GLOBAL PROSPECTS OF CO_2 EMISSIONS IN POWER GENERATION AND THE CARBON MITIGATION ROLE OF NATURAL GAS

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Abstract

This communication aims to highlight the future development of CO_2 emissions in the power sector, which has emerged as a major driver of the ongoing transformation towards less carbon-intensive energy systems. Power generation is expected to be at the forefront of the CO_2 mitigation efforts. This sector has large potential of emission mitigation, that can be tapped through various options including the switching to less carbon-intensive hydrocarbon sources, improving energy efficiency of power plants or supporting the development of renewables. Natural gas will observe increasing role in power generation in many regions, supported by its economic, environmental and technical advantages. The penetration of natural gas against coal will be an important contributor in mitigating CO_2 emissions, particularly in countries initiating aggressive policies to reduce the share of coal like China or other European countries announcing decommissioning of coal-power plants.

Introduction

Power sector is observing important changes, with increasing role of electricity in the final energy consumption and penetration of cleaner energy sources for power generation, including natural gas and intermittent renewables. These observed developments are supported by technology progress and policies, particularly the CO_2 mitigation policies, which are adopted by countries to comply with their Paris Agreement commitments. In this paper, we analyse the future CO2 emissions from power generation considering different drivers, and examine particularly the contribution of gas for power in mitigating these emissions.

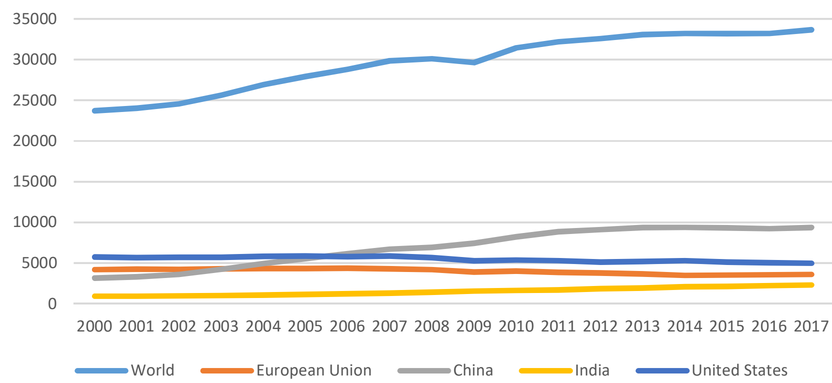
The paper is structured in three parts: the first part will assess the recent trends of CO_2 emissions, highlighting the role of power generation sector in driving the emissions momentum. We especially analyse the recent switching dynamics between gas and coal observed in some key markets, as well as its effect in terms of carbon mitigation.

The second part will examine the developments and prospects of power sector, including electricity demand perspectives and the future power generation mix in different regions, basing on the Power Module of the GECF Global Gas Model. We will highlight the main determinants affecting these prospects, specifically the costs of generating power as well as the policies adopted in key markets. In the third part, we will highlight CO_2 emissions perspectives from power generation as well as the future role of gas- power plants in mitigating these emissions.

I. Recent evolution of CO_2 emissions and the role of power sector

After three consecutive years of stagnation between 2014 and 2016, the energy-related CO_2 emissions have raised by 1.4% in 2017 compared to 2016, setting a record level at around 33.7 $GtCO_2$. India, China as well as the European Union that represent together more than 45% of the 2016 emissions, have increased their CO_2 emissions in 2017 by 3.7%, 1.5% and 1.1% respectively. The three markets added nearly 260 $MtCO_2$ to the 2016 emissions, out of the 456 $MtCO_2$ added at the global level (GECF 2018).

Figure 1.1. Energy-related CO_2 emissions in the world and in main CO_2 emitting markets ($MtCO_2$)



Source: GECF Secretariat based on data from the GECF GGM

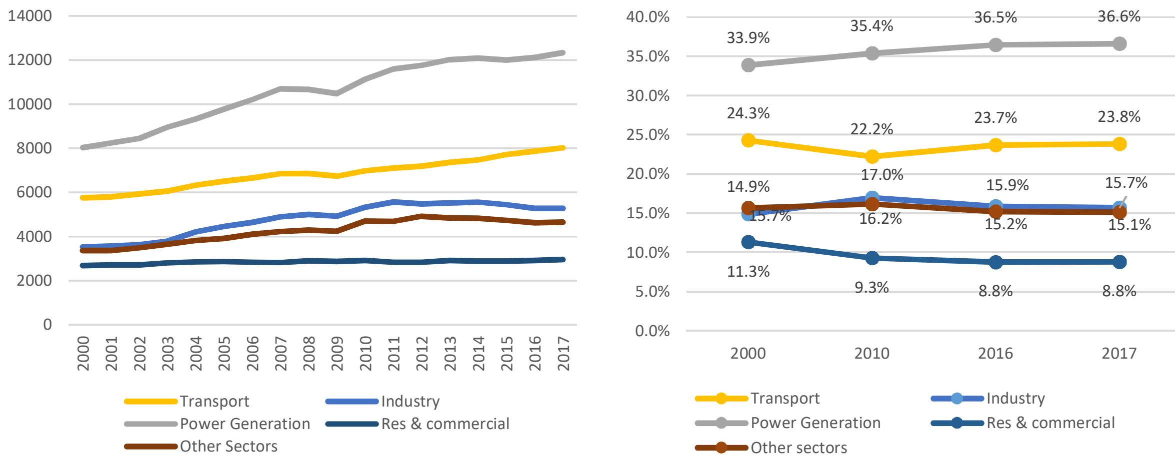
At sectoral level, the recent evolutions of CO_2 emissions showed that power generation, industry and other sectors including district heating and coke ovens, contributed in driving the global stagnating trajectory exhibited before 2016. These sectors have been affected by a slowdown of industrial activity, energy efficiency improvement as well as the reduction of coal consumption in a context of increasing demand of natural gas and renewables (excluding hydropower and biomass)[1]. The coal demand decrease occurred in countries like China, which adopted an aggressive policy to reduce pollution and to absorb the over-capacity in some coal consuming activities such as power generation and steel industry.

After 2016, the increase in industrial activities and the rise of coal for power demand in many markets, such as China and other emerging and developing economies, have driven a resumption of the CO_2 emission growth resulting from power and industrial sectors. The emission momentum of these two sectors adds to the growth of emissions observed in other sectors, particularly in the transportation sector, which has experienced a continued growth, averaging at around 2% between 2010 and 2017. The decline of oil prices in 2014 supported the consumption of oil in this sector as well as its CO_2 emissions.

As depicted in figure 1.2, despite a relative slowdown of power generation's emissions, the share of this sector continues to observe increasing trends and to dominate the global energy-related emissions. In 2017, power generation represents around 36.6% of global emissions, followed by transportation and industry whose shares respectively reached 23.8% and 15.7%. Over the last five years, emissions from the power sector increased by 566 $MtCO_2$, attaining a level of more than 12,3 $GtCO_2$ in 2017.

[1] In this paper, renewables include mainly solar, wind, tidal and geothermal. Hydro and biomass are generally considered in separate categories, except in cases where they are explicitly mentioned as part of renewables (e.g. in the section related to the decomposition analysis).

Figure 1.2. Energy-related CO_2 emissions by sectors ($MtCO_2$), and emissions shares by sectors (%)



Source: GECF Secretariat based on data from the GECF GGM

Nevertheless, the power sector has a large potential to mitigate CO_2 emissions and to reduce significantly its contribution to the climate change. The mitigation potential of power sector is mainly driven by: i) the existence of large spectrum of proven and competitive technologies and options that can be used to produce electricity with less carbon emissions, including the gas-fired power plants. This makes power sector easier to decarbonize compared to other sectors such as transport or heavy industries; ii) technology and cost improvements of the electricity-consuming appliances, equipment and vehicles that push for more utilization of these technologies in energy end-use sectors and support the role of electricity in mitigating emissions. This role is especially reinforced if the electricity consumed is associated to less carbon-intensive power production options, and iii) the worldwide orientation to implement policy measures and initiatives targeting the power sector, which marks a recognition of its role in achieving efficient and effective carbon abatement.

I.I CO_2 emissions by fuels in the power sector

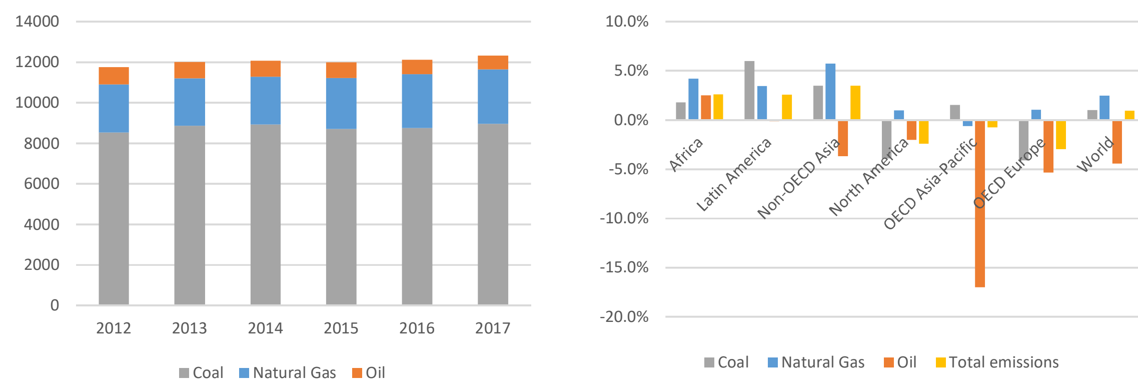
The CO_2 emissions stemming from the utilization of natural gas in power generation have increased by 2.5% annually over the last five years, and reached 22 % of the 2017 total emissions. This level remains much lower than emissions from coal, which represent around 73%. The growth of natural gas in power sector and its penetration against coal and oil in different regions, contributed in slowing down the global emissions (CAGR[2] 2012 -2017 emissions from coal is less than 1% - see figure 1.3). Oil-fired power plants, however, observed a declining role in producing electricity. The emissions from these plants shrank in almost all the regions, except in Africa, and reached around 5.5% of the total emissions in 2017.

Figure 1.3 shows that OECD Europe and North America which experienced the fastest decline in their emissions between 2012 and 2017, have seen an important substitution between coal and natural gas. This substitution dynamic is highlighted in the steep decrease of coal-based emissions (CAGR 2012-2017: -3.9% for North America and -4.1% for OECD Europe), and a relative growth of the gas-based ones (CAGR 2012-2017: 1% for each of the two regions). For North America, United States (US)

[2] CAGR: Compound Average Growth Rate

was the driver of this substitution, since the country benefited from large shale gas availability and low gas prices, which supported the replacement of coal by natural gas. The emission from coal in power sector decreased by more than 284 $MtCO_2$ between 2012 and 2017.

Figure 1.3. Power-related CO_2 emissions by fuels ($MtCO_2$), and regional average annual growth rates between 2012 and 2017 (%)



Source: GECF Secretariat based on data from the GECF GGM

For Europe, United Kingdom (UK) was the key contributor in the substitution between natural gas and coal. UK coal-fired power plants emissions dropped from 127 $MtCO_2$ in 2012 to around 20 $MtCO_2$ in 2017, while the emissions from natural gas-based plants increased by around 28 $MtCO_2$ on the same period. Other countries in Europe also observed a reduction of coal-based emissions such as Germany with a decrease of almost 30 $MtCO_2$ in 2017 compared to 2012. Improved competitiveness of natural gas underpinned by a drop of gas prices after 2014 and the application of higher carbon prices, particularly in the case of UK[3], supported natural gas in the power sector over the last five years. The upward trends of carbon prices in Europe, with the implementation of EU ETS Phase IV reforms, might reinforce this increased role of natural gas at the expense of coal in Europe.

Conversely, emerging and developing regions have witnessed a rise of their power-related emissions, driven by increased consumption of both coal and natural gas in order to meet, particularly, their baseload power needs. Non-OECD Asia observed the largest emission growth rate, though the accelerated penetration of natural gas for power compared to coal over the last five years enabled a significant deceleration of these emissions in the region. The global emission average growth IN Non-OECD Asia reached 3.5% between 2012 and 2017, while it used to exhibit an annual year on year (y-o-y) growth of more than 5% since 2000 (excluding 2008 where y-o-y emission growth dropped to 1% because of the economic crisis).

I.2 Decomposing the drivers of emissions in the power sector

Despite that the substitution momentum between fossil fuels, particularly between natural gas and coal, has played a significant role in supporting carbon mitigation in the power sector, there are other factors that weigh in this dynamic; these include penetration of renewables, nuclear, as well as the improvement of power plants' efficiency. In order to understand the contribution of natural gas in driving power emissions, we apply a Logarithmic Mean Divisia Index decomposition (LMDI) (Wang et al, 2015; ICF 2016). Accordingly. the emissions from power generation are decomposed in three categories of factors: i) intensity factors that include emission coefficients of fuels and thermal

[3] UK applies a Carbon Support Price (CSP) that adds to the EU Emission Trading System reference price.

efficiency of power plants; ii) structure factors that incorporate the substitution between fossils fuels as well as the changes in renewables and nuclear shares in generation mix; and iii) the activity or scale factors which relate to the emissions resulting from the change in the amount of power generated.

The following formula illustrates this decomposition of total CO_2 emissions (C_{tot}) from power sector:

$$Ctot = \sum_{i}^{gas;oil;coal} Emf_i * Eff_i * Fshares_i * NUCshares * RENshares * PG$$
$$= \sum_{i}^{gas;oil;coal} \frac{C_i}{ENF_i} * \frac{ENF_i}{PGF_i} * \frac{PGF_i}{PGF_{tot}} * \frac{PGF_{tot}}{PGF_{tot} + PG_{NUC}} * \frac{PGF_{tot} + PG_{NUC}}{PG_{tot}} * PG_{tot}$$

With i representing the fossil fuels: Gas; Coal; Oil

Factors included in the decomposition analysis	Calculation formula for each factor	Role of the factor in the decomposition analysis
Emf$_i$ *:* Emission coefficient for the fossil fuel i	C_i/ ENF_i : Emission from fossil fuel i / consumption of fossil fuel i	Aims to capture for each fossil fuel the effect on emissions due to the change in emission factors. Emission factors of a specific fossil fuel is mainly related to quality and carbon content of the fuel, and quality of the combustion that generates CO_2.
Eff$_i$ Thermal efficiency of power plants using fuel i	ENF_i /PGF_i : Consumption of fossil fuel i/ Power generated by fossil fuel i	Aims to capture the role of improved thermal efficiency of the fossil fuels – based power plants.
Fshares$_i$*: Share of f*ossil fuel I in power production	PGF_i/PGF_{tot} : Power generated by fossil fuel i / power generated by total fossil fuels	Aims to capture the effects of substitution and changes between fossils fuels in producing power.
NUCshares*: N*uclear penetration expressed in fossils share in total fossils plus nuclear	PGF_{tot} / (PGF_{tot} + PG_{nuc}): Power generated by total fossil fuels / power generated by total fossil fuels and nuclear	Aims to capture the role of nuclear increase or reduction in displacing or conversely supporting fossil fuels in the power mix.
RENshares: *R*enewables penetration expressed in share of non-renewables in total generated power (in this case, renewables includes hydro and biomass).	(PGF_{tot} + PG_{Nuc}) / PG_{tot}: power generated by total fossil fuels and nuclear / Total power generation	Aims to capture the role of renewables, hydro and biomass changes in total power mix
PG: Power generation output	Total power generation	Aims to capture the role of changes in power production

The change in total power-related emissions for a specified period of time is then decomposed according to the LMDI additive version (Wang et al, 2015) that enables to isolate the role of each driver in the total emissions from power sector.

$$\Delta\, Ctot \;=\; \sum_{i}^{gas;oil;coal} \Delta\, C\_emf_i + \Delta\, C\_eff_i + \Delta\, C\_Fshares_i + \Delta\, C\_NUCshares + \Delta\, C\_RENshares + \Delta\, C\_PG$$

Where Δ C_X is the CO_2 emission change, between t-1 and t, allocated to one driver considering unchanged the effects of the other drivers. *X = emf$_i$; eff$_i$; Fshares$_i$; NUCshares; RENshares; PG.*

For instance: emissions variations due to the change in thermal efficiency of power plants is calculated as follows:

$$\Delta\, C_{eff} = \sum_{i}^{gas;oil;coal} \Delta\, C_{eff\,i} = \sum_{i}^{gas;oil;coal} \mathrm{L}(\mathrm{C}_{it}, \mathrm{C}_{it-1}\,)\, Ln(\frac{\mathrm{eff}_{it}}{\mathrm{eff}_{it-1}})$$

Where L (C_{it}, C_{it-1}) is the logarithmic average calaculated as:

$L(C_{it}, C_{it-1}) = (C_{it}-C_{it-1})/(lnC_{it}-lnC_{it-1}),\ if\ C_{it} \neq C_{it-1}$

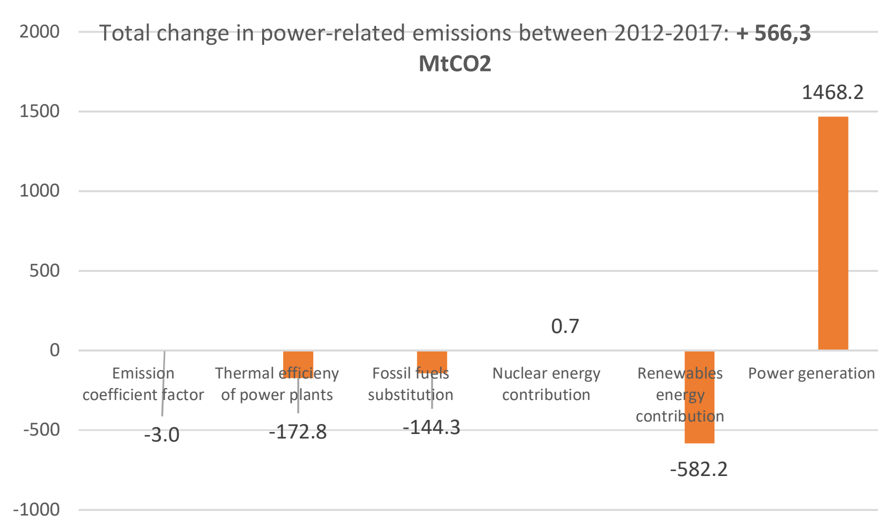
$L(C_{it}, C_{it-1}) = C_{it}\ if\ C_{it} = C_{it-1}$

$L(C_{it}, C_{it-1}) = 0_t\ if\ C_{it} = C_{it-1}=0$

C_{it}: emissions due to consumption of fuel i to produce power for the year t.

The application of LDMI decomposition method allows to estimate the contribution of the above-mentioned factors in driving power-related CO_2 emissions between 2012 and 2017. Figure 1.4 highlights these contributions.

Figure 1.4. Decomposition of power-related global CO_2 emissions change between 2012 and 2017 according to main contributing factors ($MtCO_2$)



Source: GECF Secretariat based on data from the GECF GGM

According to figure 1.4, the main contributor in global CO2 emission increase, between 2012 and 2017, is the rising power generation output which, if all the other factors are kept unchanged, would have led to almost 1470 $MtCO_2$ increase. Renewable penetration, improvement in thermal efficiency of power plants as well as penetration of natural gas against coal and oil, allowed to mitigate the upside effect on emissions due to increased global power production. The combination of these main factors allowed emissions to rise by around 566 $MtCO_2$ between 2012 and 2017.

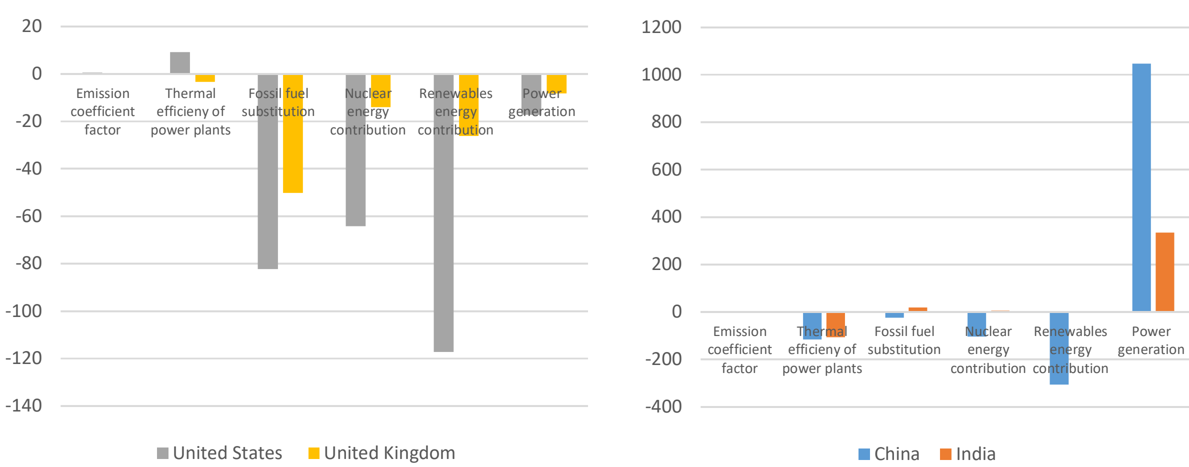
The substitution between fossil fuels, especially the penetration of natural gas against coal and oil, enabled to achieve 144 $MtCO_2$ emissions reduction between 2012 and 2017 and was the third contributor in the global carbon mitigation after renewables and thermal efficiency improvement of power plants. It is, however, worth noting that natural gas supports mitigation not only through substitution to coal and oil, but also by enabling the development of renewables since gas-fired power plants provide the required flexibility for power systems to integrate renewables. Furthermore, Gas-fired plants, particularly the Combined Cycle Gas Turbines (CCGT), contribute in improving average thermal efficiency of the power plants' fleet globally.

Additionally, the decomposition analysis also showed that the relative decrease of nuclear share in global power generation had a marginal upside effect on carbon emissions between 2012 and 2017. A small effect is also observed due to the change of emission factors reflecting improvement in the average quality of fossil fuels.

The analysis of the contribution of various factors to carbon emissions in four main CO_2 emitting markets, namely the US, China, India and UK shows the followings:

In the US and UK, gas penetration against coal was a key driver in mitigating carbon emissions. This effect is captured by the fossil fuels substitution driver (see figure 1.5) which was the first contributor in mitigating emissions in the UK and the second, after renewables development, in the US. One interesting result for the US is that thermal efficiency changes between 2012 and 2017 played a negative role with an upside effect on emissions. This is due to the fact that average efficiency of power plants, particularly coal-fired ones, decreased with some less efficient plants still producing power, especially in the states applying less restrictions on GHG and air pollutant emissions. The disparities between states in terms of decommissioning inefficient power plants contributed in this upward effect on emissions.

Figure 1.5. Decomposition of power-related CO_2 emissions change between 2012 and 2017 for selected countries ($MtCO_2$)



Source: GECF Secretariat based on data from the GECF GGM

Moreover, the increase of nuclear power production in the US and UK allowed a non-negligible carbon mitigation; this adds to the effect of power generation outputs whose observed downward trends supported emissions reduction in both US and UK between 2012 and 2017. Over this period, power generation decreased by 1.4% in the US and by 5.6% in the UK.

Conversely, power generation was the main driver of the emission increase in China and India over the last five years, contributing by more than 1000 $MtCO_2$ for China and 335 $MtCO_2$ for India (Figure 1.5). Fossil fuels substitution, particularly the penetration of natural gas against coal, had a positive effect in China. However, for India, the reduction of the gas-based electricity in the power mix and the increase of coal due mainly to coal competitiveness and difficulties to procure gas for power sector, contributed in increasing emissions.

Renewables (including hydro and biomass) are the largest contributors in compensating the upside effect of power generation output in China, with an estimated reduction of more than 300 $MtCO_2$ in 2017 compared to 2012 (assuming that the effect of all the other drivers are unchanged). In India, renewables (including hydro and biomass) supported an increase in emissions despite a strong penetration of solar; this is due to the decline of hydropower share in power mix that put an upward pressure on the power-related emissions.

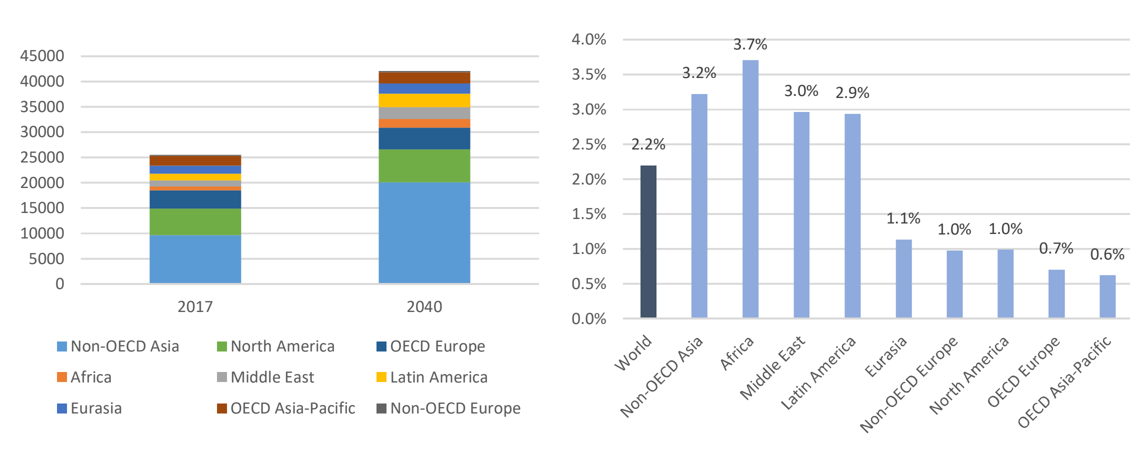
II. Global prospects of power demand and supply

The future development of power sector, both in terms of electricity demand and supply, will drive the transition's pace towards less-carbon intensive energy systems. The GECF forecasts in this paper are based on an assessment of the main macro-economic and policy drivers for the reference case, which are factored in the GECF Global Gas Model (GGM). The GGM power module is instrumental in generating electricity demand and supply forecasts for each country, and is mainly composed of two sub-modules: i) the power investment model that calculates according to technical and economic features the capacity needed for each power generation options to meet future electricity demand and reserve capacities; and the dispatching model which establishes the electricity generated by each options on the basis of cost of supply.

II.1 Electricity demand prospects

The global electricity demand is forecasted to grow by around 2.2% between 2017 and 2040 annually. This average growth contributes in increasing the demand from 25600 Twh in 2017 to 42250 Twh in 2040, but it hides, however, different prospects for the different regions.

Figure 2.1. Electricity demand by regions (Twh), and average annual growth rates of electricity demand by regions (%)



Source: GECF Secretariat based on data from the GECF GGM

What are the main drivers of this electricity demand?

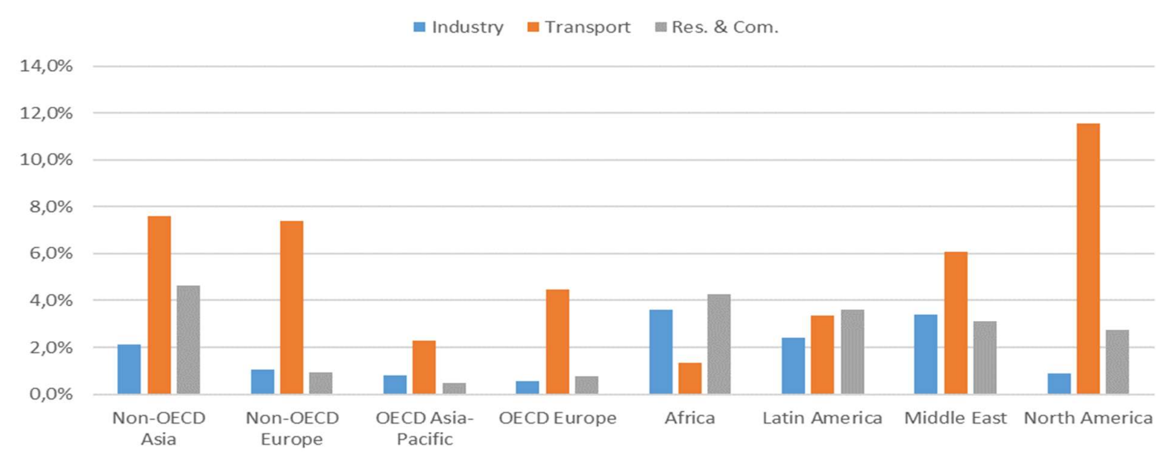
In order to understand these drivers, figure 2.2 below depicts the average annual growth rates of electricity demand by sectors and regions. According to the chart, the pace of growth of residential and commercial demand of electricity is higher in the emerging and developing regions, including Non-OECD Asia, Africa and Latin America. Particularly, the average growth over the 2017-2040 period is expected to reach 4.7% for non-OECD Asia and 4.2% for Africa; these electricity prospects of residential and commercial sectors are driven by growth of population and revenues as well as by increased urbanization in these regions. Improved access to electricity also plays a role in electricity demand growth.

Electricity demand of Industrial sector is also anticipated to observe a non-negligible increase, especially in Africa and the Middle East, supported by economic growth and by countries' efforts to diversify their economy.

One key expected development affecting electricity demand is the electrification of the transportation sector in almost all the considered regions, which is translated, as highlighted in figure 2.2, by relatively high average growth rates. Nevertheless, it is worth noting that these growth rates reflect also an increase from a relatively low level of electricity consumption in the transportation sector in different regions.

Progress of electricity demand in the transportation sector is expected to be significant in developed markets, especially North America and OECD Europe, and also in Non-OECD Asia. The uptake of electric vehicles (EVs) will drive this progress, supported by a strong policy orientation to promote this mean of transport, specifically in Europe, China and India. Furthermore, the anticipated technical progress and cost reduction of batteries support this EVs penetration. Globally, EVs share, including PEV (Plug-in Electric Vehicles) and HPEV (Hybrid Plug-in Electric Vehicles), is projected to reach around 14.6% by 2040.

Figure 2.2. Forecasts of average annual growth rates of electricity demand by sectors and regions (%)



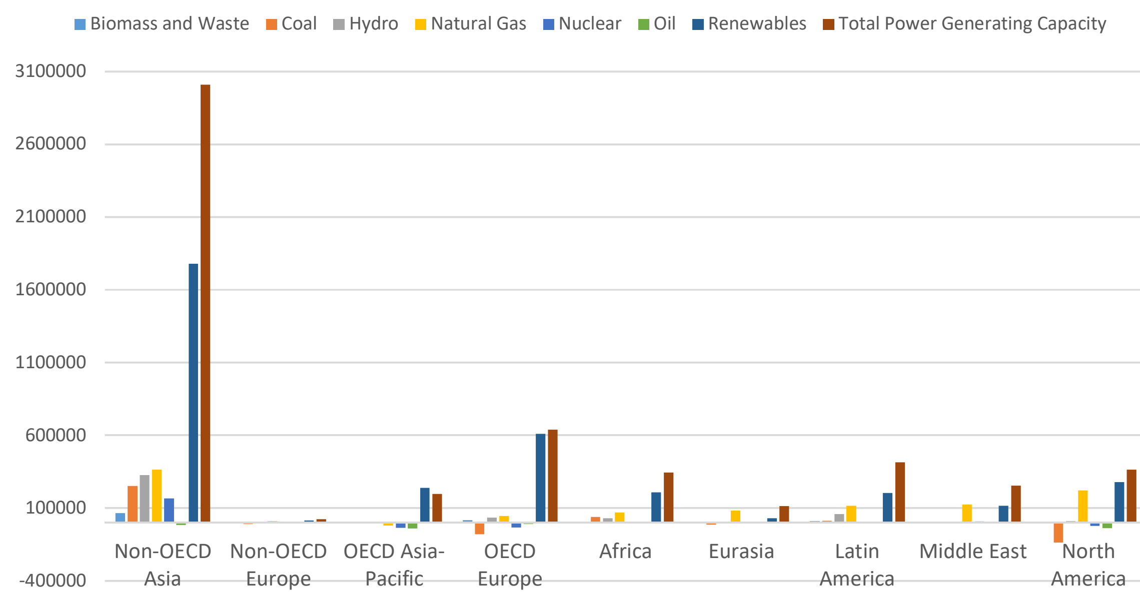
Source: GECF Secretariat based on data from the GECF GGM

The moderate electricity demand growth in residential and commercial sectors and industry in OECD Europe and OECD Asia is driven by the expected reduction of energy intensity in these regions, which is set to compensate the upside effect on electricity demand due to economic growth and electrification trends of some key energy services such as heating.

II.2 Prospects of electricity supply

The future prospects of electricity demand contribute in driving large power capacities' development, particularly in emerging and developing markets. The global power installed capacities are estimated to reach more than 12200 GW in 2040, increasing by almost 80% compared to 2017 level.

Figure 2.3. Incremental capacities between 2017 and 2040, by power generation options and regions (MW)



Source: GECF Secretariat based on data from the GECF GGM

Non-OECD Asia has the largest contribution in this capacity development, with around 56% of the global increase between 2017 and 2040. OECD Europe and North America are also anticipated to increase significantly their installed capacities despite lower growth of electricity demand. The uptake of intermittent renewables in these two regions, which have much less capacity factors compared to other power generation options, supports significantly this capacity growth.

Development of renewable capacities

The development of renewables, including solar and wind, plays a central role in future power generation prospects. Global renewable capacities are forecasted to increase by nearly 3500 GW over the 2017-2040 period, largely dominating long-term progress of installed power capacities compared to other options. Solar represents around 62% of this global increase of renewable capacities.

As depicted in figure 2.3, renewable capacities development will be driven by three main regions: Non-OECD Asia, OECD Europe and North America. Between 2017 and 2040, Non-OECD Asia, including China and India, is projected to achieve more than 50% of the renewables capacity expansion, while OECD Europe and North America will respectively represent around 18% and 8% of this increase.

Several drivers support renewables progress which are mainly related to strengthened policies that aim to reduce environmental impacts and encourage diversification of energy sources, technical progress of renewable technologies as well as their cost reduction. In Non-OECD Asia, China will be the leader of renewables development, increasing its installed capacity from 280 GW in 2017 to around 1600 GW by 2040, of which solar represents 946 GW.

Despite that China has recently reduced feed-in tariffs for renewables, leading to a slowdown of capacities development compared to previous years, renewables are projected to continue growing over the long-term, driven by cost reductions and by the auctioning of new capacities. Auctions will be an important driver of renewable capacities addition in this country reflecting a policy shift from direct subsidies to market-oriented support schemes.

It is worth mentioning that China outpaced its solar PV capacity target (i.e. 105 GW by 2020) three years ahead of schedule and has also made significant progress toward its wind capacity target (i.e. 210 GW by 2020). For the latter, the country has increased its ambitions in terms of offshore wind development in order to tap a larger share of existing potential. China is also expected to reduce the large observed renewables curtailment, mainly by improving the flexibility of its power system. Gas-fired power plants play a key role in improving this flexibility.

For India, renewables continue to be a key priority and the government has intensified auctioning of renewable projects to increase installed capacities, in line with its stated targets (175 GW by 2022 for solar, wind, biomass and small-scale hydropower). However, some key challenges will prevent India from reaching its ambitious renewables targets including funding constraints and competition from cheap coal; a lack of compliance with renewable obligations at provincial levels; a non-stable fiscal policy with the reduction of renewable subsidies funded from coal taxation; and an increase in the tax on imported solar panels. Furthermore, the ability to integrate renewables will be a key concern in India due to grid bottlenecks and the lack of flexibility of power systems; this challenge will affect the deployment of intermittent renewables in the country. India is forecasted to reach around 75 GW of solar PV out of the targeted 100 GW by 2022. Wind capacities are expected to account for around 47 GW by 2020.

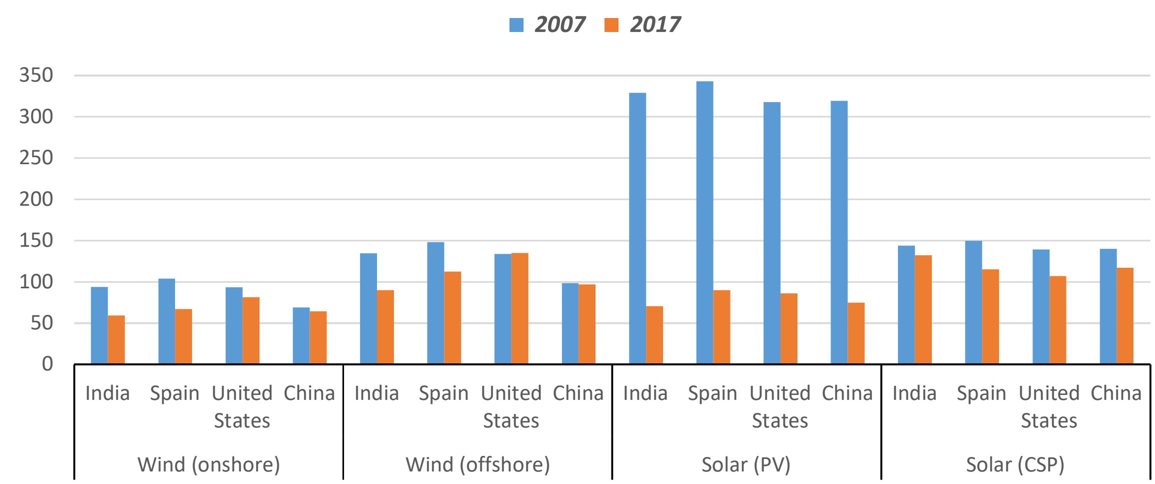
For OECD Europe, the adoption of more ambitious renewables target in the framework of the new EU renewable energy directive (i.e. new target is 32% share of renewables by 2030 replacing the previous 27% target) will encourage European countries to implement measures aimed at accelerating the development of renewables, and to deal with their different challenges, mainly the cost of subsidies and renewables integration. Several measures have been enacted by the EU including the reform of renewables support schemes favouring market instruments and the enhancement of electricity design to improve the flexibility of power systems as well as their ability to balance renewables intermittency. Implementation of these policy measures by different European countries will encourage renewable capacities' increase, projected to reach 890GW by 2040 (280 GW in 2017), of which solar is anticipated to reach around 400 GW and wind to achieve 476 GW. Germany, Spain and France are leading these capacities development and are set to represent around 50% of renewable expansion in Europe over the forecast period.

The United States is also an important contributor in the global capacity expansion of renewables, with an expected increase of around 388 GW between 2017 and 2040. Efforts deployed by communities, states and local governments, and by the private sector in supporting renewables are instrumental in this progress. It is worth mentioning that twenty-nine American states have mandatory Renewable Portfolio Standards, which are translated in local measures to increase the uptake of renewables. At federal level, the Implementation of federal tax credits for renewables contributes, in addition to decreasing costs, in supporting the development of renewable projects, especially solar PV and wind.

Renewables are also set to expand significantly in other parts of the word. Japan and Korea contribute in driving renewable capacities progress in OECD Asia-Pacific region. The two countries have set ambitious policies and targets to support renewables, in a move to reduce their reliance on coal and nuclear, and to encourage their energy self-sufficiency. Several countries in Latin America, Middle East and North Africa have intensified auctioning of new renewable projects, especially solar projects, and have achieved significant reductions in the cost of renewable electricity. Feed-in tariffs also constitutes a key instrument encouraging the deployment of renewables.

The decrease of renewables cost is set to significantly contribute in the uptake of this source of energy. During the last ten years, the cost of intermittent renewables has largely declined, especially for Solar PV that achieved the highest reduction. Based on estimated levelized costs in four countries experiencing major solar development, solar PV average cost decreased from over 330 $/Mwh to less than 90$/Mwh. China and India were able to achieve huge cost reduction reaching respectively 74$/Mwh and 70$/Mwh on average (Figure 2.4).

Figure 2.4. Levelized costs for solar and wind power generation options in selected countries ($/Mwh)



Source: GECF Secretariat based on data from the GECF GGM

Large cost decrease has also been realized for wind energy. Spain, for instance, observed a cost reduction of around 25% for offshore wind and 35% for onshore wind between 2007 and 2017. Onshore wind levelized cost for the four considered countries is less than 70$/Mwh making this power generation option as a competitive source of energy, rivalling with conventional thermal sources. However, there is a need to consider these costs carefully when comparing to conventional sources of power generation. These costs do not factor other hidden costs related to intermittent renewables integration, which mainly include costs of providing back-up and strengthening electricity networks in order to achieve continuity and stability of power systems.

Development of gas-fired capacities

Global natural gas-fired capacities are expected to observe a non-negligible increase from 1700 GW in 2017 to 2720 GW in 2040. These capacities are expected to grow in all the region, except in OECD Asia-Pacific, where gas installed capacities are anticipated to decrease due mainly to renewables development and stagnation of electricity demand in Japan and to less extent in Korea. In Non-OECD Asia, gas-fired capacities will observe an increase of more than 360 GW, equivalent to 35% of the global anticipated gas for power capacity expansion between 2017 and 2040. The development of CCGT will constitute the major driver of this expansion, of which an important share is dedicated to meet baseload power generation in emerging and developing countries. The Open Cycle Gas Turbines are also set to observe a non-negligible growth, benefiting from their technical flexibility and ability to balance variable renewables in a cost effective way.

In general, the main drivers that support increase of gas-fired capacities are the followings: i) policy orientation of many countries to promote gas against coal as a way to improve air quality and reduce carbon intensity; ii) trends to encourage gas as a substitute to oil in power generation iii) competitiveness of natural gas in producing power, reinforced by the availability of competitive supply (e.g. shale gas in the US) and the expected integration of environmental externalities (e.g. carbon prices in Europe); iv) increasing role of gas in supporting renewable integration in power grids.

In Non-OECD Asia, encouraging gas emerged as a policy orientation despite several observed challenges. China has set targets to reach 8-10% share of gas in its primary energy mix by 2020 and 15% by 2030. Various policy instruments are supporting gas in power generation, particularly clean air policies and energy market reforms that aim to stimulate investments in infrastructures and supply of natural gas. China is expected to advance these reforms enhancing energy market's functioning and supporting improved availability and accessibility of natural gas; this will encourage the penetration of this fuel in various economic sectors including power generation. Furthermore, gas will also play a role in complementing the expected penetration of renewables in the country.

For India, the government announced its intention to address different barriers to natural gas, by advancing price and market reforms. Some steps have been taken with recent domestic price adjustments and the launching of new exploration and development policies. However, the gas for power generation remains very sensitive to price evolution and competition from coal. In the future, gas-fired power plants are set to increase moderately by 1.8 GW, achieving installed capacity of 34 GW by 2040. A non-negligible part of these gas power plants will be used to provide the required flexibility of Indian power system in order to integrate large share of renewables.

For other Southeast Asian countries, it is expected that natural gas will benefit from policy support in order to reduce carbon and other air pollutant emissions, and to substitute for oil, especially in the power and industrial sectors. Policy incentives for domestic production and LNG imports, as well as cooperation, especially in the ASEAN framework, will drive the progress of natural gas, although competition from coal will mitigate its potential.

Gas-fired capacities are also anticipated to grow significantly in other developing regions including Latin America, Middle East and Africa. The 2017-2040 incremental capacities in these three regions are anticipated to reach 117GW, 125GW and 85 GW respectively. Supporting growing baseload needs, substituting to oil and complementing renewables and hydropower are the main drivers of this increase in the three above-mentioned regions.

Development of coal-fired capacities

Coal-fired capacities will continue to expand over the long-term driven by Non-OECD Asia which is set to increase these capacities by nearly 330 GW between 2017 and 2040. This region is anticipated to continue relying on coal with the commissioning of many projects in China, India and other Southeast Asian countries. However, the pace of expansion will be largely decelerated compared to the progress observed during the last decade. Many countries in the region implement policies that aim to reduce the pollution emitted from coal-fired plants and to improve the use of clean coal technologies.

In China for instance, despite the observed loosening of restrictions on coal usage in heating and power generation during the last year, following tensions on natural gas and electricity supply, the government is expected to continue implementing measures limiting coal consumption and accelerating the use of clean technologies. China is anticipated to achieve its coal objective (less than 58% of the primary mix by 2020) affecting the role of coal in power generation.

India applied recently a reduction on coal tax which might support competitiveness and growth of coal over the short to medium term. But this growth will be mitigated over the long-term by the implementation of energy efficiency measures in the power sector. In other Southeast Asian countries, such as Vietnam and Indonesia, coal will remain a strategic option that contributes at meeting growing energy needs and security of supply.

Conversely to this expected development in Non-OECD Asia, coal is projected to observe an important decline between 2017 and 2040 in OECD Europe and North America, estimated respectively at 80 GW and 138 GW. Furthermore, OECD Asia Pacific and Non-OECD Europe will observe a decrease by 2 GW and 8 GW respectively on the same period.

In OECD Europe, coal utilization is projected to be strongly reduced due to the phase-out decisions adopted by several EU Member States, as well as the implementation of reinforced emissions standards in the context of Industrial Emissions Directive and EU ETS Phase IV reforms. United States is projected to experience the largest coal decline due to the competition of gas-fired power plants and renewables, and this expected coal decline reflects continued difficulties of the coal industry despite attempts of the current American administration to revive it.

Development of nuclear capacities

Global nuclear capacities are projected to increase by around 100 GW in 2040 compared to 2017 level; and this increase is essentially driven by Non-OECD Asia region that is set to offset the significant decline anticipated in OECD Europe, North America and OECD Asia Pacific (See figure 2.3).

China will lead nuclear progress and will increase its capacity by around 140 GW in 2040 compared to 2017. For India, despite an ambitious policy target (i.e. 63 GW by 2032), it is assumed that the country will realize around 16 GW of nuclear capacity due to several challenges including funding constraints, access to technology and expertise as well as concerns around the nuclear fuel supply.

For OECD Europe, Germany is expected to proceed with its nuclear phase-out by 2022. In other European countries, it is anticipated that security of supply concerns and carbon mitigation will delay the decommissioning of some projects (e.g. France and Spain). Nevertheless, no large replacement programmes of old nuclear fleet will be initiated, and therefore, nuclear will see a steep decline after 2025. The capacity reduction is estimated at around 35 GW between 2017 and 2040, essentially in Germany and France.

OECD Asia-Pacific nuclear capacity's reduction is driven by Japan, which is anticipated to not achieve its nuclear capacity re-starting target due to public opposition and legal procedures. Nuclear capacity will see a strong decline in this country after 2030 driven by the decommissioning of old plants. For Korea, Nuclear will still play a role over the long-term despite a notable decrease and would reach a share of around 21% by 2040. South Korea is expected to keep a footprint in the nuclear industry and that the country will continue to position itself as an exporter of nuclear technology and expertise.

North America is the second largest region set to see an important decline of nuclear capacities. This decline is estimated at more than 22 GW in 2040 compared to 2017 level and is driven by the retirement of large fleet of old power plants in the US. Gas and renewables will be viable options that substitute to nuclear in the US.

Development of oil-fired capacities

Retirement of oil-fired power plants and their replacement by other alternatives, particularly natural gas and renewables, will be an important determinant of the future power configuration. The oil-fired total installed capacity is set to decrease by more than 110 GW between 2017 and 2040, setting the share of oil in the global power generation capacity at around 2.5% by 2040. OECD Asia-Pacific, essentially Japan, is anticipated to achieve a large part of this oil-fired capacity reduction, which is expected to be replaced by renewables and clean coal plants. Other developing regions such as the Middle East and Non-OECD Asia will also reduce their oil-fired capacities, substituting them by more competitive power plants including gas-fired plants as well as renewables.

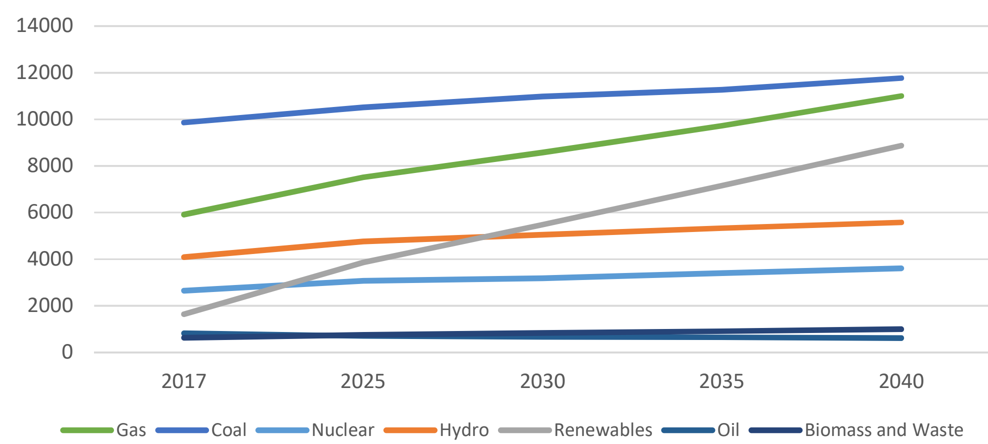
Prospects of power generation

Global power generation is projected to increase significantly, by around 65% between 2017 and 2040, supported by the important development of capacities to meet growing electricity demand. Renewable electricity generation is set to observe the highest annual growth (CAGR 2017 – 2040: 7.6%), followed by natural gas-based generation (CAGR 201-2040: 2.7%), reflecting the increased role of less carbon-intensive fuels in producing power.

Gas-fired generation will consolidate its role as a second source of power production, after coal which is expected to continue dominating the power mix by 2040. Coal-fired power production is, however, anticipated to stagnate significantly after 2030, encouraged by the implementation of strengthened environmental policies in different regions. Renewables (excluding hydro and biomass) are set to overpass nuclear by 2022 and hydropower by 2030 becoming the third source of power generation by 2040. Hydropower as well as nuclear are set to observe a moderate increase of their power production, with an annual average growth rate estimated respectively at around 1.35% and 1.36% over the 2017-2040 forecast period.

The large expansion of renewable capacities (excl. hydro and biomass), essentially solar and wind, will drive the increase of generation from this source. Renewables are anticipated to rise their share in the global generated electricity from 6.4% in 2017 to 21% in 2040. However, this renewables share in electricity generation remains less important than its share in the total installed power capacity, which is estimated at around 36% by 2040 (Figure 2.6). This difference between renewables contribution in electricity production and in installed capacities reflects the low utilization rates of solar and wind, estimated respectively at around 15% and 30% on average by 2040.

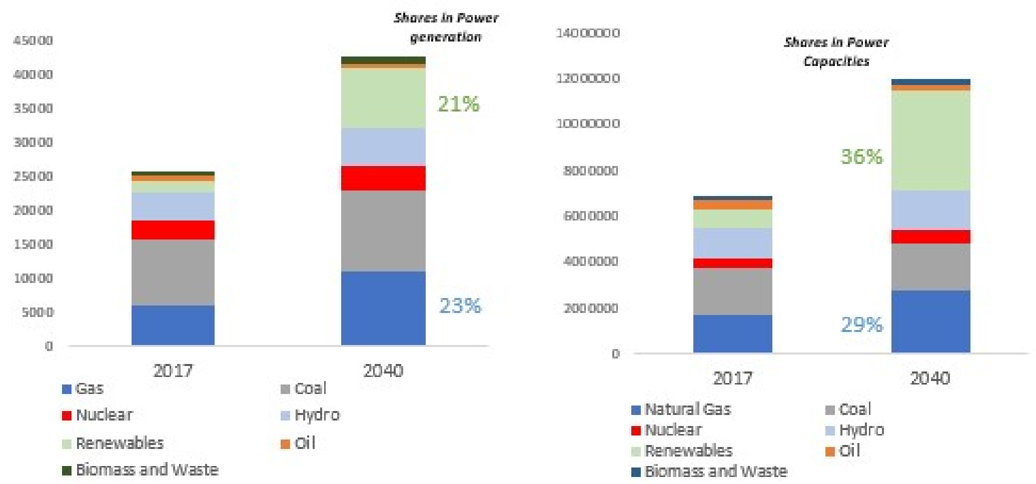
Figure 2.5. Global power generation prospects by source of energy (Twh)



Source: GECF Secretariat based on data from the GECF GGM

Conversely, the share of gas-fired electricity in the global production is projected to reach 23% by 2040, and this electricity will be the output of around 2700 GW of gas power plants capacity, that represent 29% of the total installed capacity globally. The higher contribution of gas in power generation compared to renewables, despite much less capacities, reflects larger efficiency and utilization rate. The latter is estimated at around 45% by 2040.

Figure 2.6. Global power generation (Twh) vs. capacities (MW) by source of energy



Source: GECF Secretariat based on data from the GECF GGM

It is worth mentioning that the increasing role of gas-fired power plants in providing back-up to cope with renewables intermittency would play a downside effect on the average utilization rate of gas-fired capacities. However, this downside effect will be compensated by the still expected important role of gas power plants in baseload generation, especially in the emerging and developing countries. Gas-fired power plants have ability to operate efficiently in both baseload, intermediate load and peak load regimes, and can be instrumental in providing a large flexibility for power systems.

III. Prospects of CO_2 emissions from power generation and future role of gas-fired power plants

Based on electricity demand and supply forecasts in different regions, the CO_2 emissions from power sector are expected to observe an average annual growth of 0.8%, leading to increase emissions level from 12.3 $GtCO_2$ in 2017 to around 14.6 $GtCO_2$ in 2040. Non-OECD Asia will take the lead in these prospects and will account for around 58% of global power-related emissions by 2040. This region will see positive emissions growth over the long-term (CAGR 2017-2040: 1.5%) despite a net slowdown compared to historical trends. As previously highlighted (figure 2.3), the increase in power installed capacities including coal- and gas- fired power plants will support the rise of these emissions.

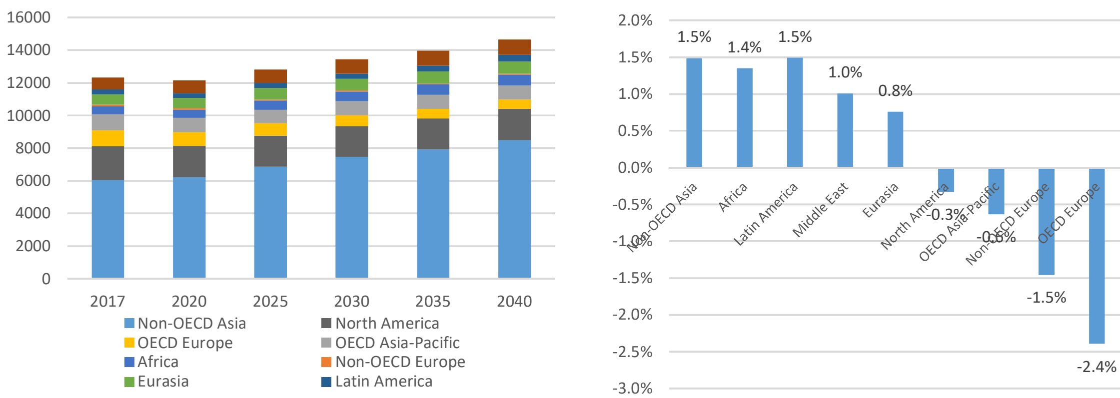
Middle East, Latin America and Africa are also forecasted to experience high emission growth rates, driven by important increase of power generation in order to meet the needs of growing population and economies. The three regions will rise their power-related emissions by around 500 $MtCO_2$ over the 2017-2040 period.

Conversely, in electricity-mature markets (including OECD Asia-Pacific, North America and OECD Europe), the power-related emissions are set to observe a decline. The latter is driven by the expected low growth of electricity demand in several countries as well as by large development of renewables and switching to less carbon intensive fuels, natural gas in particular.

OECD Europe is anticipated to lead the power emissions' reduction with around 2.5% average annual decrease between 2017 and 2040. This reflects the fact that Europe will continue to be at the forefront of carbon mitigation effort, with the implementation of strong climate and environmental policies.

For North America, the decline of emissions is particularly expected in the US, driven by initiatives undertaken at non-federal level (e.g. States, cities and businesses) that support the uptake of carbon mitigation options, including renewables. Market fundamentals will also play a role in the US, since they favour the penetration of abundant and affordable natural gas in producing power.

Figure 3.1. CO_2 emissions from power generation by regions ($MtCO_2$), and Average Annual Growth Rates (%)



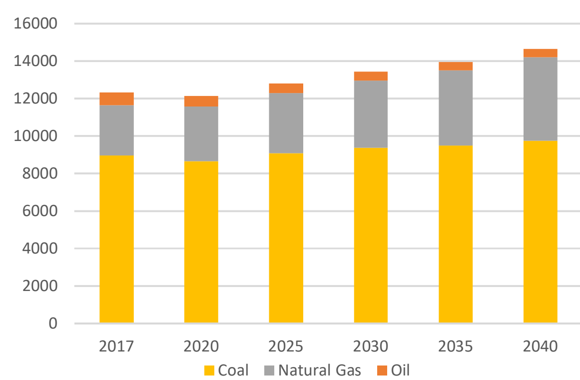
Source: GECF Secretariat based on data from the GECF GGM

III.1 Power emissions forecasts by fuels

Basing on the forecasted electricity generation by fuels, power-related emissions are anticipated to be dominated by coal at the global scale. Indeed, coal-fired plants' emissions will increase annually by nearly 1% over the 2017-2040 period, reaching around two-thirds of the global emissions by 2040. Natural gas plants' emissions, however, are forecasted to grow by 2.2% annually, representing 30% of the 2040 global emissions.

It is worth noting that gas-fired plants are set to generate more than 50% less CO2 emissions than coal plants by 2040, and to produce only 6% less electricity; this is due to higher efficiency of gas power plants and lower carbon content of natural gas. Accordingly, increasing the share of natural gas at the expense of dominant coal in producing power, can be an appropriate response to mitigate carbon emissions from this sector.

Figure 3.2. CO_2 emissions from power generation by fuels ($MtCO_2$)



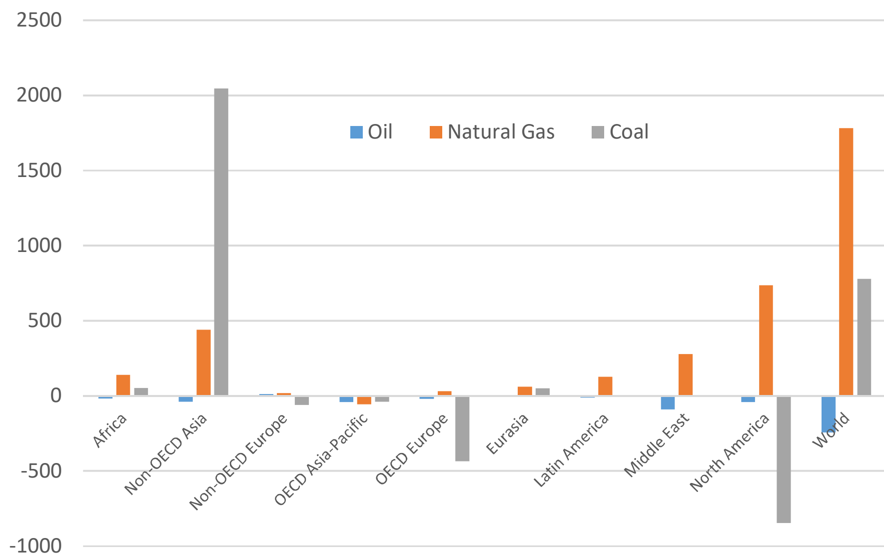
Source: GECF Secretariat based on data from the GECF GGM

At regional level, it is important to note that Non-OECD Asia will concentrate the bulk of power-related emissions increase between 2017 and 2040, especially from the coal power plants that will be responsible of 2 $GtCO_2$ rise (Figure 3.3). This emissions growth in Non-OECD Asia is significantly compensated by the anticipated strong decline of coal-based emissions in OECD Europe and North America. The global emissions from coal power plants will grow by around 780 $MtCO_2$ over the 2017-2040 period.

As depicted in figure 3.3, natural gas-fired plants will be responsible of increased emissions driven by the growth of gas-based electricity in almost all the regions. The additional gas-based emissions are estimated at around 1,8 $GtCO_2$ in 2040 compared to 2017 level, of which Non-OECD Asia and North America represent almost two-thirds.

Emissions resulting from oil-fired plants are expected to continue their decline over the long-term, mainly in Asia and the Middle East; this reduction, which is estimated at more than 240 MtCO2 in 2040 compared to 2017 level, is underpinned by the anticipated substitution momentum of oil by other alternatives to produce power including gas and renewables. Emissions due to oil utilization in power sector are forecasted to reach less than 3% of the global power-related emissions by 2040.

Figure 3.3: Incremental CO_2 emissions from power generation by fuels between 2017 and 2040 ($MtCO_2$)

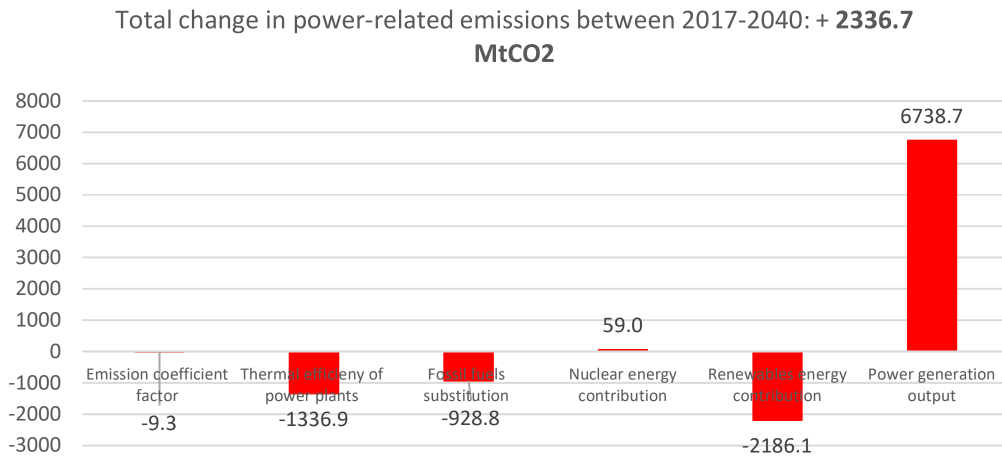


Source: GECF Secretariat based on data from the GECF GGM

III.2 Analysis of the future drivers of CO_2 emissions from power generation sector

In order to analyse the contribution of various factors in driving future CO_2 emissions from power sector, we apply the Logarithmic Mean Divisia Index decomposition (LMDI). Figure 3.4 highlights the results of this decomposition of the global CO2 emissions, and it is possible to note that the increase of power generation outputs to meet energy needs of growing world population and economies is the main contributor in rising emissions. However, this driver is expected to be counterbalanced by the anticipated increase of renewables and thermal efficiency improvement. These two factors might reduce emissions from power sector by around 3.5 GtCO2 in 2040 compared to 2017 level if the effects of the other factors remain constant. Fossil fuels substitution, especially through penetration of gas against coal, might be responsible of nearly 0, 93 GtCO2 reduction between 2017 and 2040, marking an important role in the carbon mitigation, especially when considering the cost efficiency of this option.

Figure 3.4. Decomposition of global power-related CO_2 emissions change between 2017 and 2040 ($MtCO_2$)



Source: GECF Secretariat based on data from the GECF GGM

The reduction of nuclear share in power generation mix is set to play a small role in driving emissions increase. Indeed, the upward effect due to expected nuclear decline in Europe, North America and OECD Asia, is projected to be offset by an increase of nuclear in emerging countries, China in particular. The effect due to the carbon emission factor's reduction of each fossil fuel is anticipated to be marginal with less than 10 MtCO2 reduction over the forecast period.

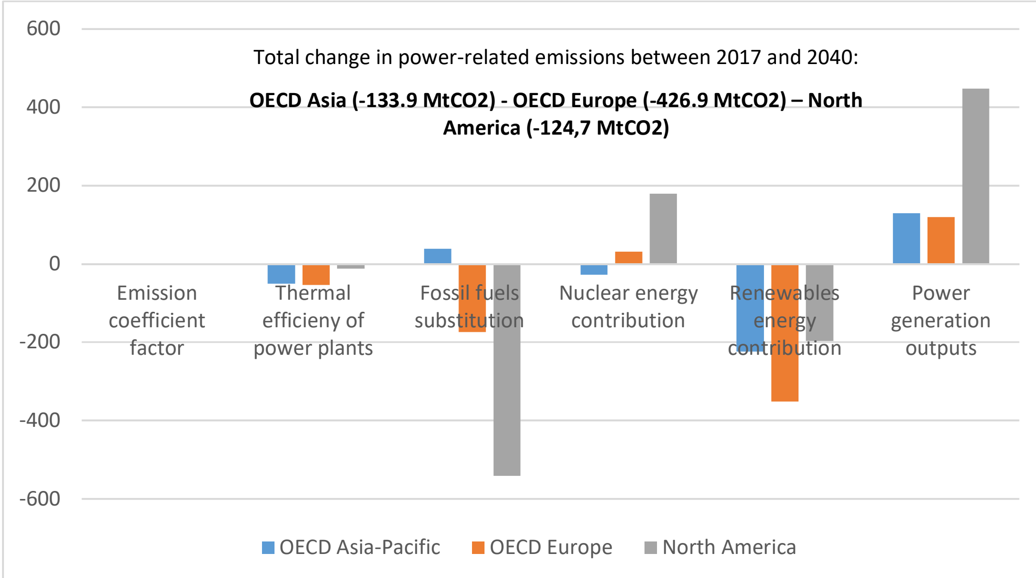
In the following paragraphs, we will analyse the decomposition of power-related emissions, distinguishing between developed and mature markets on one side (Figure 3.5), and developing and emerging regions on the other side (Figure 3.5).

Figure 3.5 highlights the LMDI decomposition results for OECD Europe, North America and OECD Asia-Pacific, which include developed countries with mature electricity markets. All these regions are anticipated to observe emissions reduction over the long-term. OECD Europe is projected to take the lead of this reduction, with nearly 427 MtCO2 decrease in emissions between 2017 and 2040.

These regions exhibit different drivers of emissions over the long-term. Increase in electricity production, supported by economic growth and increased electrification of economies, is set to play a role, particularly in North America. For the latter, United States in particular, the growth of electricity generation will be responsible of around 450 $MtCO_2$ increase in 2040 over 2017 (all other factors kept unchanged). The anticipated reduction of nuclear will also put an upside pressure on CO_2 emissions. However, these drivers of increase will be significantly offset by penetration of renewables and substitution of gas to coal. Substitution between fossil fuels in North America is estimated to be the largest contributor in CO_2 mitigation.

For OECD Europe and OECD Asia, the main contributors in mitigating CO_2 emissions are penetration of renewables and improvement of power plants thermal efficiency. Substitution between fossil fuels is expected to play a non-negligible mitigating role in OECD Europe where natural gas is expected to replace more carbon-intensive coal. In OECD Asia, the expected reduction of gas for power utilization in Japan will benefit coal combustion in power sector and will have an upside effect on CO_2 emissions; this is highlighted in the positive change of emissions due to fossil fuels substitution (figure 3.5).

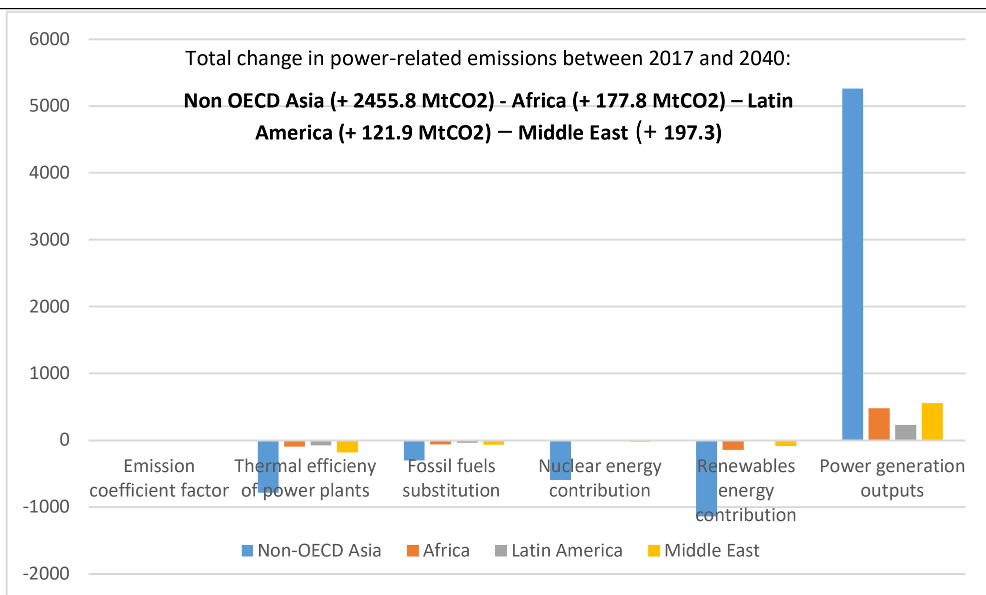
Figure 3.5. Decomposition of power-related CO_2 emissions change between 2017 and 2040 ($MtCO_2$) for developed regions



Source: GECF Secretariat based on data from the GECF GGM

Figure 3.6 depicts the decomposition of CO_2 power-related emissions change between 2017 and 2040 by different contributing factors for emerging and developing regions. The figure highlights that increase of power generation output to support growing population and economies is a critical driver of emissions growth in these regions, especially in Non-OECD Asia. In this region, the power generation increase over the 2017-2040 period will contribute in rising power-related CO_2 emissions by more than 5.2 $GtCO_2$ (if all other effects are kept constant). Nevertheless, renewables and nuclear penetration, thermal efficiency improvement and to less extent penetration of gas against coal and oil (i.e. Fossil fuels substitution), are set to counterbalance this upside effect of power generation and to contain the emissions increase to around 2.5 $GtCO_2$.

Figure 3.5. Decomposition of power-related CO_2 emissions change between 2017 and 2040 ($MtCO_2$) for developing and emerging regions



Source: GECF Secretariat based on data from the GECF GGM

For the Middle East and Africa, thermal efficiency improvement and renewables will have a downside effect on CO_2 emissions offsetting the contribution of increased power generation outputs. In Latin America, the anticipated decrease in the share of hydropower from 56% in 2017 to around 51% in 2040 will transform the effect of renewables (including hydro) in an upside effect on emissions. Indeed, decreasing share of hydro supports a rising role of fossil fuels in producing power, and therefore contributes in increasing emissions in the region.

Conclusion

Power generation sector will contribute significantly in slowing down global CO_2 emissions over the long-term. However, large disparities in the power-related emissions are expected, especially between OECD and Non-OECD countries. These disparities are driven by various electricity demand prospects and also by different options and choices adopted for electricity production.

To understand the drivers of CO2 emissions from the power sector, the Logarithmic Mean Divisia Index (LMDI) decomposition is used. This method enables to decompose emissions in three categories of factors: i) intensity factors that include emission coefficients of fuels and thermal efficiency of power plants; ii) structure factors that incorporate the substitution between fossil fuels as well as the changes in renewables and nuclear; and iii) the activity or scale factors which relate to the emissions resulting from the change in the amount of power generated.

Decomposing the drivers of future emissions highlights that the increase of electricity production, in order to support growing economies and population and increasing electrification of final energy usages, is set to play a crucial role in driving emissions growth in emerging and developing regions. This factor is still expected to have an effect in developed regions, where electricity demand is anticipated to grow, though at moderate level. Electrification of the final energy consuming sectors in developed economies will support power generation and emissions from this sector.

Renewables penetration will have a strong mitigating effect in developed regions, especially in OECD Europe. For the Non-OECD regions, renewables are set to play a crucial role in Non OECD Asia, China in particular driven by the country effort to support this source of energy. This carbon mitigating role of renewables is less important in other developing areas. Furthermore, the expected reduction of hydropower share in countries like India and Brazil would play an upside effect on CO2 emissions.

Substitution between fossil fuels, and especially between natural gas and coal, will contribute significantly in mitigating CO2 emissions from the power sector. This effect is expected to be specifically important in Non-OECD Asia and North America driven by the anticipated growing role of natural gas, which is stimulated by environmental policy support and competitiveness. OECD Asia is the only region where substitution between fuels plays in the opposite way with regards to emissions mitigation. Indeed, the expected reduction of gas for power utilization in Japan will benefit coal combustion in the power sector and will have an upside effect on these emissions.

Improved thermal efficiency of power plants is expected to contribute significantly in reducing the emissions, and this effect is important in Asian countries, which are expected to improve significantly the efficiency of both coal-fired power plants and gas-fired plants. The latter will benefit from expanding role of the combined cycle gas turbines.

The reduction of nuclear share in power generation mix is set to play a small role in driving emissions increase. Indeed, the upward effect due to expected nuclear decline in Europe, North America and OECD Asia, is projected to be offset by an increase of nuclear in emerging countries, China in particular.

The decomposition analysis of power-related emissions highlights that three factors: renewables, particularly the intermittent renewables; substitution between fossils, and thermal efficiency improvement are the driving forces of emissions mitigation. Natural gas can fit with these three drivers, because it allows to substitute to more intensive fossil fuels, contributes in increasing thermal efficiency and in enabling penetration of intermittent renewables by providing the required flexibility for power systems. As a consequence, natural gas can be an optimal CO_2 mitigation option for power generation.

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