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Transitions to low carbon electricity systems: Key economic and investment trends

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There is substantive evidence of an ongoing transition to low carbon electricity systems, but progress remains too slow and unevenly distributed to prevent the most severe impacts of climate change

Transitions to low carbon electricity systems: Key economic and investment trends

The availability of clean electricity is critical for meeting the Paris Agreement objectives

CO_2

At least **80%** of mitigation efforts required by 2030 in the energy sector could be concentrated in the power sector

The global decarbonization of the electricity sector is proceeding at a slow pace

34% The share of low carbon electricity in 2016 was only two percentage points higher than in 2010

Fuelling rapid economic growth with sustainable energy is challenging

13% more electricity than in 2010

In 2016, each person in emerging economies consumed 13% more electricity than in 2010, as opposed to those in developed countries

Low carbon electricity is often a rare commodity

10 countries account for more than 70% of low carbon electricity generation worldwide

61 countries still rely on low carbon sources for less than a quarter of their electricity needs

Nuclear power can play a key role in meeting some of the climate pledges

1/3

Every third low carbon kWh is nuclear

Every third kWh generated worldwide is low carbon; The carbon footprint of electricity generation in 30 nuclear countries is 19% below the global average

19%

Flexible operation will be central to future power systems

80% of yearly renewable capacity additions (about 140 GW per year) are non-dispatchable

Low carbon investments should expand and address more countries

Yearly capital requirements in nuclear and renewable power must increase by 50% and 90% respectively through 2030; China and the United States receive almost half of low carbon capital

+50%
+90%

Low carbon power investments are closing the gap with fossil fuels

Fossil fuel investments in the power sector are declining by 15% every year

$350 billion are invested yearly in nuclear and renewable capacity

Power markets should be reformed to ensure the sustainability of operators

14%

Since 2015, electricity prices in the manufacturing sector have decreased by 14% on average in about 75% of countries

Carbon prices are fundamental instruments for supporting low carbon deployment

Only 20% of global GHG emissions, mostly from the power sector, are currently covered by a carbon price

20%

CO_2

Transitions to low carbon electricity systems: Key economic and investment trends

The electricity sector may act as a catalyst for an economy-wide transition to a low carbon, climate-resilient and sustainable future. This booklet provides an overview of the nature and pace of the ongoing transition to low carbon electricity systems and discusses some of the inherent challenges. The booklet provides a reality check through selected indicators, notably in relation to income levels.[1]

POWER SECTOR: THE ENGINE OF DECARBONIZATION

A global transition towards more sustainable, affordable and reliable energy systems is being stimulated by the implementation of the Paris Agreement and the UN 2030 Agenda for Sustainable Development. Political ambitions are rising in many countries, low carbon solutions are becoming increasingly cost-effective and financiers are considering climate-resilient infrastructure as an attractive investment opportunity.

As a prerequisite for global decarbonization, economies will need to expand while using energy more efficiently, although this potential remains vastly untapped (IEA et al., 2019). But much greater efforts are needed. A cost-effective decarbonization is now deemed possible only through the electrification of energy usage wherever possible, including heat and transport, provided that electricity is generated from clean sources (ETC, 2018; IPCC, 2018; WEF, 2019). This places the power sector at the heart of countries' mitigation strategies, as reflected in Nationally Determined Contributions (NDC). According to the International Energy Agency, 81% of mitigation efforts in the energy sector through to 2030 should be concentrated in the power sector alone to keep the rise in global temperatures well below 2°C (Fig. 1).

Low carbon electricity generation has increased in recent years, largely driven by solar and wind deployment. The merits of nuclear energy for climate mitigation are also increasingly recognized by policy-makers worldwide. Power utilities operating fossil fuel capacities have also modernized their assets and improved their resource efficiency. In some cases, they have also switched fuels from coal to natural gas. Nonetheless, this multifaceted transition remains too slow to limit exposure to the most severe impacts of climate change, despite revised policy ambitions, support for innovation and increased investments in low-carbon capacities. Fossil fuels still meet two-thirds of global electricity needs.

Future power systems will be characterized by large shares of variable power generation sources. Their integration will require existing and new power capacities to be operated more flexibly. They will be complemented by power interconnectors, demand-side management or energy storage solutions, including behind-the-meter devices. Operators' business models and value propositions will need to be adapted to more competitive environments and demanding regulatory regimes. Strict policy enforcement by governments is also required, in coordination with the private sector, research institutions and civil society. Only then will we get closer to the 2050 objective of cutting the carbon intensity of electricity more than ten-fold compared to current levels, under 50 gCO_2 per kWh (IPCC, 2018).

The availability of clean electricity is critical to achieve the decarbonization of energy end-use and meet the Paris Agreement objectives

Figure 1. Illustrative transition to low carbon power systems in line with the Paris Agreement.[2]

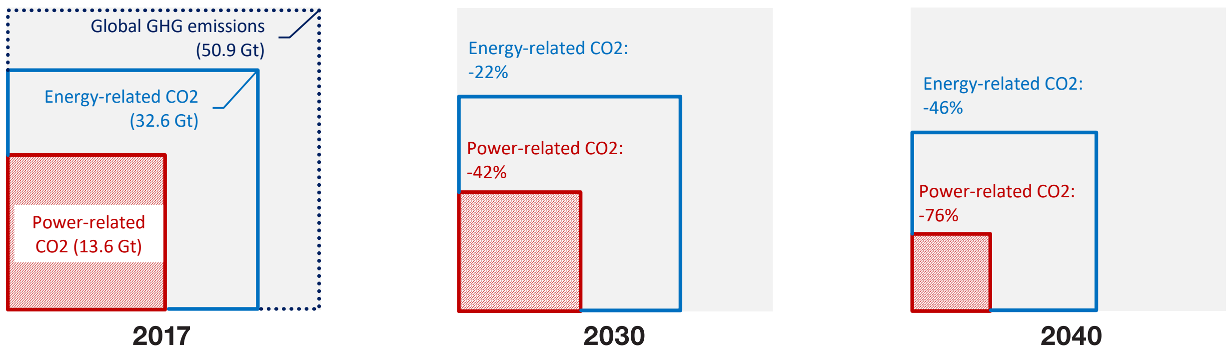
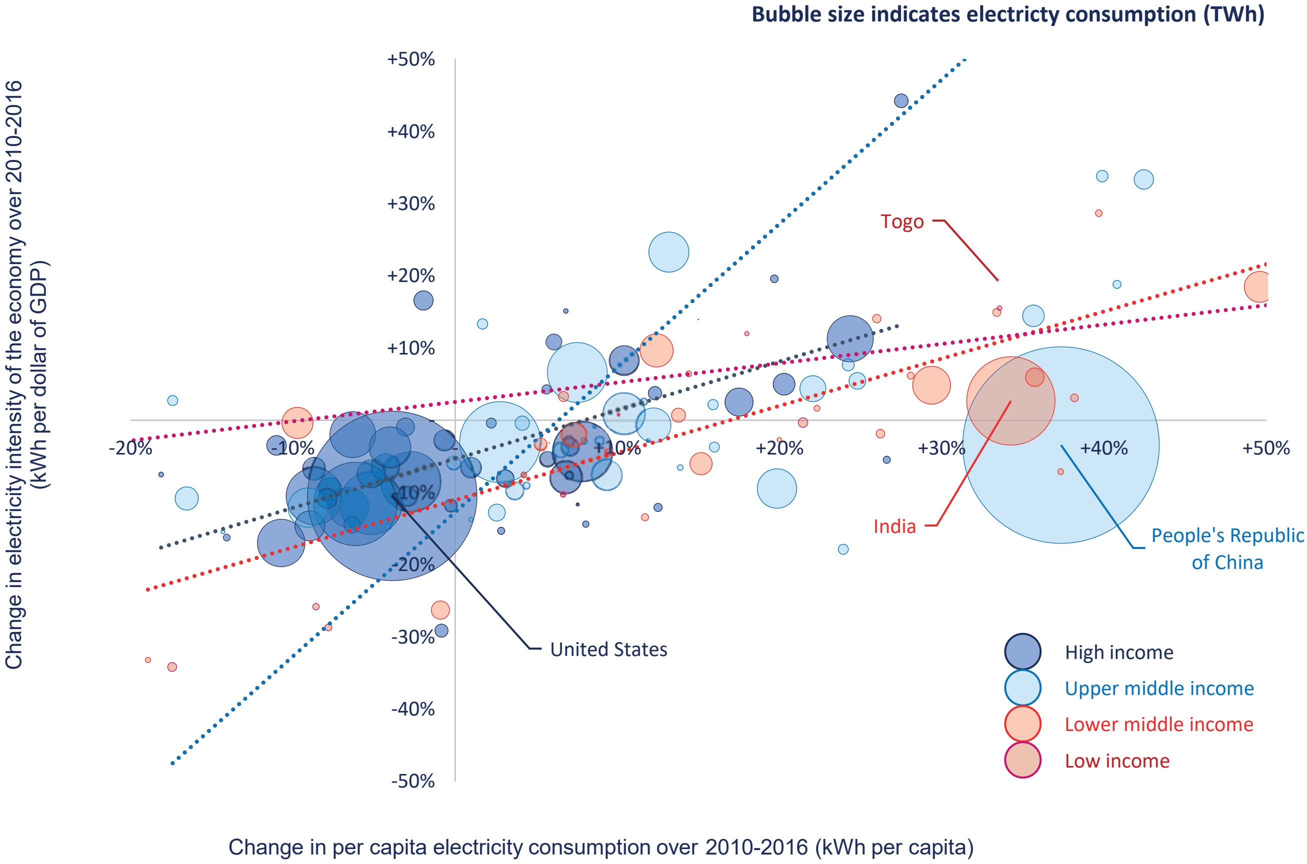


Figure 2. Electricity intensity by country and income level, 2016.[3]



PACE OF TRANSITION: A CONTRASTING PICTURE

The latest stocktaking of progress towards the achievement of Sustainable Development Goal 7 objectives in the *Energy Progress Report* highlights a hastened decoupling between overall economic activity and energy use in recent years. This noticeable improvement was driven by twenty countries with the largest energy consumption, often in higher ranges of income (IEA et al., 2019). Their ability to moderate further their energy footprint will be critical to meet the global targets.

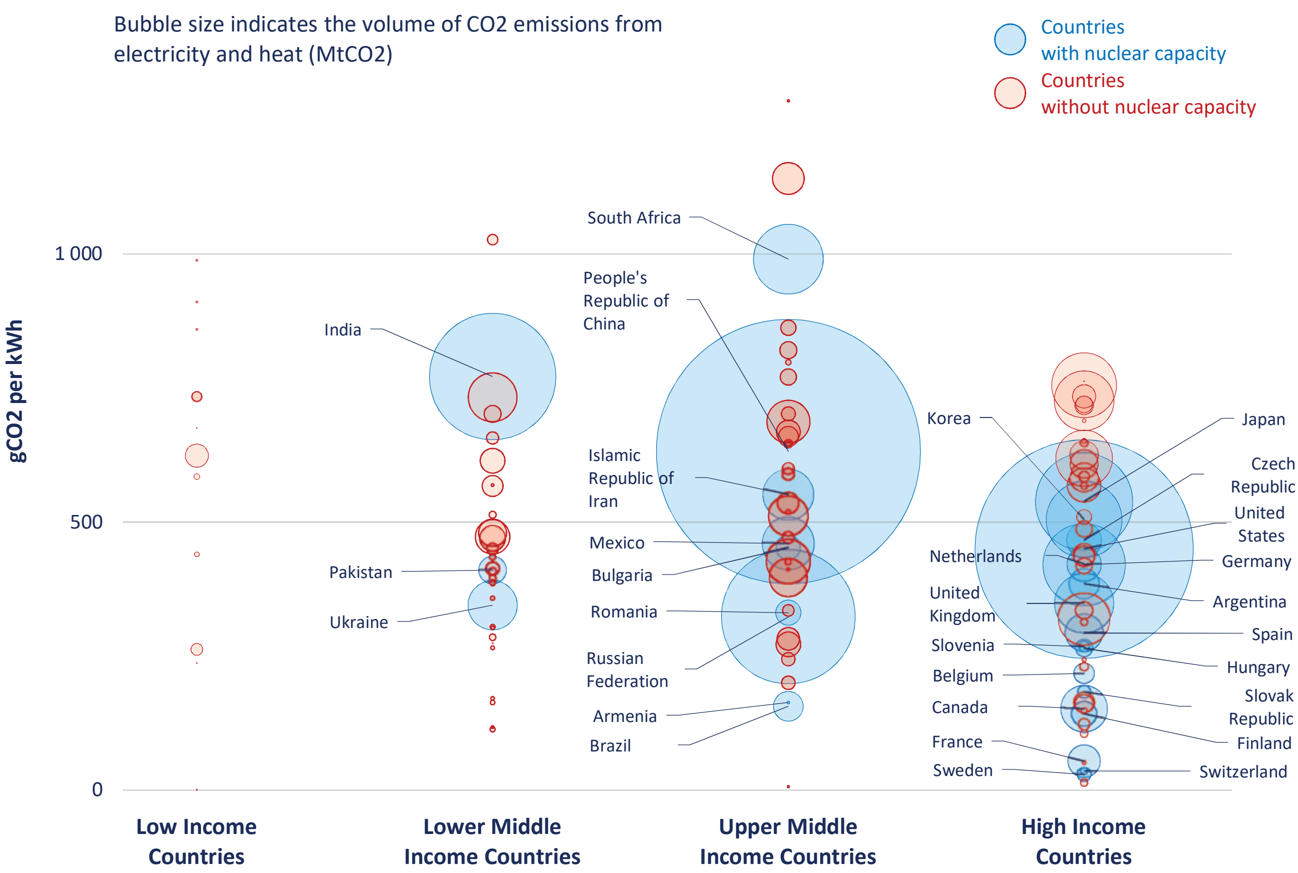
Electricity is a key factor in economy-wide efficiency improvements realized in most high and upper-middle income countries, which represented almost 90% of global electricity consumption in 2016. Favourable regulatory frameworks and business environments have been instrumental in the adoption of efficient appliances, including efficient lighting and the replacement of inefficient industrial motors. Since 2010, most of the 51 high-income economies have managed to use electricity more efficiently (as a productive input and in per capita terms).

Progress in upper-middle income countries is more uneven due to dissimilar economic growth dynamics. Overall, both the electricity intensity of these economies and per capita electricity usage grew 13% on average during 2010-2016 (Fig. 2).

By contrast, electricity consumption in lower-income yet fast-growing economies is still small but is expected to increase significantly, both in absolute and per capita terms. In many of these countries, large populations, particularly those living in rural areas, often remain without access to electricity services. These countries are likely to emerge as key centres of energy consumption. The outcome of the global energy transition will thus also depend on their success in meeting sustainable development objectives. These lower income countries are facing the dual challenge of fuelling their economic growth while producing and consuming energy more sustainably. Often, the actors of the energy transition evolve in deficient business environments with limited regulatory incentives (World Bank, 2018-2019b).

The transition to more sustainable energy solutions in low to middle income countries is indispensable to their economic growth

Figure 3. Carbon intensity of electricity by income level, 2016.[4] Countries with operating nuclear capacity are named.



ECONOMIC DEVELOPMENT CAN ACCOMPANY CLIMATE MITIGATION

The global movement towards less resource- and carbon-intensive electricity hides contrasting outcomes across countries. Indeed, the carbon intensity of electricity generation often correlates with domestic income levels.

High-income countries account for a third of global CO_2 emissions from electricity and heat. These countries tend to rely on more diversified and more efficient power mixes than less developed economies and often include larger shares of low carbon electricity sources. Their carbon intensity lies about 11% below the global average (Fig. 3).

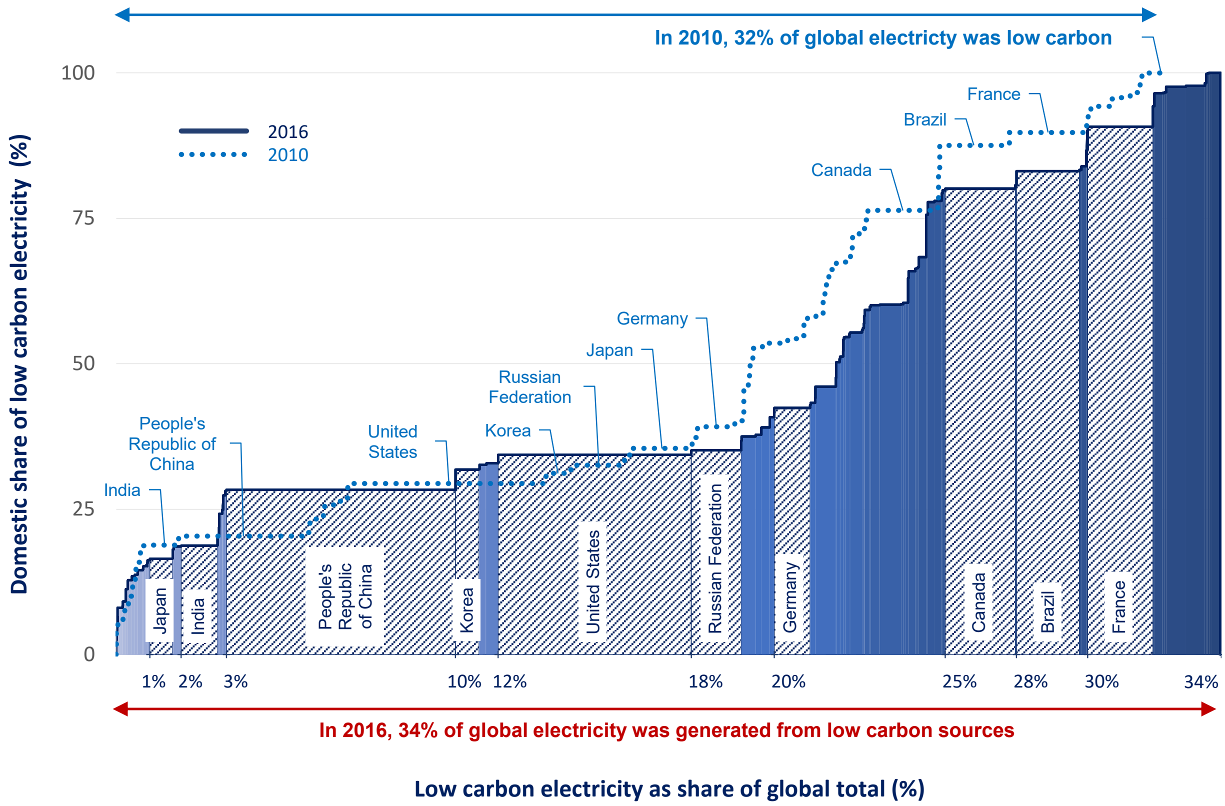
The historical deployment of nuclear power in 30 countries, high income economies for the main part, has thus far avoided 20% of cumulative CO_2 emissions from electricity generation (IEA, 2019c). As a consequence, the carbon intensity in these 30 countries with operating nuclear capacity, sometimes combined with access to large hydropower resources, is even lower. At 360 gCO_2 per KWh on average in 2016, their carbon intensity was 19% below the global average.

Conversely, among countries in lower income brackets, electricity and heat-related emissions have generally increased in recent years, boosted by rapid economic development and, in some cases, reliance on abundant and cheap coal or natural gas resources. After several years of stagnation and efforts to stop operation of the most inefficient coal-fired plants, power-related CO_2 emissions are on the rise again, driven notably by industrial demand and building cooling needs (IEA, 2019b).

The global carbon footprint of electricity generation in the lowest income countries remains insignificant. Without adequate policies to promote cleaner and more efficient technologies, their CO_2 emissions are poised to increase swiftly in the mid-term, driven by progress in electrification and growing needs from middle-class consumers. Future deployment of power capacities must therefore be cautiously planned by decision-makers to avoid locking energy systems into carbon-intensive infrastructures.

Growing electricity needs in low to middle income countries will drive future CO_2 emissions in the power sector

Figure 4. Distribution of low carbon electricity by country, including top 10 contributors to global low carbon electricity, 2016.[5]



LOW CARBON DEPLOYMENT: A REALITY YET?

The global decarbonization of electricity is occurring at a slow pace. Currently, a third of electricity is produced from low carbon sources, i.e. renewable and nuclear energy. This share has barely increased since 2010 (Fig. 4). During this period, global demand for electricity grew 16% but the bulk of these additional energy needs were met by newly-built fossil fuel power plants.

The growth in low carbon electricity generation only makes up for incremental electricity needs: since 2010, low carbon electricity has been rising steadily (+3.5% yearly), driven by hydropower developments in places such as North America, Norway, China and Vietnam, and the global emergence of wind and solar power (+6% annual growth in total renewable power). While nuclear production largely stalled in Japan and Germany after the Fukushima accident in 2011, nuclear generation elsewhere grew annually by 3.4% between 2010 and 2016. These low carbon developments have barely exceeded the expansion of fossil fuel-based electricity generation (+2.1% per year globally with +4.8% in China alone).

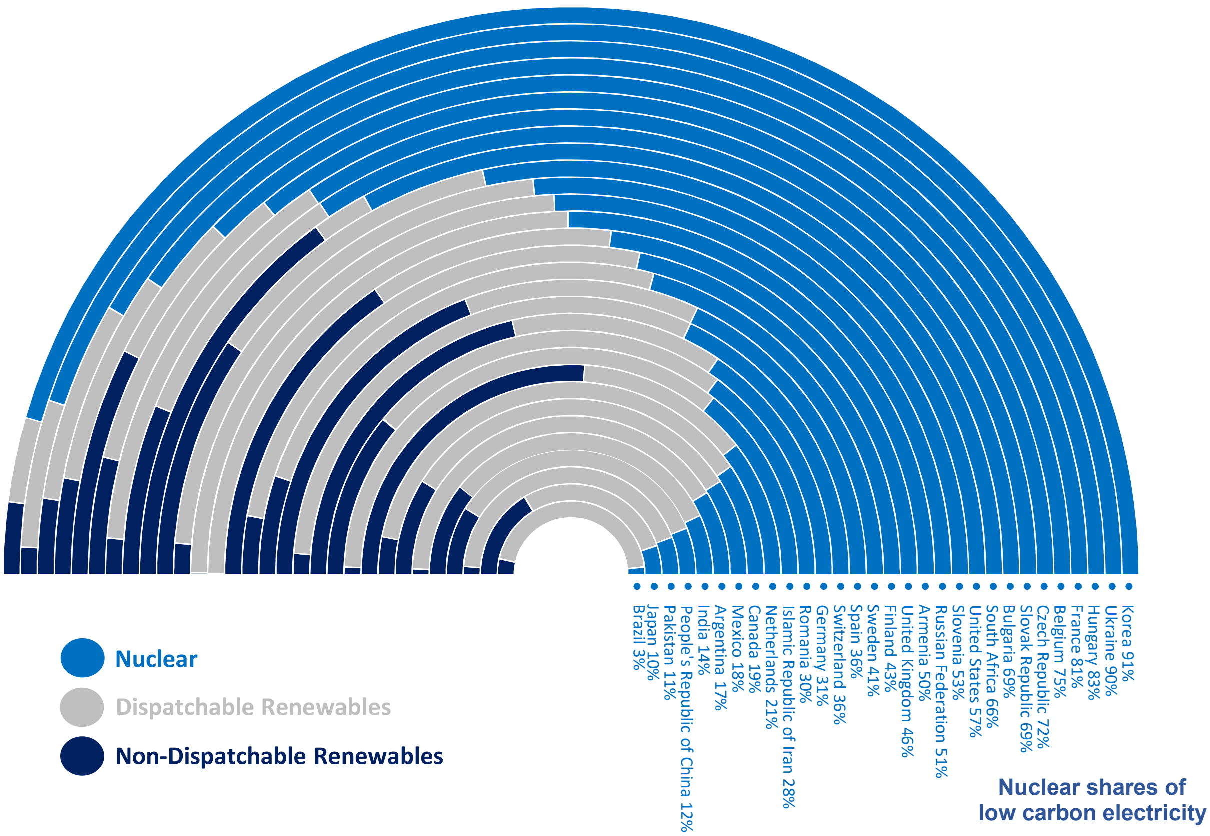
Ten countries have driven the uptake of low carbon electricity, with China alone accounting for almost half of renewable energy growth and a third of nuclear growth (excluding Japan and Germany). These ten large economies generated more than 70% of total low carbon electricity in 2016, with a similar proportion in 2010.

On average, overall low carbon electricity accounts for roughly 40% of domestic electricity production. Sixty-one countries, representing a quarter of global electricity production, still rely on low carbon sources for less than a quarter of their electricity needs.

The roll-out of low carbon electricity, albeit already substantial, must now accelerate and expand in all countries if we are to pave the way for a full power sector decarbonization around mid-century and, moreover, achieve the broader goals of sustainable development.

Ten countries account for more than 70% of low carbon electricity generation worldwide

Figure 5. Breakdown of low carbon electricity in countries with operating nuclear capacity, 2016.[6]



TOWARDS A MORE FLEXIBLE POWER INFRASTRUCTURE

As countries revise their national climate ambitions, their ability to transform electricity infrastructures – and achieve more ambitious goals – depends on the structure of existing assets and on the degree of system flexibility when integrating new variable capacity.

Hydropower accounted for 16% of total electricity generation in 2016 and was the main source of low carbon electricity, with almost half the total. Nuclear power provided 10% of total electricity and 30% of low carbon electricity generated worldwide. But a closer look at countries' electricity mixes reveals that nuclear power makes a significant contribution to low carbon electricity in many of the 30 countries that have been developing nuclear capacity since the late 1950s. Nuclear energy provides more than half of low carbon power in 13 of them (Fig. 5).

The remaining clean electricity production stems from geothermal, bioenergy and non-dispatchable sources that are not continuously available (including wind and solar energy). These sources made up a modest 5% share of total electricity in 2016. However, they are now expanding fast and account for 80% of new renewable capacity additions (about 140 GW per year). Despite significant deployment, non-dispatchable renewables are unlikely to alter radically the low carbon electricity landscape in the immediate future, mainly because of relatively low capacity factors.[7]

Sustaining operations of existing baseload technologies, including hydropower and nuclear plants characterized by large scale and high capacity factors, would be critical for an effective and timely climate action, as concluded by the International Energy Agency (IEA, 2019c).

The steady and cost-effective deployment of variable, non-dispatchable renewable capacity deserves careful monitoring, including tailored regulatory responses, to maintain grid reliability and overall security of supply. The expected shift towards systems with high shares of renewables (and nuclear wherever applicable) implies more flexible operations from conventional utilities, which will impact their revenues and, as a result, business models and market rules (NEA, 2018). The emergence of new energy storage solutions and stronger reliance on digital services will help alleviate such risks.[8]

Nuclear power accounts for at least half of low carbon electricity in 13 of the 30 countries with nuclear power

IMPACT OF THE TRANSITION ON END-USER PRICES

Reliable and competitively-priced electricity supply is a key enabler of entrepreneurial activity, value creation and countries' attractiveness to investors, particularly in low income countries (World Bank, 2019b). Moderate tariffs are likely to stimulate the energy transition on condition that power and grid utilities generate sustainable revenue streams from their operations.

Since 2015, electricity prices in the manufacturing sector have fallen by 14% on average in about three quarters of countries (Fig. 6). While enhanced competition and reduced tariffs benefit end-users, they also reduce incentives for new market entrants and can be detrimental to low-carbon uptake, therefore putting the energy transition at risk.

Electricity prices are determined by multiple factors, including policy and regulatory measures such as carbon pricing schemes or capacity payment mechanisms. Also, surges in variable renewable power bring down spot prices, hurting the profitability of higher-cost conventional operators. Power market regulators also consider time-of-use tariffs, meant to encourage customers to shift their consumption to off-peak times and thus balance demand. In such evolving environments, traditional cost comparisons of technologies become less relevant (See Box 1).

Smart electricity pricing policies are key levers for the energy transition

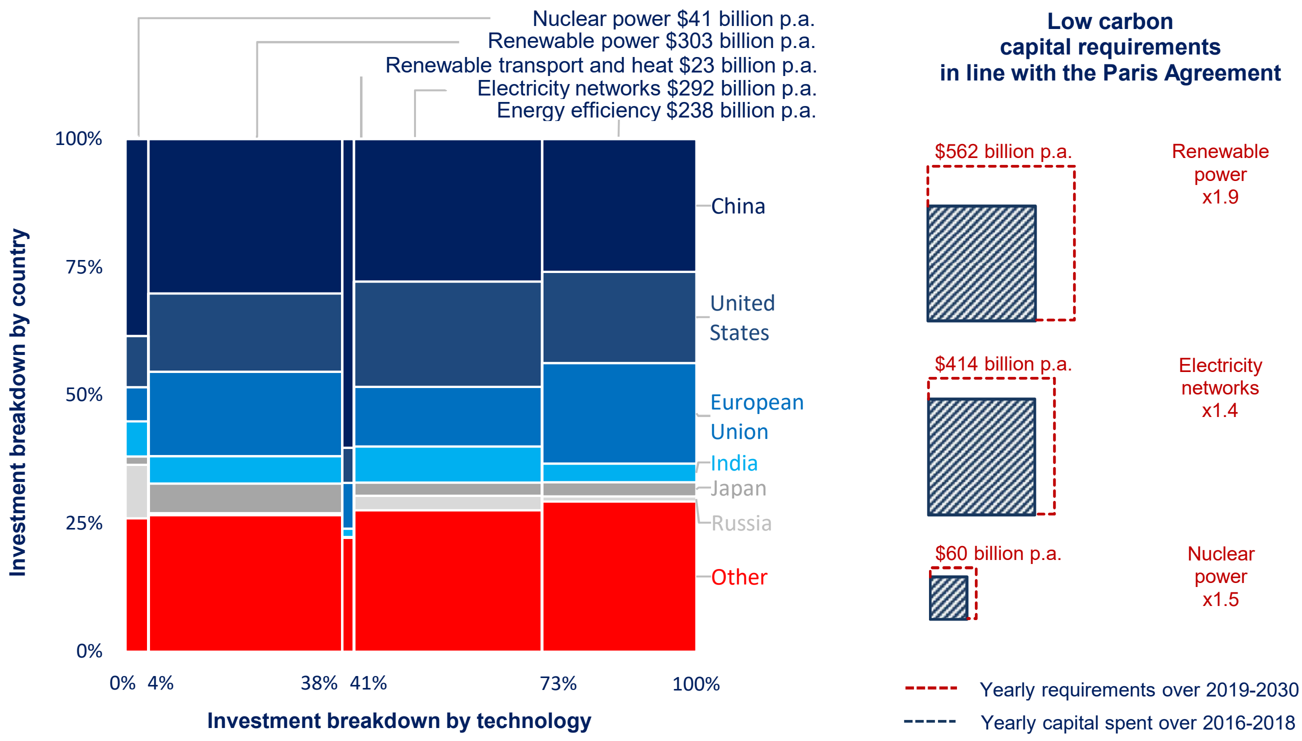
Figure 6. Electricity price changes by country between 2015 and 2018. Bubble size indicates the net increase in renewable installed capacity between 2015 and 2018.[9]

Box 1. Re-assessing the competitiveness of nuclear power: Beyond LCOE estimations

The Levelized Cost of Electricity (LCOE) measures a plant's average revenues over its lifetime relative to its total energy production. Traditionally, levelized costs of electricity (LCOE) have been used to measure electricity generation costs. LCOEs are suitable representations for baseload technologies operating under regulated markets but do not account properly for financial risk. Moreover, future energy systems are likely to incorporate large shares of variable renewable-based electricity, impacting the revenues of conventional baseload power operators. New metrics are emerging to assess the competitiveness of electricity sources more accurately and better reflect the value of system-wide ancillary services from the various power sources. Such services, which are either not or only partially remunerated, include the contribution to the security of domestic power supply, its reliability, as well as local and global environmental or health impacts. System costs for dispatchable technologies, including nuclear, are low, in the order of a few US dollars per MWh. By comparison, estimates for solar and wind technologies are in the order of a few tens of dollars per MWh depending on their generation shares and other system characteristics (NEA, 2019).

Water cooling availability or the exposure to extreme weather events will impact investment decisions and optimal mix determinations. Power operators will thus incur extra insurance and climate adaptation costs due to changing local environmental conditions. According to a recent study (McKinsey, 2019), each utility in the United States will face $1.7 billion in average economic losses by 2050 due to climate impacts. Smart grid-balancing measures will reduce overall system vulnerability but will influence technology competitiveness.

Figure 7. Global cumulative investments in low carbon technologies (annual average 2016-2018) and low-carbon power-sector requirements in line with the Paris Agreement (annual average 2018-2030).[10]



LOW CARBON FINANCE: NEED FOR UPSIZING AND DIVERSIFICATION

The destination of energy investment flows is a good predictor of the sustainability of future energy systems. The transition to low carbon electricity systems will gain more traction once capital disbursements make an across-the-board shift away from unabated fossil fuel energy.

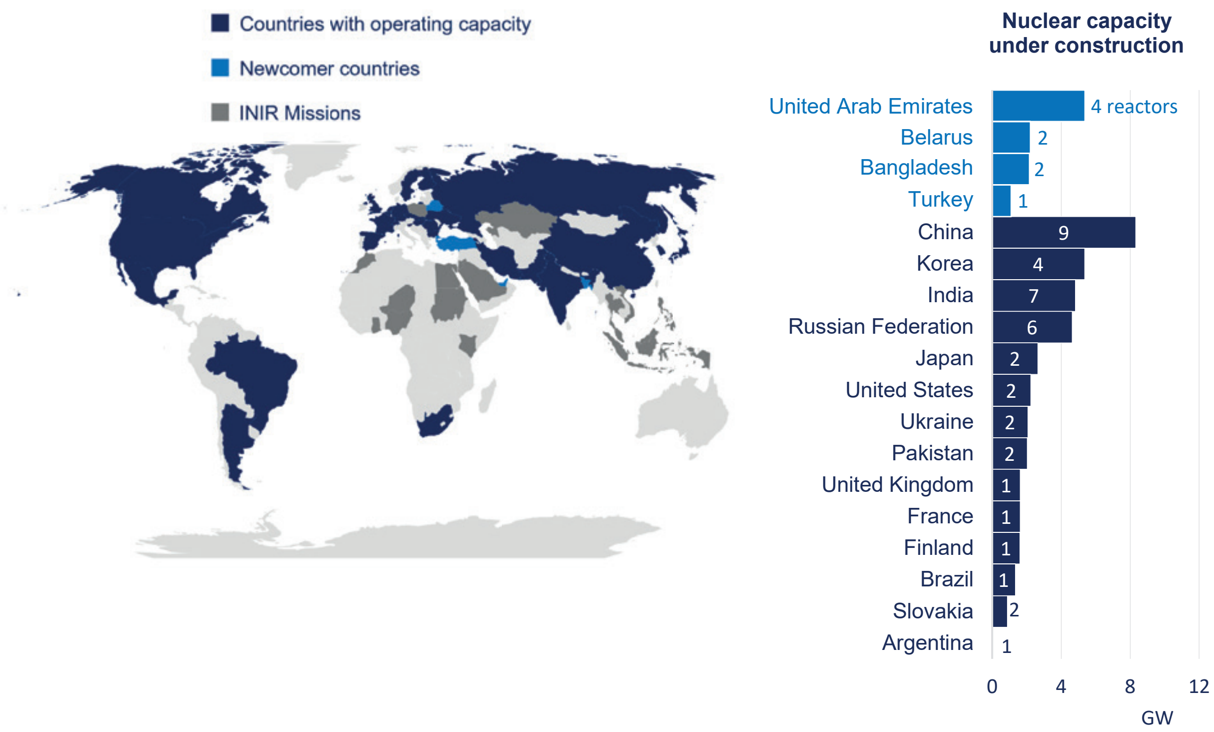
Since 2010, average fossil fuel investments in the power sector have been eroding at 15% yearly. However, almost $130 billion were still allocated to carbon power projects in 2018, i.e. a quarter of total power generation investments. Coal remains an attractive option in South Asia, South East Asia and Africa where the immediate necessity to fund new infrastructure is sometimes prioritized over energy sustainability goals.

Low carbon investments are progressively closing the gap with fossil fuel investments, thanks to favourable policies, technological advances and market forces. In 2018, clean energy investments, including spending on the extension and modernization of electricity networks, as well as energy efficiency measures, amounted to almost $900 billion. Between 2015 and 2018, average investments in nuclear and renewable energy totalled 38% of low carbon investments (Fig. 7). China and the United States, accounting for less than a quarter of the global population, received almost half of low carbon capital, suggesting some imbalance in climate finance allocation. Entrepreneurs addressing markets that are less attractive to international investors often face challenges to fund projects with domestic money. There is thus potential for improving the accessibility of climate finance mechanisms to underserved recipients, which are often disadvantaged by a lack of domestic capacity and resources to engage with complex accreditation requirements (UNFCCC, 2019).

Building climate-resilient energy systems would not necessarily come at considerable expense. If planned wisely, with a long-term orientation, a thorough sustainable energy strategy would only require 15% in extra investment overall, compared to unsustainable outcomes (IEA, 2018a), with especially large opportunities in emerging markets (IFC, 2016). Bold climate action, requiring 50% and 90% more capital for nuclear and renewable respectively through to 2030, may deliver at least $26 trillion in net economic benefits, equivalent to about one third of current world GDP (GCEC, 2018).

Low carbon investments are progressively closing the gap with fossil fuel investments

Figure 8. Countries with operating nuclear capacity, new nuclear programmes with plants under construction in "newcomer countries", or that have hosted IAEA Integrated Nuclear Infrastructure Review (INIR) missions since 2009; Nuclear projects currently under construction.[11]



NUCLEAR PROSPECTS: AN EVOLVING LANDSCAPE

The global appetite for cleaner energy solutions, associated with new market pressures, is shifting the geopolitics of energy, with deep implications in terms of country competitiveness, supply chains and innovation efforts (IRENA, 2019b). Nuclear is no exception. Market deregulation and the shale gas revolution are leading to early nuclear retirements in the United States. Some other countries with longstanding nuclear operations are currently considering downsizing their reactor fleets due to the burden of more stringent safety and security obligations, difficulty in financing large-scale, capital-intensive projects in deregulated markets, and a lack of public or political support. In many countries however, nuclear lifetime extension remains the most cost-effective way to generate cheap electricity. Each dollar invested in lifetime extension yields three times more electricity output than the same dollar invested in new builds. The return on investment for nuclear lifetime extension can also outweigh the return on new variable renewable capacity.[12] Revised pricing schemes, notably rewarding climate benefits, would restore nuclear competitiveness.

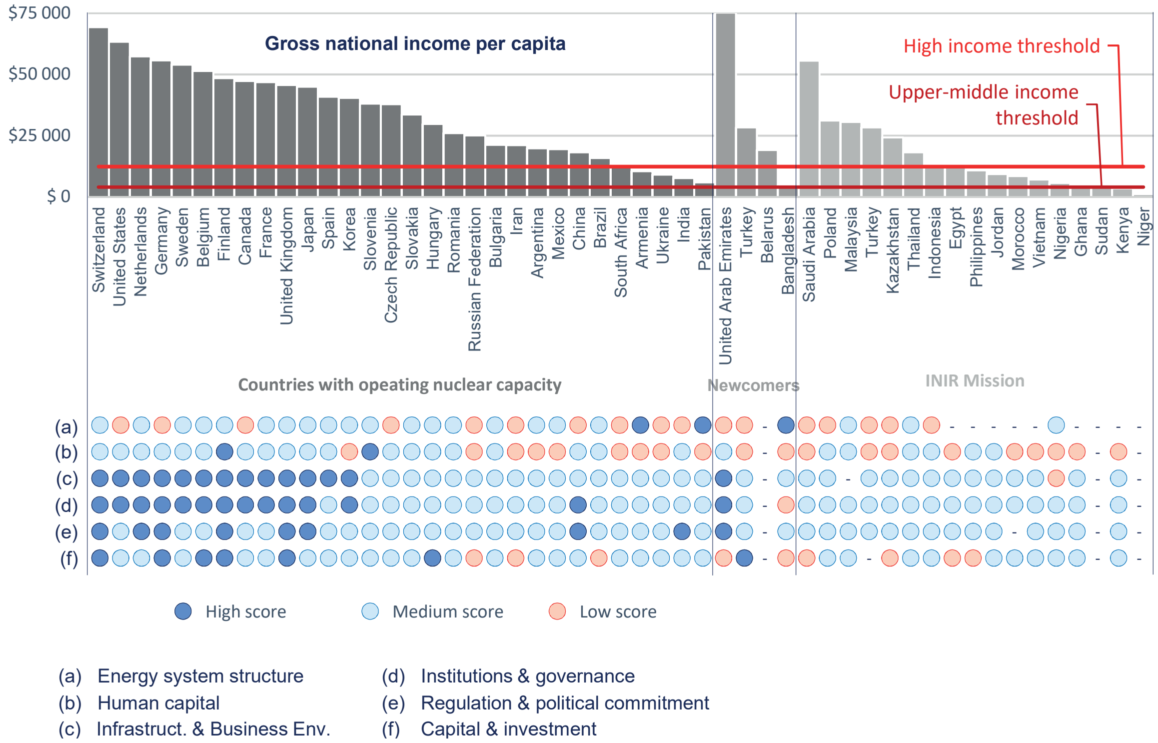
By contrast, some countries, often emerging economies with growing electricity needs, are developing their nuclear ambitions. Most of these countries feature regulated environments and public ownership of assets, thereby reducing investors risks. Regulated asset-based models, as envisaged in the United Kingdom, can also reduce the cost of raising private finance for new nuclear projects.

A total of 52 reactors are under construction worldwide, nine of which as part of new nuclear programmes spread over four countries (Fig. 8). In most cases, these nuclear plans have not yet been reflected in NDC submissions and climate pledges. So far, nuclear projects have not been eligible for funding from international finance institutions supporting climate action.

The portfolio of nuclear vendors has also evolved in recent years, with attractive value propositions from Russian, Chinese and Korean manufacturers. New cooperation agreements between major industrial and financial players are also emerging, as illustrated by the recent UAE-China initiative. Smaller, more modular nuclear designs, with pilot projects in Argentina, China and Russia, are also likely to reshuffle the cards further.

Emerging economies offer new prospects for nuclear power development

Figure 9. Per capita GDP (top panel) and World Economic Forum Energy Transition Readiness indicators (bottom panel) in selected countries with nuclear operations or plans, 2018.[13]



A LACK OF INCENTIVES FOR LOW CARBON SOLUTION DEVELOPERS

The World Economic Forum has created composite indices to measure each country's readiness to build more sustainable energy systems (WEF, 2019). The immediate market availability of a technology does not necessarily imply its adoption and deployment. Many levers can be activated to foster the energy transition. For investors and low carbon solutions developers to thrive, a conducive environment should also include the domestic availability of skilled labour, comprehensive and consistent regulatory frameworks, trustworthy governance, access to credit and freedom to invest.

Putting these conditions in place is a challenge in many countries, especially those in lower income ranges (Fig. 9). Governments have a central role to play to facilitate and coordinate the strengthening of these vectors of change.

Carbon pricing is the other indispensable instrument to accompany the decarbonization of electricity supply. (See Box 2).

Regulatory and financial frameworks are insufficiently conducive in emerging economies

Box 2. The missing link: Carbon pricing

Carbon pricing schemes are gaining traction among policy-makers as the physical and economic impacts of climate change are factored into their decision making. Forty-six national and 28 subnational jurisdictions are now implementing carbon pricing initiatives, which generated $44 billion of revenues in 2018 (World Bank, 2019c). Climate change is also driving new business and financiers' strategic orientations. Over 1,300 companies are using or planning to use internal carbon pricing in 2018-19. Despite these burgeoning initiatives, only 20% of global GHG emissions are currently covered by a carbon price, with carbon price levels generally far too low to deter fossil fuel investments.

Other ongoing reforms of the energy sector depend upon implicit carbon pricing measures, including reforms of subsidization of production and consumption of fossil fuels and other taxes.

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Endnotes

[1] Unless otherwise specified, low carbon electricity referred to in this document includes nuclear and renewable energy. Market shares of other low carbon potential sources, such as carbon capture, storage and utilization, are not yet significant enough to influence current patterns.

[2] Sources: UNEP (2019); IEA Sustainable Development Scenario in line with the 2°C objective of the Paris Agreement (IEA, 2018a).

[3] One country per income group is highlighted for the sake of illustration. Sources: IEA (2019a), World Bank (2019a). This analysis draws largely on data for a selection of 142 countries extracted from the IEA database on energy related CO_2 emissions, covering more than 99% of global CO_2 emissions from electricity and heat. Korea refers to the Republic of Korea. Country income groups are based on the 2018 World Bank classification: GNI per capita in low income countries was $995 or less in 2017; between $995 and $3,895 in lower-middle income countries; between $3,895 and $12,055 in higher-middle income countries; $12,055 or more in high income countries. https://datahelpdesk.worldbank.org/knowledgebase/articles/378834-how-does-the-world-bank-classify-countries

[4] Sources: IEA (2019); World Bank (2019a).

[5] Sources: IEA (2018b).

[6] Sources: IEA (2018b).

[7] In 2018, average capacity factors for wind and new utility-scale solar PV were respectively 34% and 18% (IRENA, 2019a).

[8] The potential for storage deployment in the next two decades lies within 220-540 GW depending on realized cost reductions (IEA, 2018a).

[9] Sources: IEA (2019a); World Bank (2019a).

[10] Sources: IEA *World Energy Investment* (2019d) and previous 2015-2018 editions; IEA (2018a).

[11] Since 2009, 26 IAEA Member States have hosted INIR missions for the different phases of developing a nuclear power programme. https://www.iaea.org/services/review-missions/integrated-nuclear-infrastructure-review-inir. Source for ongoing nuclear construction: IAEA PRIS database (2019).

[12] IAEA calculations based on IEA *World Energy Investment* (2018).

[13] Source: IAEA analysis based on World Bank (2019a) and WEF (2019).

Planning and Economic Studies Section
Department of Nuclear Energy
International Atomic Energy Agency
Vienna International Centre
PO Box 100, 1400 Vienna, Austria
Tel: +43-1-2600-22776, Fax: +43-1-26007-22529
Email: NE.Communication@iaea.org

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