. All nuclear power facilities are located in the UK. These are responsible for 23.0% of the total public power produced in the UK and Ireland in 2016. The share of total renewable power production was 19.7% with about two-third from wind turbines. Wind energy and biofuels increased significantly in recent years: wind energy from 6.1% in 2012 to 12.7% in 2015 and bio from 1.9% in 2012 to 5.5% in 2015. However, in 2016 there has been a decline in the share of most renewable energies including wind and bio, except for solar that increased to 0.7% compared to 0.4% in 2015.

New electricity market reforms were announced in 2011 and aimed to increase the proportion of non-fossil fired power generation. This included a technology-specific quota scheme with tradable green certificates as well as a feed-in tariff scheme for small installations. In 2014 the United Kingdom introduced a so-called Contract for Differences, that includes key elements of an auctioned feed-in premium scheme. As the Renewables Obligation is scheduled for closure in 2017, the Contract for Difference scheme will be the only support scheme for all new renewable energy plants exceeding 5 MW from 2017.

Ireland has a renewable energy target of 40% in gross electricity consumption by 2020. Up until the 31st of December 2015 renewable energy was supported through a feed-in-tariff scheme, but as of January 2016, there was no support scheme available for renewable energies. The Irish government approved a new renewable energy support scheme in 2018 as an auctioning system with the first auction expected to take place in 2019 after state aid approval has been secured from the European Union. Although support levels were comparatively low, onshore wind is the dominant technology being applied. This is due to the high electricity market price and the good wind sites with low generation costs. Wind power in general had a share of 21.9% in Ireland in 2016.

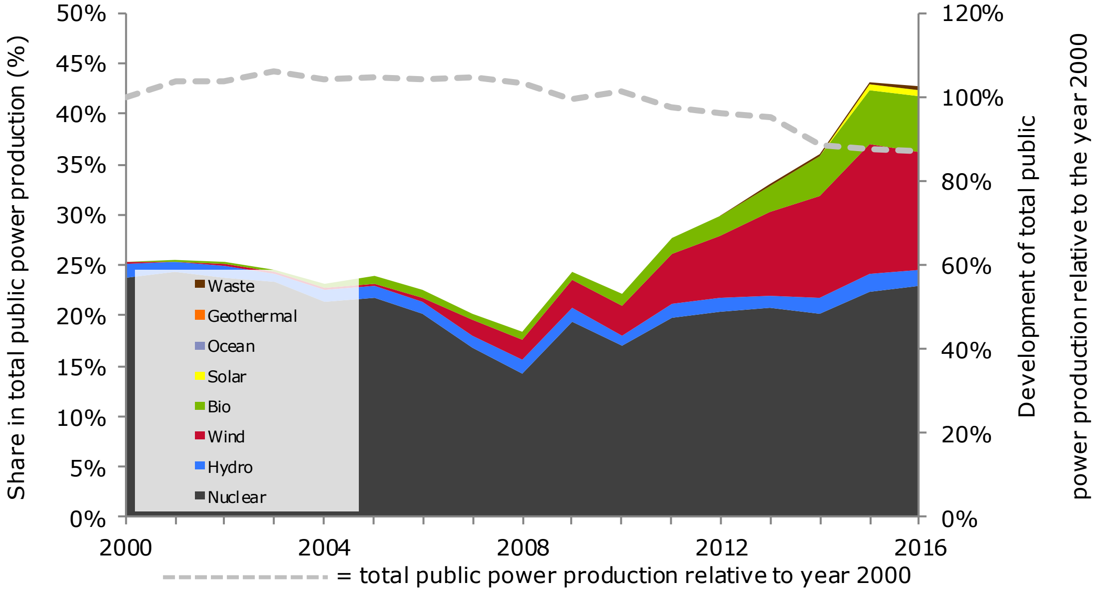

Figure 47 Share of renewable and nuclear power production during 2000 - 2016 in the UK and Ireland.

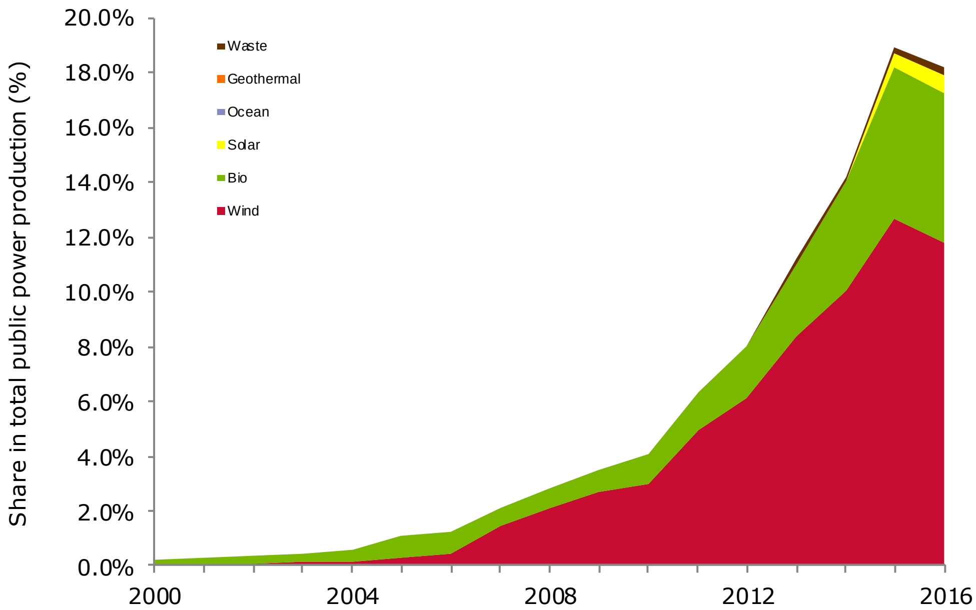

Figure 48 Share of renewable power production (excluding hydropower) during 2000 - 2016 in the UK and Ireland.

United States

For the United States, the share of nuclear and hydropower production remained constant over 2000 – 2016 between 19.6% and 21.6% for nuclear and between 5.0 and 7.7% for hydro. After hydro, the biggest renewable power generation technology deployed in 2016 was wind energy (5.6%), which increased from 1.8% in 2009. Besides that, there are small amounts of biofuels (0.7%), geothermal energy (0.5%) and solar energy (0.9%). Solar increased in recent years from 0.0% in 2011 to 0.9% in 2016. The energy mix and energy prices in the US have been affected significantly in recent years by the availability of relatively cheap shale gas. The incentives for renewable energy depend on the state, as well as the national government.

Although there is no federal target, a majority of the 50 states (and the District of Columbia) have a Renewable Portfolio Standard (RPS) in place. However, Renewable Portfolio Standards have been revised in several states, altering standards for different technologies or including small-scale installations. The main federal support for renewable power is through fiscal measures (accelerated depreciation schemes, investment and production tax credits). The Clean Power Plan, of which the final version was revealed by President Obama in August 2015, aims to reduce emissions from coal-burning power plants by 32% below 2005 levels by 2030. However, President Trump’s executive order signed in March 2017 giving green light to undo and rewrite the Clean Power Plan has put a question mark behind the progress of renewable energy policies going forward.

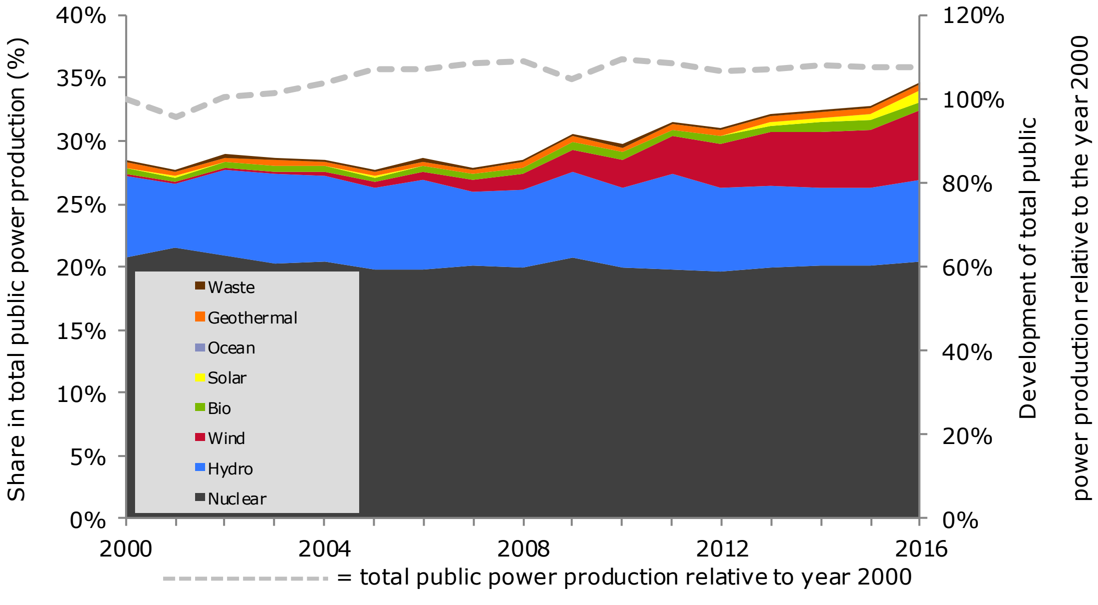

Figure 49 Share of renewable and nuclear power production during 2000 - 2016 in the United States.

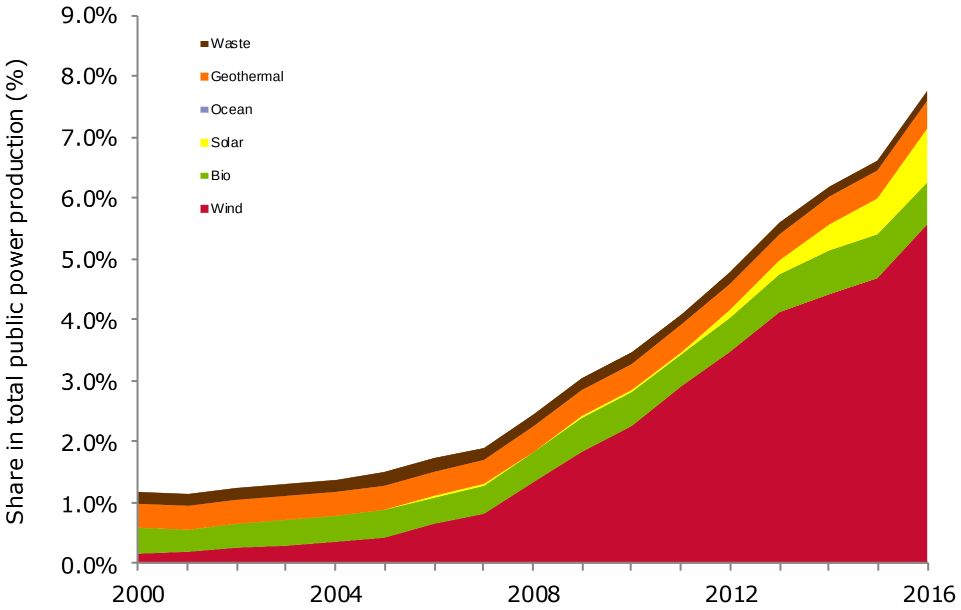

Figure 50 Share of renewable power production (excluding hydropower) during 2000 - 2016 in the United States.

4 Conclusions

The main purpose of this study is to compare fossil-fired power generating efficiency for several countries over the period 1990 – 2016. A distinction is made between different energy carriers (coal, oil, gas and fossil fuels in general). The countries taken into account are Australia, China, France, Germany, India, Japan, Nordic countries[9], South Korea, United Kingdom and Ireland, and the United States. In total, the abovementioned regions and countries were responsible for 66% of the public worldwide power generation in 2016. Secondly, the CO_2 intensity and CO_2 reduction potential of public power production is determined for these countries. Finally, the development of the share of renewables in the public power mix was analysed for the years 2000-2016, distinguishing the different renewable energy sources.

In this study two approaches are applied for benchmarking electricity generating efficiency: (1) by using non-weighted average efficiencies and (2) by using weighted average efficiencies.

On average in the period 2014-2016, the United Kingdom and Ireland had a 8% higher weighted fossil efficiency, followed by South Korea (+7%), Japan (+5%) and Germany (+5%), the Nordic countries (+4%), France (1%) and the United States (+0%). China is slightly below the benchmark (-0.1%), while India and Australia are the most prominent underperformers with generating efficiencies at 7% and 8% below the benchmark respectively.

For the period 1990-2016 the following can be concluded when considering the weighted average efficiencies for the studied countries:

- Gas-fired power: the efficiency for gas-fired power generation shows a strong increase from 38% in 1990 to 49% in 2016 (average annual improvement of 1.0%). The reason for this improvement is mainly the large amount of (more efficient) new generating capacity; gas-fired power generation increased more than threefold over the period 1990 - 2016.
- Coal-fired power: only a limited increase in efficiency is seen of 35% to 37% (average annual improvement of 0.3%). The reason for this is that a significant part of the growth in coal-fired power generation took place in India where the efficiency still remains well below levels for best available technology.
- Oil-fired power: the efficiency for oil fired generation increased significantly after 2009, but recently was stable at 40% because there were no further efficiency increases for the largest oil-fired power generators, the United States and Japan.
- Fossil-fired power: the efficiency increased from 36% to 40% which corresponds to an annual average improvement of 0.4%. The limited improvement in generating efficiency is caused by the large installed base that is being replaced slowly and the dominance of coal as fuel for public power production.

[9] Denmark, Finland, Sweden and Norway aggregated

If all plants currently operating in these countries were replaced by plants operating according to best available technology (BAT) efficiencies, absolute CO_2 emissions related to fossil power production would be 20% lower due to the improved generating efficiency (not taking into account fuel switching).

China, United States and India show very high absolute emission reduction potentials of 785, 380 and 189 Mt respectively. The absolute abatement potential is very much dictated by the total amount of power produced in the country and the extent to which this occurs by making use of inefficient technologies combusting CO_2-intensive fuels.

In most of the assessed countries, the share of nuclear and hydropower production typically remained constant in the past decade (2000 - 2016) or slowly declined. In Japan and to a lesser extent Germany and South Korea, the share of nuclear power notably declined after the Fukushima incident.

In the year 2000, production from renewable sources other than hydropower did not exceed 1% of the generated power in the public mix with only few exceptions (Germany, Nordic Countries, United States). However, in most countries a significant uptake of the use of renewable power generation technologies can be observed from 2000 up to 2016. The strongest average growth in the share of renewables (excluding hydro) in the public mix in 2000-2016 occurred in Germany, the United Kingdom and Ireland and the Nordic Countries. In particular the share of power generation from wind increased in the last decade, and recently power production based on solar energy has been developing.

Finally, it should be noted that there are uncertainties within the data, including differences between this year’s and last year’s IEA balances (Table 8) and rapid fluctuations (e.g. peaks in gas-fired generating efficiency for Australia and India in Figure 14) which cannot always be explained. This means that one should beware of drawing too definitive conclusions from the data.

5 Discussion of uncertainties & recommendations for follow-up work

In this chapter a few points of uncertainty are discussed and recommendations for improvement are given (in bold).

1. Currently the scope of this study is public power generation only. The reason for this is that the IEA historically distinguishes between private and public power generation (e.g. heavy industry with autonomous power supply vs. public power plants). However, the boundaries between public and private power production have slowly faded within the past decade(s). This trend is expected to continue. A relevant example is the use of decentralized power generation by individual households (e.g. by means of solar panels). As a consequence, the classical statistical distinction between public and private power generation is slowly becoming less applicable for studying public power production.

In future work, the scope could be expanded by not only taking into account public, but total (i.e. including private) power production.

2. Uncertainties in the analysis arise in the first place from the input data regarding power generation, heat output and fuel input. This uncertainty can be reduced by comparing IEA statistics to national statistics, but it is often difficult to compare national statistics to IEA statistics due to a different method of representing statistics (e.g. net versus gross power generation, fuel input based on net or gross calorific value, different method for combined-heat and power plants). Therefore IEA statistics remain the sole data source for this analysis to allow for better comparisons. For a number of countries, efficiencies based on IEA show sharp increases or decreases for individual years that cannot be explained. Therefore we show, in some cases, results as average efficiencies for the three most recent years (2014 - 2016) to reduce this uncertainty.

For follow-up research checks can be made with assistance of national statistical experts to determine structural errors and inconsistencies in statistics.

3. In the CO_2-intensity analysis, uncertainties arise mainly from the CO_2 emission factor used per fuel source. We based the analysis on average CO_2 emission factors per fuel category (hard coal, lignite, natural gas and oil). However, the emissions factor for specific fuel type used in a country can be different (e.g. different type of hard coal or oil). The resulting uncertainty is estimated to be lower than 10%, which is possibly a substantial influence.

We recommend improving this study by using national emission factors in calculating the total emissions and the CO_2 reduction potential. In addition, national calorific values would allow us to calculate efficiencies based on those national statistics that only give fuel input in units of weight (and not in units of energy). This is the case for e.g. China, the largest generator of fossil-fired power.

4. Another source of uncertainty is the assumed efficiency loss resulting from heat generation. In this study a factor of 0.175 is used. This may be different when heat is delivered at high temperatures (e.g. to industrial processes). We estimate that the effect on the average efficiency is not more than an increase of 0.5 percent-point.

We recommend carrying out an assessment of the validity of the 0.175-factor.

5. Uncertainty also arises from some structural factors that are not taken into account in the analysis. For instance, a higher ambient temperature leads to a slightly lower efficiency (0.1-0.2%/°C). Surface water cooling leads to slightly higher efficiencies than the use of cooling towers. The effect of cooling method on efficiency may be up to 1-2 percent point.

We do not recommend further work on this point.

6. The primary energy saving potential resulting from moving towards BAT levels in the countries under study is significant. This aspect is currently not within the scope of this study, but is considered worthwhile for further investigation.

We recommend further work on this point.

7. On several occasions throughout this study it is noted that the annual fluctuations in total operating hours for fossil power plants can be large in the countries under study, due to structural economic effects or changing policy and power markets. With the introduction of more renewable capacity this is expected to become a more important topic in the coming years.

We recommend to perform a more detailed analysis on the annual capacity factors by relating the annual electricity production to installed production capacity.

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Appendix I: Generating efficiencies and comparison previous Ecofys report

The tables below show generating efficiencies for coal-fired, gas-fired, oil-fired and fossil-fired power plants, based on IEA (2018). In Table 8 differences between the efficiency of fossil power generation between this report and last year's report (Ecofys, 2017) is shown. Differences are the result of changes in historical data of the IEA (2018) database compared to the 2017 database, due to for example revisions or methodological changes. Table 9 provides explanations for the differences found.

Table 4 Efficiency of coal-fired power generation (%)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	36.3%	36.3%	36.2%	36.6%	37.3%	36.8%	36.6%	36.8%	35.2%	35.7%	36.4%	37.7%	34.1%	34.7%	34.4%	34.3%	34.3%	34.4%	34.3%	33.1%	34.5%	34.7%	35.0%	34.7%	35.0%	35.2%	35.2%
CN	28.8%	29.3%	30.1%	29.7%	30.7%	29.7%	28.5%	31.3%	30.5%	31.7%	32.1%	32.0%	31.7%	31.6%	31.7%	31.7%	32.1%	33.7%	34.2%	34.3%	35.2%	35.4%	34.9%	35.5%	36.6%	36.9%	37.4%
FR	39.5%	41.7%	42.9%	38.2%	39.3%	38.5%	38.9%	35.8%	38.2%	37.1%	37.2%	38.3%	38.8%	39.6%	39.4%	39.5%	39.1%	38.6%	40.5%	38.2%	41.6%	40.8%	37.8%	38.2%	37.0%	38.7%	39.1%
DE	34.4%	35.1%	35.1%	35.6%	35.8%	36.3%	36.2%	36.5%	37.6%	37.9%	38.6%	37.3%	37.8%	38.7%	38.7%	38.4%	38.0%	38.0%	38.4%	38.0%	38.5%	38.5%	38.7%	38.9%	39.0%	39.6%	39.5%
IN	32.7%	32.2%	32.1%	31.7%	32.0%	31.5%	31.2%	31.6%	31.7%	31.7%	31.6%	31.9%	33.1%	33.0%	32.3%	32.0%	32.4%	31.9%	32.0%	31.8%	31.2%	32.1%	31.4%	32.4%	32.6%	34.7%	37.2%
JP	39.6%	39.6%	39.6%	39.2%	39.7%	39.8%	40.2%	40.5%	40.8%	41.1%	41.3%	41.5%	41.7%	41.7%	41.3%	41.3%	41.2%	41.3%	41.5%	41.6%	42.0%	42.0%	42.5%	42.0%	42.7%	42.8%	41.6%
KR	25.8%	23.4%	25.9%	30.0%	34.4%	36.5%	33.2%	35.1%	37.3%	36.5%	34.3%	36.8%	39.1%	37.5%	35.3%	35.5%	35.4%	39.0%	38.6%	36.6%	36.5%	35.5%	38.6%	36.5%	37.6%	37.6%	37.8%
DK+FI+ SE+NO	39.5%	39.6%	39.6%	40.7%	41.4%	41.6%	41.0%	40.7%	40.4%	41.7%	41.2%	41.5%	41.5%	41.2%	40.0%	39.7%	40.3%	40.4%	39.8%	40.3%	40.7%	40.4%	39.6%	40.5%	39.7%	38.8%	40.1%
UK+IE	37.0%	38.1%	36.9%	38.3%	38.2%	39.2%	39.1%	37.6%	37.3%	37.6%	38.1%	37.5%	38.1%	38.4%	37.9%	37.6%	37.7%	37.6%	39.1%	39.6%	39.1%	38.7%	38.8%	39.2%	39.4%	38.9%	38.1%
US	36.8%	37.0%	36.1%	36.4%	36.3%	35.5%	35.7%	35.2%	35.9%	36.5%	36.5%	34.0%	36.6%	36.7%	36.5%	36.8%	37.0%	36.2%	37.0%	37.0%	37.0%	37.0%	36.9%	37.0%	37.1%	37.1%	36.7%

Table 5 Efficiency of gas-fired power generation (%)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	36.7%	36.9%	36.8%	37.6%	34.5%	37.1%	36.1%	35.5%	36.3%	37.4%	37.6%	37.0%	36.7%	55.5%	52.9%	39.5%	39.1%	39.0%	40.1%	37.4%	39.3%	41.8%	37.8%	39.5%	41.0%	37.9%	36.1%
CN	39.0%	39.0%	39.0%	39.0%	39.0%	39.0%	39.0%	39.0%	39.0%	39.0%	39.0%	39.0%	39.0%	40.0%	40.3%	41.5%	44.6%	47.5%	47.1%	48.6%	50.3%	50.2%	50.4%	49.3%	46.9%	47.5%	48.1%
FR	41.5%	41.1%	41.1%	44.1%	43.0%	50.8%	46.6%	40.4%	39.9%	39.9%	49.5%	46.0%	47.4%	47.6%	49.2%	48.9%	48.2%	47.6%	45.6%	31.5%	35.5%	50.3%	45.3%	46.4%	46.0%	48.9%	52.7%
DE	32.6%	31.3%	30.0%	30.7%	29.1%	35.2%	33.6%	34.7%	37.2%	36.3%	39.0%	38.5%	38.1%	42.7%	42.5%	43.0%	43.5%	45.1%	45.9%	45.0%	46.3%	47.7%	47.0%	46.9%	46.6%	47.1%	48.4%
IN	23.2%	24.9%	28.2%	32.0%	36.7%	37.8%	40.4%	44.1%	49.2%	57.7%	56.8%	53.1%	52.1%	52.1%	49.6%	47.0%	47.4%	49.8%	49.1%	41.0%	35.7%	37.2%	35.2%	37.0%	37.0%	40.0%	40.0%
JP	43.0%	43.0%	43.1%	42.6%	43.2%	43.2%	43.7%	44.1%	44.3%	44.7%	44.9%	45.0%	45.4%	45.4%	46.7%	46.6%	46.5%	46.7%	46.9%	47.1%	47.5%	47.4%	47.4%	47.5%	48.2%	48.4%	47.0%
KR	40.5%	40.6%	40.3%	42.3%	42.3%	42.2%	44.8%	45.2%	49.3%	47.1%	45.2%	41.9%	50.1%	50.6%	50.4%	50.6%	51.6%	50.9%	51.0%	51.0%	51.1%	51.6%	45.1%	56.7%	58.0%	57.8%	54.9%
DK+FI+ SE+NO	44.5%	44.8%	43.9%	43.7%	42.4%	39.5%	42.7%	40.7%	43.8%	45.2%	45.4%	45.8%	45.2%	46.1%	47.1%	47.0%	47.3%	46.9%	47.2%	46.4%	44.7%	44.8%	45.0%	46.1%	47.6%	48.0%	45.3%
UK+IE	40.4%	41.9%	35.1%	40.5%	45.6%	47.3%	47.1%	49.4%	49.3%	50.0%	50.1%	50.3%	51.4%	51.1%	51.3%	51.1%	50.0%	51.5%	51.9%	51.5%	51.9%	52.9%	51.9%	52.6%	52.1%	52.8%	53.9%
US	37.2%	37.8%	38.0%	38.5%	38.9%	38.2%	38.3%	37.9%	37.5%	37.8%	39.6%	40.5%	41.9%	43.1%	44.4%	44.8%	46.0%	45.7%	46.7%	47.6%	47.4%	47.6%	48.2%	48.6%	48.8%	49.1%	49.0%

Table 6 Efficiency of oil-fired power generation (%)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	29.6%	30.5%	23.5%	25.1%	25.7%	21.8%	26.5%	27.1%	24.1%	32.9%	30.9%	33.6%	41.4%	19.6%	15.6%	29.2%	29.9%	30.7%	30.5%	31.0%	39.8%	39.8%	40.2%	39.1%	40.9%	42.7%	40.8%
CN	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%
FR	37.9%	38.3%	38.4%	37.0%	35.8%	36.3%	36.2%	37.0%	35.4%	33.5%	72.4%	54.6%	57.0%	51.2%	45.3%	35.6%	33.7%	33.1%	35.7%	25.5%	29.7%	31.1%	31.3%	30.3%	30.3%	31.2%	37.2%
DE	27.8%	30.0%	29.6%	26.4%	26.3%	28.3%	30.4%	30.4%	31.4%	31.8%	22.9%	26.9%	42.7%	36.6%	37.8%	40.2%	39.2%	39.1%	39.4%	38.5%	38.9%	39.6%	38.6%	37.7%	36.1%	37.9%	37.3%
IN	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	24.3%	21.1%	21.9%	24.4%	27.2%	27.8%	29.2%
JP	40.6%	40.6%	40.7%	40.3%	40.8%	40.8%	41.4%	41.8%	42.0%	42.4%	42.6%	42.8%	43.1%	43.1%	40.1%	39.6%	39.9%	40.1%	40.2%	40.5%	40.9%	40.6%	41.5%	41.2%	41.8%	42.4%	40.5%
KR	35.9%	37.1%	38.7%	40.5%	43.1%	38.5%	42.6%	35.8%	38.0%	33.8%	32.1%	33.3%	33.0%	34.6%	33.5%	32.6%	32.2%	37.2%	37.2%	37.8%	38.4%	44.0%	38.4%	38.4%	42.0%	37.3%	38.1%
DK+FI+ SE+NO	36.7%	37.0%	40.2%	39.2%	42.0%	40.7%	39.9%	38.6%	37.1%	40.0%	39.1%	38.7%	39.5%	42.0%	36.1%	36.8%	37.9%	37.1%	38.8%	33.5%	37.5%	36.0%	33.5%	33.4%	34.9%	35.0%	34.0%
UK+IE	40.6%	38.2%	38.9%	37.6%	31.6%	34.0%	36.0%	36.5%	40.7%	46.8%	44.2%	42.7%	49.5%	33.9%	33.6%	35.0%	38.8%	39.9%	38.7%	34.2%	33.5%	29.7%	33.5%	30.3%	30.0%	32.7%	29.0%
US	39.5%	38.3%	37.9%	38.2%	37.9%	37.3%	36.9%	19.0%	18.9%	18.5%	21.5%	22.0%	36.7%	37.3%	37.3%	37.9%	38.9%	38.1%	39.0%	40.0%	39.8%	41.5%	43.4%	43.1%	40.0%	40.7%	41.2%

Table 7 Efficiency of fossil-fired power generation (%)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	36.2%	36.2%	36.2%	36.6%	37.0%	36.8%	36.5%	36.6%	35.2%	35.8%	36.5%	37.6%	34.4%	35.9%	35.5%	34.6%	34.6%	34.7%	34.8%	33.6%	35.2%	35.8%	35.5%	35.6%	36.2%	35.8%	35.4%
CN	29.3%	29.7%	30.4%	30.1%	30.9%	30.0%	28.8%	31.5%	30.7%	31.8%	32.2%	32.1%	31.8%	31.7%	31.8%	31.8%	32.3%	33.8%	34.3%	34.5%	35.5%	35.7%	35.2%	35.8%	36.9%	37.2%	37.8%
FR	39.2%	40.8%	42.1%	38.2%	39.0%	38.3%	38.6%	36.0%	37.7%	36.8%	41.5%	41.6%	42.4%	42.7%	42.6%	41.0%	40.5%	40.1%	41.3%	33.9%	37.5%	45.0%	40.4%	40.4%	39.9%	43.3%	47.9%
DE	34.0%	34.5%	34.4%	34.8%	34.8%	36.0%	35.8%	36.2%	37.5%	37.6%	38.5%	37.3%	37.9%	39.3%	39.3%	39.2%	39.0%	39.2%	39.8%	39.4%	40.0%	40.2%	40.0%	39.9%	39.9%	40.5%	40.9%
IN	31.6%	31.2%	31.4%	31.4%	31.9%	31.6%	31.5%	32.3%	32.8%	33.4%	32.9%	33.1%	34.2%	34.3%	33.5%	33.1%	33.6%	33.3%	33.1%	32.8%	31.8%	32.6%	31.6%	32.6%	32.7%	34.9%	37.3%
JP	41.2%	41.2%	41.3%	40.9%	41.4%	41.4%	41.9%	42.3%	42.6%	43.0%	43.1%	43.2%	43.5%	43.5%	43.3%	43.0%	43.2%	43.2%	43.5%	44.0%	44.3%	44.3%	44.5%	44.3%	45.2%	45.4%	44.1%
KR	33.0%	33.3%	35.2%	36.9%	39.5%	38.4%	38.6%	37.4%	39.8%	38.4%	35.7%	37.1%	40.2%	39.4%	38.4%	38.5%	38.9%	42.0%	41.7%	39.5%	40.3%	40.1%	40.5%	42.6%	43.4%	42.9%	42.4%
DK+FI+ SE+NO	39.8%	39.9%	40.1%	40.9%	41.6%	41.1%	41.1%	40.5%	40.8%	42.4%	42.3%	42.4%	42.3%	42.5%	41.7%	41.9%	42.0%	41.8%	41.9%	41.7%	41.9%	41.7%	41.0%	41.6%	41.1%	40.8%	41.0%
UK+IE	37.5%	38.1%	37.0%	38.6%	39.1%	40.6%	41.2%	42.0%	42.0%	43.7%	43.5%	42.9%	44.1%	43.6%	43.6%	43.1%	42.4%	43.8%	45.3%	45.7%	45.9%	45.4%	42.9%	43.5%	44.4%	45.1%	49.4%
US	37.0%	37.2%	36.5%	36.7%	36.7%	35.9%	36.0%	34.5%	34.6%	35.3%	36.0%	34.3%	37.7%	37.9%	38.1%	38.5%	39.0%	38.5%	39.3%	39.8%	39.9%	40.1%	41.0%	40.8%	40.9%	41.9%	42.0%

Table 8 Difference fossil efficiencies in this report and the previous version of this report (Ecofys, 2017) in percentage points (calculated as efficiency in this report minus efficiency in last report). Difference larger than 1.0 % are marked red. Differences between 1.0 and 0.3% are marked yellow.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CN	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	-0.4%	-0.6%	-1.2%	-1.5%	-1.2%	-1.4%	-2.3%	-2.4%	-1.6%	-1.6%
FR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.5%	0.1%	-1.5%	2.1%	8.7%	1.2%	-0.9%	-1.1%	-0.5%
DE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
IN	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.4%	-1.6%	-1.4%	0.1%
JP	-0.2%	-0.3%	-0.2%	-0.3%	-0.2%	-0.3%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.4%	-0.3%	-0.3%	-0.2%	0.0%	-0.1%
KR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DK+FI+ SE+NO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.8%	-0.5%	0.0%	-0.1%	0.0%	-0.1%
UK+IE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
US	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.2%	-1.6%	-1.4%	-1.5%	-1.6%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 9 Explanation for differences in fossil efficiencies in this report and the previous version of this report (Ecofys, 2017)

Region	Years of deviation	Explanation and remarks	Source
China	M: 2005-2007 L: 2008-2015	In the 2018 edition of the World Energy Balances, coal and natural gas inputs to main activity heat plants and part of coal and natural gas inputs to main activity electricity plants were allocated to main activity CHP plants for the period 2005-2016.	a
France	S: 2008 M: 2007, 2013, 2015 L: 2009-2012, 2014	In the 2018 edition, data for France were revised back to 2011 following changes in methodology and procedures used by the energy statistics sub-department (SDSE) within the Ministry for the ecological and inclusive transition. As a result, the revisions, to bring the reporting more in line with the international standards, impacted all fuels. In the 2018 edition, the calorific value of coking coal has been revised in agreement with Eurostat and the IEA. The revision was made for the period 1990 to 2016. The French administration revised the methodology used in the 2018 edition for natural gas to bring it more in line with the international standards. More specifically, (i) Supply figures were revised for the period 2007-2016, (ii) Transformation sector consumption for 2007-2016, (iii) Energy sector consumption for 2011-2016.	a
India	S: 2015 L: 2012-2014	The net calorific values of coking coal, sub-bituminous coal and other bituminous coal, were revised again in 2018 to take into account more detailed information on imports and IEA Secretariat experts estimates.	a
Japan	S: 1990-2009 & 2012-2015 M: 2010, 2011	In the 2018 edition of the World Energy Balances, data for Japan were revised back to 1990 based on new methodology in all questionnaires. The net calorific values for coal and coal products have been recalculated by the IEA Secretariat based upon gross values submitted by Japan. In the 2018 edition, oil data for Japan were revised back to 1990 by the Japanese administration based on new methodology for the Energy Balance Table. The 2018 edition contains major revisions for natural gas to time series which go back to 1990. These have occurred as the result of a change in the statistical methodology implemented in November 2017. In the 2018 edition, main activity and auto-producer electricity plants for natural gas were revised back to 1990. Similarly, flows of the energy sector were revised back up to 1990.	a
DK + FI + SE + NO	S: 2013, 2015 M: 2010-2011	In the 2018 edition, data for Norway were revised back to 2010, following the introduction of a new system for energy balances and energy accounts. Breaks in series may appear between 2009 and 2010 as a result.	a

UK + Ireland	S: 2012	Data was updated, but no explanation was provided with regard to the changes made.	-
United States	S: 2002 L: 1997-2001	Data was updated, but no explanation was provided with regard to the changes made.	-

Legend	**Sources**
S: Small differences (≤ 0.3 ppts). For these differences no explanation is provided. M: Medium differences are 0.3-1.0 ppts L: Large differences are > 1.0 ppts	a = IEA (2018). World Energy Balances 2018 Edition: Database Documentation

Appendix II: Input data

Table 10 Public power generation absolute by source (TWh) in 2016

	Coal	Natural gas	Oil	Nuclear	Hydro	Other renewables	*Total*
Total	**7,436**	**2,316**	**107**	**1,917**	**1,966**	**983**	**14,726**
China	4,151	170	1	213	1,163	237	5,936
United States	1,340	1,316	27	840	268	328	4,119
India	945	47	3	38	137	56	1,226
Japan	301	392	58	18	76	28	873
Germany	255	57	1	85	20	170	589
France	10	30	2	403	59	28	532
Korea	213	120	13	162	3	13	524
Nordic countries	20	6	0	86	220	51	383
UK + Ireland	38	140	1	72	5	58	312
Australia	163	39	1	0	15	14	232

Table 11 Public power generation relative by source in 2016

	Coal	Gas	Oil	Nuclear	Hydro	Other renewables
China	70%	3%	0%	4%	20%	4%
United States	33%	32%	1%	20%	7%	8%
India	77%	4%	0%	3%	11%	5%
Japan	34%	45%	7%	2%	9%	3%
Germany	43%	10%	0%	14%	3%	29%
France	2%	6%	0%	76%	11%	5%
Korea	41%	23%	2%	31%	1%	2%
Nordic countries	5%	1%	0%	23%	57%	13%
UK + Ireland	12%	45%	0%	23%	1%	19%
Australia	70%	17%	1%	0%	6%	6%

Power generation

Table 12 Coal-fired power generation of public power plants in TWh

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	119	123	127	129	133	136	143	149	162	167	173	186	175	170	177	181	185	187	184	185	180	172	172	159	152	159	163
CN	440	497	563	615	692	741	819	865	880	960	1057	1125	1278	1515	1715	1964	2281	2631	2700	2882	3197	3659	3716	4025	4040	4032	4151
FR	22	30	27	15	15	18	22	17	28	31	28	22	25	27	25	29	23	24	25	23	25	17	21	23	11	11	10
DE	263	262	254	254	256	256	270	260	270	261	280	281	290	291	286	277	277	285	266	245	254	254	275	287	273	268	255
IN	172	191	205	227	237	268	283	295	305	331	350	366	384	402	419	432	460	486	507	537	561	612	691	746	835	895	945
JP	95	101	107	115	128	139	147	157	156	175	194	208	225	239	245	261	253	267	253	243	261	246	268	300	297	297	301
KR	12	11	13	21	32	39	47	59	70	74	98	110	118	120	127	134	139	155	173	193	200	204	218	204	211	215	213
DK+FI+ SE+NO	37	49	40	45	54	45	64	49	38	36	31	37	40	55	43	28	49	42	32	34	40	31	22	29	24	16	20
UK+IE	209	214	199	174	164	160	149	124	127	110	126	136	130	142	135	139	153	140	128	106	110	111	147	137	107	83	38
US	1675	1671	1689	1767	1769	1788	1878	1929	1959	1966	2075	1951	2013	2058	2064	2129	2103	2096	2110	1874	1969	1854	1624	1694	1695	1455	1340

Table 13 Gas-fired power generation of public power plants in TWh

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	13	9	10	11	11	13	11	9	9	11	11	11	22	19	20	16	15	21	24	29	34	37	37	39	41	40	39
CN	3	2	2	3	3	3	3	8	6	5	6	5	4	5	7	12	24	34	35	57	78	96	99	107	115	145	170
FR	0	0	0	0	0	0	0	0	0	0	5	8	10	10	11	11	11	11	11	17	21	24	18	13	9	16	30
DE	25	23	19	20	22	24	29	32	36	37	36	40	39	49	49	57	60	62	72	63	69	66	57	47	40	39	57
IN	8	11	13	15	18	25	27	34	41	49	48	47	53	58	62	61	64	70	72	96	98	92	65	43	39	45	47
JP	165	175	174	173	186	189	200	209	217	232	239	239	241	250	246	230	252	277	271	271	285	359	380	383	397	369	392
KR	10	10	12	14	18	20	27	32	27	30	28	31	39	40	56	59	69	80	79	68	101	113	109	142	127	120	120
DK+FI+ SE+NO	4	5	5	6	7	9	11	11	14	15	16	17	18	20	20	17	19	15	16	15	22	16	10	9	6	6	6
UK+IE	4	4	9	32	50	62	80	106	111	134	134	132	142	139	146	139	129	155	168	160	171	141	93	90	95	94	140
US	283	283	282	277	311	329	281	303	331	317	548	572	627	585	648	706	758	830	828	867	929	955	1168	1060	1065	1273	1316

Table 14 Oil-fired power generation of public power plants in TWh

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	1	2	1	1	1	1	1	1	1	1	1	1	2	1	1	2	2	2	3	1	1	1	1	1	1	2	1
CN	40	39	35	49	36	43	36	34	40	37	33	34	37	47	58	44	32	23	14	8	5	2	2	2	1	1	1
FR	5	10	5	2	2	3	3	3	5	3	5	3	4	5	4	6	5	5	4	3	4	2	2	2	1	1	2
DE	6	9	8	5	5	4	4	3	3	2	2	3	3	3	4	5	4	3	3	4	3	2	3	3	2	2	1
IN	7	7	7	6	6	7	7	7	6	6	10	9	10	9	8	5	4	5	10	7	6	4	4	4	4	3	3
JP	205	193	199	158	193	160	150	123	107	106	94	66	88	91	75	88	70	114	94	52	60	120	153	120	83	66	58
KR	19	27	35	35	40	42	41	41	15	14	22	24	21	22	19	18	17	18	10	14	13	11	16	16	9	9	13
DK+FI+ SE+NO	2	2	3	3	6	6	11	8	7	6	5	5	6	5	2	2	2	2	2	2	2	1	1	1	0	0	0
UK+IE	31	25	27	21	15	14	14	9	9	9	7	8	6	5	5	6	7	5	6	5	3	1	2	1	1	1	1
US	125	119	95	107	97	65	72	83	118	93	112	124	95	121	122	126	67	67	49	41	40	32	24	28	31	30	27

Table 15 Fossil-fired power generation of public power plants in TWh

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	134	134	137	140	144	150	155	158	171	178	184	198	199	190	198	199	202	210	211	216	215	211	209	199	194	201	203
CN	483	538	601	667	732	787	858	907	926	1001	1096	1164	1319	1568	1781	2020	2337	2688	2749	2947	3280	3757	3817	4134	4156	4178	4323
FR	28	40	33	17	17	22	26	20	34	35	38	33	38	42	41	46	39	40	40	43	50	43	41	38	21	29	42
DE	294	294	282	279	282	283	302	295	308	301	317	323	332	344	339	339	341	350	341	312	326	322	335	336	314	309	313
IN	187	209	225	248	262	299	317	336	353	386	408	422	447	469	488	498	528	560	588	640	665	708	760	792	878	943	994
JP	464	469	480	446	508	488	497	489	479	514	527	513	554	581	566	579	575	658	619	566	606	725	801	803	776	732	751
KR	40	48	61	71	91	101	116	132	112	118	148	166	178	182	202	211	225	252	263	276	314	329	343	363	348	344	346
DK+FI+ SE+NO	43	56	48	54	67	60	86	68	58	57	51	60	64	80	65	47	70	59	49	51	63	47	33	39	30	23	26
UK+IE	244	244	235	226	229	236	244	238	246	253	267	276	277	286	287	285	289	300	302	270	283	253	242	228	203	178	178
US	2082	2073	2066	2150	2177	2182	2231	2316	2408	2376	2735	2647	2734	2764	2834	2960	2928	2993	2986	2783	2938	2842	2816	2782	2791	2758	2683

Fuel input

Table 16 Fuel consumption of coal-fired power plants in PJ

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	1185	1225	1258	1267	1284	1333	1412	1460	1650	1681	1704	1777	1849	1769	1851	1899	1938	1956	1933	2018	1874	1786	1767	1650	1561	1623	1669
CN	5504	6094	6743	7451	8116	8989	10341	9950	10382	10913	11858	12643	14523	17259	19481	23449	26721	29336	29576	31388	33902	38524	39738	42230	41127	40816	41541
FR	203	259	229	137	135	171	206	172	267	304	276	205	232	250	232	262	211	227	225	217	218	148	199	218	105	105	91
DE	2894	2804	2723	2674	2665	2621	2775	2662	2668	2573	2681	2762	2804	2782	2730	2671	2694	2760	2559	2382	2440	2439	2618	2726	2578	2502	2384
IN	1890	2132	2297	2578	2670	3061	3268	3358	3466	3756	3991	4135	4188	4380	4666	4868	5104	5478	5710	6073	6467	6879	7932	8285	9229	9296	9133
JP	860	922	972	1052	1160	1259	1314	1393	1377	1532	1688	1809	1943	2066	2137	2276	2214	2328	2195	2099	2234	2108	2274	2566	2506	2498	2607
KR	164	166	182	256	337	388	513	606	675	731	1024	1079	1087	1153	1296	1353	1415	1426	1617	1900	1972	2068	2032	2012	2026	2062	2031
DK+FI+ SE+NO	383	498	415	455	521	444	621	487	388	351	308	367	397	532	443	297	485	424	338	353	399	316	246	302	251	190	216
UK+IE	2038	2025	1944	1634	1543	1473	1375	1185	1226	1048	1185	1308	1228	1334	1288	1337	1460	1336	1180	962	1008	1030	1367	1256	975	770	356
US	16399	16254	16837	17480	17535	18155	18953	19748	19662	19371	20507	20710	19844	20246	20376	20820	20531	20875	20577	18281	19190	18086	15866	16485	16448	14155	13149

Table 17 Fuel consumption of gas-fired power plants in PJ

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	127	90	99	104	112	131	110	86	87	101	102	110	220	123	140	144	138	192	219	283	310	321	352	354	363	383	387
CN	26	22	23	29	29	28	26	75	56	44	53	46	39	46	67	118	210	273	284	448	582	720	737	829	969	1211	1393
FR	2	2	2	2	2	2	2	2	3	2	42	72	92	92	97	95	92	95	104	220	238	190	160	117	78	132	216
DE	331	330	296	297	356	287	360	364	391	410	363	432	432	474	483	548	570	565	632	566	597	553	489	411	350	345	471
IN	126	166	172	166	181	237	240	281	302	306	305	319	364	401	446	465	487	504	525	847	986	892	662	414	378	403	419
JP	1377	1469	1454	1457	1553	1576	1652	1711	1761	1870	1919	1907	1914	1983	1891	1772	1950	2134	2083	2075	2162	2726	2881	2906	2963	2744	3008
KR	85	88	109	123	163	174	226	263	205	237	241	281	293	296	414	434	494	578	577	498	730	811	897	923	809	764	806
DK+FI+ SE+NO	43	47	55	65	81	103	117	124	138	145	154	169	174	189	180	158	169	139	144	145	207	151	101	90	58	55	58
UK+IE	34	39	95	281	395	469	616	770	809	963	966	945	993	982	1024	982	930	1084	1164	1116	1184	961	644	617	658	638	931
US	2736	2712	2684	2603	2899	3113	2658	2894	3190	3036	5074	5180	5497	4994	5323	5731	6071	6674	6504	6689	7169	7343	8843	7974	7962	9444	9804

Table 18 Fuel consumption of oil-fired power plants in PJ

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	18	20	9	10	8	10	8	8	8	8	9	11	13	13	20	20	22	24	33	12	10	9	6	11	8	13	12
CN	409	396	357	504	374	444	368	351	416	379	341	351	382	484	598	447	333	237	145	81	52	25	18	20	15	13	13
FR	48	96	51	19	15	32	32	25	52	35	27	28	26	39	40	68	63	56	47	48	53	27	30	22	18	21	22
DE	108	138	127	105	91	75	74	57	52	47	41	47	28	35	40	47	38	30	31	38	31	20	28	26	17	17	14
IN	112	108	108	100	106	114	114	107	99	97	167	144	158	146	128	87	74	76	158	114	84	63	72	59	50	38	35
JP	1818	1707	1757	1416	1704	1411	1300	1060	915	903	791	553	735	761	674	803	631	1027	846	462	528	1067	1330	1047	713	561	515
KR	189	264	329	310	337	396	351	413	138	150	245	265	231	231	210	203	192	179	100	138	126	95	149	155	78	89	126
DK+FI+ SE+NO	22	28	34	37	59	60	107	76	74	63	51	52	61	49	31	25	29	21	18	22	25	12	11	8	6	5	7
UK+IE	274	238	247	196	172	148	140	86	75	71	57	64	41	49	54	64	61	44	58	50	30	15	18	11	9	11	10
US	1141	1132	915	1012	931	634	708	1584	2245	1816	1879	2032	934	1174	1184	1205	636	649	467	389	376	292	212	250	294	276	245

Table 19 Fuel consumption of fossil-fired power plants in PJ

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	1330	1335	1366	1380	1404	1474	1531	1555	1746	1791	1815	1897	2082	1905	2010	2064	2098	2173	2185	2313	2194	2116	2125	2015	1932	2019	2068
CN	5939	6513	7123	7984	8519	9461	10736	10376	10854	11337	12252	13040	14944	17789	20146	24015	27264	29847	30005	31917	34535	39269	40493	43080	42111	42040	42947
FR	252	357	282	157	153	205	240	200	323	340	345	305	350	381	369	425	366	378	375	485	509	365	389	357	201	257	329
DE	3332	3272	3146	3076	3112	2984	3209	3084	3112	3030	3085	3240	3264	3291	3253	3266	3303	3355	3222	2985	3068	3013	3136	3162	2946	2864	2870
IN	2128	2406	2577	2844	2957	3411	3622	3747	3868	4158	4463	4598	4710	4926	5240	5421	5665	6058	6393	7033	7537	7835	8666	8758	9657	9737	9586
JP	4055	4097	4183	3925	4417	4245	4266	4163	4054	4305	4398	4269	4592	4810	4702	4851	4795	5489	5124	4636	4925	5901	6484	6519	6182	5802	6129
KR	438	518	620	689	837	959	1090	1283	1019	1118	1510	1625	1611	1680	1920	1990	2101	2183	2294	2537	2828	2975	3078	3091	2913	2916	2963
DK+FI+ SE+NO	447	573	504	556	661	606	845	686	599	559	512	587	631	769	653	480	683	583	499	520	631	479	359	400	315	250	281
UK+IE	2346	2302	2287	2112	2110	2089	2131	2042	2110	2083	2208	2317	2263	2364	2366	2383	2451	2464	2402	2128	2222	2006	2029	1883	1642	1419	1297
US	20276	20099	20435	21094	21365	21902	22319	24226	25097	24224	27459	27922	26276	26413	26882	27756	27238	28198	27548	25358	26736	25722	24921	24709	24704	23875	23198

Heat output

Table 20 Heat output from coal-fired public CHP plants in PJ

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2058	2154	2350	2253	2297	2462	2635	2851	2959	2943	3172	3443
FR	0	0	0	0	0	0	0	0	0	0	2	3	3	3	1	1	1	1	5	1	0	1	1	1	1	1	0
DE	289	245	220	210	190	181	198	199	183	188	165	111	108	164	170	158	150	139	143	140	149	136	142	155	133	139	130
IN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DK+FI+ SE+NO	112	127	122	128	120	122	133	123	110	104	97	109	110	114	116	105	114	110	104	106	114	100	99	96	85	83	86
UK+IE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
US	6	9	20	11	21	20	23	23	23	17	82	74	57	56	41	50	105	100	96	104	103	96	68	54	39	40	31

Table 21 Heat output from oil-fired public CHP plants in PJ

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR	0	0	0	0	0	0	0	0	0	0	15	15	12	12	13	14	12	12	8	7	9	7	5	7	7	7	8
DE	38	58	57	54	36	40	54	42	42	40	20	14	13	4	4	3	2	1	1	2	2	1	2	1	1	1	1
IN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KR	0	0	0	0	0	1	1	0	0	1	3	3	2	6	6	6	5	9	4	5	5	3	3	3	2	2	7
DK+FI+ SE+NO	10	13	15	16	20	19	22	12	20	13	7	11	16	15	14	12	13	8	7	8	11	6	5	4	3	3	4
UK+IE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
US	0	25	23	19	15	11	12	8	6	6	7	8	9	16	11	27	36	37	41	39	36	37	40	29	25	25	31

Table 22 Heat output from gas-fired public CHP plants in PJ

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	45	45	53	68	66	90	91	141	244	296	320
FR	0	0	0	0	0	0	0	0	0	0	17	33	42	42	42	42	38	39	44	55	47	47	47	36	28	31	34
DE	98	109	108	120	147	93	88	74	95	83	67	131	131	149	163	175	185	173	172	157	161	145	146	131	117	117	137
IN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KR	0	0	0	0	15	20	23	26	20	27	37	37	32	41	40	43	39	46	51	50	57	62	67	66	60	59	55
DK+FI+ SE+NO	20	23	30	35	42	49	56	63	68	70	76	81	84	81	80	76	71	66	69	73	86	67	52	46	29	28	32
UK+IE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
US	0	46	22	23	33	33	32	32	31	33	208	206	282	264	171	156	358	366	352	330	325	333	349	328	317	309	388

Table 23 Heat output from fossil-fired public CHP plants in PJ

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2089	2199	2395	2305	2365	2528	2725	2942	3101	3187	3468	3763
FR	0	0	0	0	0	0	0	0	0	0	35	52	57	57	56	56	52	52	57	63	56	55	52	43	35	39	42
DE	424	411	385	383	372	314	340	315	320	311	252	257	252	317	337	336	338	313	316	299	313	283	290	288	251	257	268
IN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KR	0	0	0	0	15	20	24	26	20	28	40	41	34	47	46	49	44	55	55	56	62	66	70	69	62	61	62
DK+FI+ SE+NO	142	163	167	179	183	190	211	198	198	186	180	201	210	210	210	192	198	184	180	187	211	173	156	146	117	113	121
UK+IE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
US	6	80	64	52	70	64	66	63	60	56	297	288	348	336	223	233	499	504	489	473	464	466	456	412	382	374	450

Benchmark indicators

Table 24 Benchmark indicators for coal (by non-weighted average)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	104%	103%	102%	103%	102%	101%	101%	102%	96%	97%	99%	102%	92%	93%	94%	94%	93%	93%	91%	89%	92%	93%	94%	93%	93%	93%	92%
CN	82%	83%	85%	83%	84%	81%	79%	87%	84%	86%	87%	87%	85%	85%	86%	86%	87%	91%	91%	93%	94%	94%	93%	95%	97%	97%	98%
FR	113%	118%	121%	107%	108%	105%	108%	99%	105%	101%	101%	104%	104%	106%	107%	108%	106%	104%	108%	103%	111%	109%	101%	102%	98%	102%	102%
DE	98%	100%	99%	100%	98%	99%	100%	101%	103%	103%	105%	101%	101%	104%	105%	105%	103%	102%	102%	103%	102%	103%	103%	104%	104%	104%	103%
IN	93%	91%	91%	89%	88%	86%	87%	88%	87%	86%	86%	87%	89%	88%	88%	87%	88%	86%	85%	86%	83%	86%	84%	86%	87%	91%	97%
JP	113%	112%	112%	110%	109%	109%	111%	112%	112%	112%	112%	113%	112%	112%	112%	113%	112%	111%	111%	112%	112%	112%	114%	112%	113%	113%	109%
KR	74%	66%	73%	84%	94%	100%	92%	97%	102%	99%	93%	100%	105%	101%	96%	97%	96%	105%	103%	99%	97%	95%	103%	97%	100%	99%	99%
DK+FI+ SE+NO	113%	112%	112%	114%	113%	114%	114%	113%	111%	113%	112%	113%	111%	110%	109%	108%	110%	109%	106%	109%	108%	108%	106%	108%	105%	102%	105%
UK+IE	106%	108%	104%	107%	105%	107%	108%	104%	102%	102%	104%	102%	102%	103%	103%	103%	103%	101%	104%	107%	104%	103%	104%	105%	105%	102%	100%
US	105%	105%	102%	102%	99%	97%	99%	97%	98%	99%	99%	92%	98%	98%	99%	100%	101%	98%	99%	100%	98%	99%	99%	99%	98%	98%	96%

Table 25 Benchmark indicators for oil (by non-weighted average)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	86%	88%	68%	74%	76%	65%	76%	84%	74%	98%	85%	96%	104%	55%	46%	85%	86%	87%	86%	92%	111%	111%	113%	111%	114%	118%	113%
CN	101%	101%	101%	103%	103%	105%	101%	108%	108%	104%	96%	100%	88%	99%	104%	102%	101%	99%	98%	104%	98%	98%	98%	99%	98%	96%	97%
FR	110%	110%	111%	108%	105%	108%	104%	114%	109%	99%	200%	155%	143%	144%	135%	104%	97%	94%	100%	75%	83%	87%	88%	86%	85%	86%	103%
DE	80%	86%	86%	77%	77%	85%	88%	94%	97%	94%	63%	77%	107%	103%	112%	117%	113%	111%	111%	114%	109%	110%	108%	107%	101%	104%	103%
IN	64%	63%	64%	64%	65%	66%	63%	68%	68%	65%	61%	63%	55%	62%	65%	64%	63%	62%	62%	65%	68%	59%	61%	69%	76%	77%	81%
JP	117%	117%	118%	118%	120%	122%	119%	129%	129%	126%	117%	122%	108%	121%	119%	115%	115%	114%	113%	120%	114%	113%	116%	117%	117%	117%	112%
KR	104%	107%	112%	119%	127%	115%	123%	111%	117%	100%	89%	95%	83%	97%	100%	95%	93%	106%	104%	112%	107%	123%	107%	109%	117%	103%	105%
DK+FI+ SE+NO	106%	107%	117%	115%	123%	122%	115%	119%	114%	119%	108%	110%	99%	118%	107%	107%	109%	105%	109%	99%	105%	100%	94%	95%	97%	96%	94%
UK+IE	117%	110%	113%	110%	93%	102%	104%	113%	125%	139%	122%	121%	124%	95%	100%	102%	112%	113%	109%	101%	94%	83%	94%	86%	84%	90%	80%
US	114%	110%	110%	112%	111%	111%	106%	59%	58%	55%	59%	63%	92%	105%	111%	110%	112%	108%	109%	118%	111%	116%	121%	122%	112%	112%	114%

Table 26 Benchmark indicators for gas (by non-weighted average)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	97%	97%	98%	96%	87%	90%	88%	86%	85%	86%	84%	85%	82%	117%	112%	86%	84%	83%	85%	84%	87%	89%	83%	84%	87%	79%	76%
CN	103%	102%	104%	100%	99%	95%	95%	95%	92%	90%	87%	89%	87%	84%	85%	90%	96%	101%	100%	109%	112%	106%	111%	105%	99%	99%	101%
FR	110%	108%	109%	113%	109%	124%	113%	98%	94%	92%	111%	105%	106%	100%	104%	106%	104%	101%	97%	70%	79%	107%	100%	99%	97%	102%	111%
DE	86%	82%	80%	79%	74%	86%	81%	84%	87%	83%	87%	88%	85%	90%	90%	93%	94%	96%	97%	101%	103%	101%	104%	100%	99%	99%	102%
IN	61%	65%	75%	82%	93%	92%	98%	107%	116%	133%	127%	121%	116%	110%	105%	102%	102%	106%	104%	92%	79%	79%	78%	79%	78%	84%	84%
JP	114%	113%	115%	109%	109%	105%	106%	107%	104%	103%	100%	103%	101%	96%	98%	101%	100%	99%	99%	105%	106%	101%	105%	101%	102%	101%	99%
KR	107%	106%	107%	108%	107%	103%	109%	110%	116%	108%	101%	96%	112%	107%	106%	110%	111%	108%	108%	114%	114%	109%	99%	120%	123%	121%	115%
DK+FI+ SE+NO	118%	117%	117%	112%	107%	96%	104%	99%	103%	104%	102%	105%	101%	97%	99%	102%	102%	100%	100%	104%	99%	95%	99%	98%	101%	101%	95%
UK+IE	107%	110%	93%	104%	116%	115%	114%	120%	116%	115%	112%	115%	115%	108%	108%	111%	108%	109%	110%	115%	115%	112%	114%	112%	110%	111%	113%
US	98%	99%	101%	98%	99%	93%	93%	92%	88%	87%	89%	93%	94%	91%	94%	97%	99%	97%	99%	106%	105%	101%	106%	103%	103%	103%	103%

Table 27 Benchmark indicators for fossil (by non-weighted average)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	101%	100%	99%	100%	99%	99%	99%	99%	94%	95%	95%	99%	89%	92%	92%	90%	90%	89%	88%	87%	90%	89%	90%	90%	90%	88%	85%
CN	82%	82%	83%	82%	83%	81%	78%	85%	82%	84%	84%	84%	82%	81%	82%	83%	84%	87%	87%	90%	90%	89%	90%	90%	92%	91%	90%
FR	109%	113%	115%	105%	105%	103%	104%	97%	101%	97%	109%	109%	109%	109%	110%	107%	105%	103%	105%	88%	96%	112%	103%	102%	100%	106%	115%
DE	95%	95%	94%	95%	94%	97%	97%	98%	100%	99%	101%	98%	98%	101%	101%	102%	101%	100%	101%	102%	102%	100%	102%	100%	100%	99%	98%
IN	88%	86%	86%	86%	86%	85%	85%	87%	88%	88%	86%	87%	88%	88%	86%	86%	87%	85%	84%	85%	81%	81%	80%	82%	82%	86%	89%
JP	115%	114%	113%	112%	111%	112%	113%	115%	114%	114%	113%	113%	112%	111%	112%	112%	112%	111%	110%	114%	113%	111%	113%	112%	113%	111%	105%
KR	92%	92%	97%	101%	106%	104%	104%	101%	107%	102%	93%	97%	103%	101%	99%	100%	101%	108%	106%	103%	103%	100%	103%	107%	108%	105%	101%
DK+FI+ SE+NO	111%	110%	110%	112%	112%	111%	111%	110%	109%	112%	111%	111%	109%	109%	108%	109%	109%	107%	106%	108%	107%	104%	104%	105%	103%	100%	98%
UK+IE	105%	105%	101%	106%	105%	110%	111%	114%	112%	116%	114%	112%	114%	112%	112%	112%	110%	112%	115%	119%	117%	113%	109%	110%	111%	111%	118%
US	103%	103%	100%	101%	99%	97%	97%	93%	93%	93%	94%	90%	97%	97%	98%	100%	101%	99%	99%	103%	102%	100%	104%	103%	102%	103%	100%

Table 28 Benchmark indicators for coal (by weighted average)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	104%	103%	104%	105%	107%	107%	108%	107%	102%	102%	103%	110%	97%	99%	99%	99%	99%	98%	97%	94%	96%	97%	99%	97%	96%	95%	94%
CN	82%	83%	87%	85%	88%	87%	84%	91%	88%	90%	91%	94%	90%	90%	91%	92%	93%	96%	96%	97%	98%	99%	98%	99%	100%	100%	100%
FR	113%	118%	124%	110%	112%	112%	115%	104%	110%	106%	106%	112%	110%	113%	114%	114%	113%	110%	114%	108%	116%	114%	106%	106%	101%	105%	104%
DE	98%	100%	101%	102%	102%	106%	107%	106%	109%	108%	110%	109%	108%	110%	112%	111%	110%	108%	108%	108%	108%	107%	109%	108%	107%	107%	105%
IN	93%	91%	92%	91%	91%	92%	92%	92%	92%	90%	90%	93%	94%	94%	93%	93%	93%	91%	90%	90%	87%	90%	88%	90%	89%	94%	99%
JP	113%	113%	114%	113%	114%	116%	119%	118%	118%	117%	117%	122%	119%	119%	119%	119%	119%	118%	117%	118%	117%	117%	120%	117%	117%	116%	111%
KR	74%	66%	75%	86%	98%	106%	98%	102%	108%	104%	97%	108%	111%	107%	102%	103%	102%	111%	109%	104%	102%	99%	109%	102%	103%	102%	101%
DK+FI+ SE+NO	113%	113%	114%	117%	118%	121%	121%	118%	117%	119%	117%	122%	118%	118%	115%	115%	116%	115%	112%	114%	114%	113%	111%	113%	109%	105%	107%
UK+IE	106%	108%	106%	110%	109%	114%	115%	109%	108%	107%	108%	110%	108%	110%	109%	109%	109%	107%	110%	112%	109%	108%	109%	109%	108%	105%	102%
US	105%	105%	104%	105%	104%	104%	105%	102%	104%	104%	104%	100%	104%	105%	105%	106%	107%	103%	104%	105%	103%	103%	104%	103%	102%	100%	98%

Table 29 Benchmark indicators for gas (by weighted average)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	96%	96%	95%	96%	86%	92%	89%	86%	87%	88%	88%	86%	84%	123%	115%	86%	84%	83%	85%	80%	84%	88%	80%	81%	84%	78%	74%
CN	102%	101%	101%	99%	98%	97%	96%	94%	94%	92%	92%	91%	89%	88%	87%	90%	96%	102%	99%	103%	107%	106%	107%	102%	96%	97%	99%
FR	108%	106%	106%	112%	108%	127%	114%	98%	96%	94%	116%	107%	108%	105%	107%	107%	104%	102%	96%	67%	76%	106%	96%	96%	95%	100%	108%
DE	85%	81%	77%	78%	73%	88%	82%	84%	90%	85%	92%	90%	87%	94%	92%	94%	93%	96%	97%	96%	99%	100%	99%	97%	96%	96%	100%
IN	61%	64%	73%	82%	92%	94%	99%	107%	118%	136%	133%	124%	119%	115%	108%	102%	102%	107%	104%	87%	76%	78%	74%	76%	76%	82%	82%
JP	112%	111%	111%	109%	108%	108%	107%	107%	107%	105%	105%	105%	103%	100%	101%	102%	100%	100%	99%	100%	101%	100%	100%	98%	99%	99%	97%
KR	106%	105%	104%	108%	106%	105%	110%	110%	119%	111%	106%	98%	114%	112%	109%	110%	111%	109%	108%	109%	109%	109%	95%	117%	119%	118%	113%
DK+FI+ SE+NO	116%	116%	113%	111%	106%	98%	105%	99%	105%	106%	107%	107%	103%	102%	102%	102%	102%	100%	100%	99%	95%	94%	95%	95%	98%	98%	93%
UK+IE	105%	109%	91%	103%	114%	118%	115%	120%	119%	118%	118%	117%	117%	113%	111%	111%	107%	110%	110%	110%	111%	111%	110%	109%	107%	108%	111%
US	97%	98%	98%	98%	97%	95%	94%	92%	90%	89%	93%	95%	95%	95%	96%	98%	99%	98%	99%	101%	101%	100%	102%	100%	100%	100%	101%

Table 30 Benchmark indicators for oil (by weighted average)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	77%	80%	61%	66%	67%	58%	69%	91%	87%	116%	106%	119%	110%	52%	43%	79%	81%	81%	81%	83%	104%	100%	100%	97%	101%	106%	103%
CN	91%	92%	91%	92%	91%	93%	91%	117%	127%	124%	120%	123%	93%	93%	96%	95%	94%	92%	93%	94%	91%	88%	87%	87%	87%	87%	88%
FR	98%	101%	100%	98%	93%	96%	94%	124%	128%	118%	248%	193%	152%	136%	124%	96%	91%	87%	95%	69%	78%	78%	78%	75%	75%	77%	94%
DE	72%	79%	77%	70%	68%	75%	79%	102%	114%	112%	78%	95%	114%	97%	104%	109%	106%	103%	105%	104%	102%	99%	96%	94%	90%	94%	94%
IN	57%	58%	57%	58%	57%	58%	57%	73%	80%	78%	75%	78%	59%	59%	60%	60%	59%	58%	59%	59%	63%	53%	54%	61%	67%	69%	74%
JP	105%	107%	106%	106%	106%	108%	108%	140%	152%	150%	146%	151%	115%	115%	110%	107%	108%	106%	107%	109%	107%	102%	103%	102%	104%	105%	102%
KR	93%	97%	101%	107%	112%	102%	111%	120%	138%	119%	110%	117%	88%	92%	92%	88%	87%	98%	99%	102%	100%	111%	95%	96%	104%	92%	96%
DK+FI+ SE+NO	95%	97%	105%	103%	109%	108%	104%	129%	135%	141%	134%	137%	105%	112%	99%	100%	102%	98%	103%	90%	98%	90%	83%	83%	87%	87%	86%
UK+IE	105%	100%	102%	99%	82%	90%	94%	122%	148%	165%	152%	151%	132%	90%	92%	95%	105%	105%	103%	92%	87%	75%	83%	75%	74%	81%	73%
US	102%	101%	99%	101%	99%	99%	96%	63%	69%	65%	74%	78%	98%	99%	102%	103%	105%	100%	104%	108%	104%	104%	108%	107%	99%	101%	104%

Table 31 Benchmark indicators for fossil (by weighted average)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AU	103%	102%	103%	104%	105%	106%	106%	106%	101%	101%	102%	109%	96%	101%	101%	98%	98%	96%	95%	92%	94%	95%	95%	94%	93%	92%	90%
CN	83%	84%	87%	86%	88%	87%	84%	92%	90%	91%	92%	95%	90%	90%	91%	92%	93%	96%	96%	97%	99%	99%	98%	99%	100%	100%	100%
FR	110%	114%	120%	109%	111%	110%	112%	106%	113%	107%	125%	120%	114%	114%	113%	110%	107%	105%	107%	89%	96%	108%	100%	101%	97%	101%	107%
DE	97%	98%	99%	100%	100%	104%	104%	104%	107%	105%	107%	107%	105%	108%	109%	108%	107%	106%	106%	105%	106%	106%	107%	107%	105%	106%	104%
IN	91%	89%	90%	90%	91%	91%	92%	93%	95%	96%	94%	97%	96%	96%	94%	93%	94%	93%	91%	89%	85%	88%	87%	89%	89%	93%	98%
JP	109%	110%	110%	109%	109%	110%	111%	119%	120%	118%	117%	118%	111%	110%	110%	110%	109%	108%	108%	109%	109%	106%	107%	106%	106%	106%	103%
KR	90%	92%	96%	101%	106%	104%	105%	109%	114%	107%	101%	107%	109%	106%	103%	104%	104%	110%	108%	105%	104%	103%	104%	107%	109%	107%	105%
DK+FI+ SE+NO	112%	112%	113%	116%	116%	117%	117%	116%	116%	118%	115%	119%	113%	113%	111%	110%	112%	111%	108%	109%	107%	106%	106%	108%	106%	103%	104%
UK+IE	106%	107%	105%	108%	109%	114%	114%	114%	114%	115%	114%	115%	113%	111%	110%	110%	108%	109%	110%	110%	110%	110%	109%	109%	107%	107%	109%
US	104%	104%	103%	104%	103%	102%	104%	100%	100%	100%	100%	97%	102%	102%	103%	104%	105%	102%	103%	104%	103%	102%	103%	102%	101%	100%	99%

CO_2-intensity

Table 32 CO_2-intensity coal-fired power (g/kWh)

	2014	2015	2016	Average
Australia	998	994	993	995
China	930	922	910	921
France	920	879	871	890
Germany	907	895	897	900
India	1,048	985	917	983
Japan	798	795	819	804
South Korea	907	906	902	905
Nordic countries	858	877	850	862
United Kingdom + Ireland	865	875	894	878
United States	921	923	931	925

Table 33 CO_2-intensity oil-fired power (g/kWh)

	2014	2015	2016	Average
Australia	652	625	654	643
China	762	762	762	762
France	881	854	717	818
Germany	739	704	715	719
India	981	958	915	951
Japan	639	629	659	642
South Korea	635	716	701	684
Nordic countries	765	763	784	771
United Kingdom + Ireland	889	815	921	875
United States	667	655	648	657

Table 34 CO_2-intensity gas-fired power (g/kWh)

	2014	2015	2016	Average
Australia	493	532	560	528
China	430	425	420	425
France	439	413	384	412
Germany	433	429	417	426
India	546	505	505	519
Japan	419	417	430	422
South Korea	348	349	368	355
Nordic countries	424	420	446	430
United Kingdom + Ireland	388	383	374	382
United States	414	411	412	412

Table 35 CO_2-intensity fossil-fired power (g/kWh)

	2014	2015	2016	Average
Australia	889	898	908	898
China	916	905	891	904
France	717	616	514	615
Germany	846	834	809	830
India	1,026	962	898	962
Japan	587	590	604	594
South Korea	695	708	709	704
Nordic countries	766	755	761	761
United Kingdom + Ireland	641	616	487	581
United States	724	684	674	694

Table 36 CO_2 emission reduction potential fossil-fired power (g/kWh)

	2014	2015	2016	Average
Australia	234	238	244	239
China	203	194	182	193
France	165	120	78	121
Germany	148	136	133	139
India	317	255	190	254
Japan	80	77	96	84
South Korea	118	124	126	123
Nordic countries	126	136	125	129
United Kingdom + Ireland	101	98	70	90
United States	149	140	141	144

Table 37 CO_2 emission reduction potential fossil-fired power (Mtonne)

	2014	2015	2016	Average
Australia	45	48	50	48
China	842	811	785	813
France	3	3	3	3
Germany	46	42	42	43
India	278	240	189	236
Japan	62	56	72	63
South Korea	41	43	44	42
Nordic countries	4	3	3	3
United Kingdom + Ireland	20	17	13	17
United States	417	387	380	395

Table 38 CO_2 emission reduction potential fossil-fired power (%)

	2014	2015	2016	Average
Australia	26%	27%	27%	27%
China	22%	21%	20%	21%
France	23%	19%	15%	19%
Germany	17%	16%	16%	17%
India	31%	26%	21%	26%
Japan	14%	13%	16%	14%
South Korea	17%	17%	18%	17%
Nordic countries	16%	18%	16%	17%
United Kingdom + Ireland	16%	16%	14%	15%
United States	21%	21%	21%	21%

Appendix III: IEA Definitions

Coal

Coal includes all coal, both primary (including hard coal and lignite/brown coal) and derived fuels (including patent fuel, coke oven coke, gas coke, BKB, coke oven gas, and blast furnace gas). Peat and peat products, and gas works gas are also included in this category.

Oil

Crude oil comprises crude oil, natural gas liquids, refinery feed stocks, and additives as well as other hydrocarbons (including emulsified oils, synthetic crude oil, mineral oils extracted from bituminous minerals such as oil shale, bituminous sand, etc., and oils from coal liquefaction).

Petroleum products are also included. These comprise refinery gas, ethane, LPG, aviation gasoline, motor gasoline, jet fuels, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirit, lubricants, bitumen, paraffin waxes, petroleum coke and other petroleum products.

Gas

Gas includes natural gas (excluding natural gas liquids). The latter appears as a positive figure in the "gas works" row but is not part of production.

Public power supply

The IEA makes a distinction between *auto-producers* and *main activity producers* of heat and power:

- *Main activity* undertakings generate electricity and/or heat for sale to third parties, as their primary activity.
- *Auto-producing* undertakings generate electricity and/or heat, wholly or partly for their own use as an activity which supports their primary activity.

In this study only public power (and heat) supply - i.e. production from main activity producers - is taken into account. Both installations producing only power and combined heat and power (CHP) installations are taken into included in the assessment.

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