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

Changing course in a post-pandemic world

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The clean energy transition has been too slow and progress too uneven to prevent the most severe impacts of climate change. But the COVID-19 pandemic forces decision-makers to change their course of action and prioritize green recoveries over unsustainable strategies.

Countries, financiers, innovators and the civil society are increasingly rallying around carbon neutrality objectives around mid-century. The years ahead will be decisive for climate action. Sustainable lifestyles are within reach if the challenges inherent to clean energy transitions are suitably anticipated.

Recent trends on the energy transition

From a global crisis to a global opportunity p.2

- Climate science underpins the considerable physical, social and economic benefits of reaching carbon neutrality by 2050.
- The shift to clean and secure electricity will lay the foundations for end-use electrification. Coal displacement is now a political priority.

Clean electricity roll-out: From marathon pace to sprint speed p.4

- The transition to clean electricity manifests itself in many markets but remains too slow for net-zero emission targets to be met on time.
- Thirty five percent of global electricity was supplied by low carbon sources in 2018. This share barely evolved over the past thirty years.

No more one-size-fits-all in an evolving nuclear landscape p.8

- Nuclear power provides predictable and reliable electricity in 32 countries and is a direct alternative to coal.
- At a levelized cost of $30-35 per MWh, extending the operation of existing nuclear plants by 10 to 20 years is one the most cost-effective low-carbon options.

Growing more with less: A sober electrification p.10

- The availability of clean electricity alone does not guarantee the sustainable transformation of the energy sector.
- Energy-saving measures are crucial to circumvent the burst of electricity consumption foreseen in many countries, often outpacing economic activity. Unmonitored electricity consumption would result in overinvestments and higher energy bills.

Topical issues on the energy transition

The impact of the COVID-19 outbreak on the electricity sector p.12

- The COVID-19 pandemic transformed the operation of power systems across the globe and offered a glimpse of a future electricity mix dominated by low carbon sources.
- The competitiveness and resilience of low carbon technologies have often resulted in higher market shares for nuclear, hydro, solar and wind power.

More flexible systems to enable the transition p.14

- Flexible electricity infrastructure revolves around regional interconnectors, dispatchable power generation units, including natural gas assets, pumped storage hydropower plants and nuclear plants operated flexibly.
- Energy storage and demand-response options are also indispensable to reach carbon neutrality.

Key features and drivers of the transition

Setting the global decarbonization in motion: All roads lead to carbon neutrality p.18

- Electricity production and end-use energy consumption require a swift displacement of unabated fossil fuels and a convergence towards clean energy technologies.
- By 2040, over 80% of electricity should be low carbon, more than double current levels.

From recovery packages to low carbon finance p.20

- The proposed energy plans in response to the pandemic remain largely at odds with climate goals.
- More than $600 billion are invested yearly in clean electricity infrastructures. Clean energy investments must double immediately to pave the way for carbon neutrality.

Linking up local pollution and climate change agendas p.23

- Local air pollution and climate change have common origins: unsustainable urban infrastructures. Clean power, clean mobility and efficient energy used in manufacturing improve air quality and reduce societal costs.
- CO_2 emissions are declining in high income countries but often continue to rise elsewhere. Populations living in lower income countries are particularly exposed to outdoor (and indoor) pollution.

Factoring the changing natural environment into investments decisions p.25

- Severe environmental conditions episodically affect infrastructures worldwide, at great economic and social expense for asset owners, insurers and local communities.
- Investing in built-in resilience of future energy systems to cope with a broader range of external shocks will largely offset risk mitigation costs.

Policy priorities

Aligning actions to *build back better* p.26

- Governmental leadership and institutional initiatives, incl. the establishment of sustainable finance taxonomies based on objective, transparent and science-based criteria, are critical to boost low carbon investments.
- Green recovery measures are expected to stimulate employment and economic activity. Social and inequality concerns inherent to the transition must be tackled to ensure successful and just outcomes.

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

Changing course in a post-pandemic world

The electricity sector[1] acts as a catalyst for an economy-wide transition to a low carbon, climate-resilient and sustainable future. This document shines a light on the nature and pace of the ongoing transition to low carbon electricity systems, takes stock of the immediate impact of the COVID-19 pandemic, and weighs prospects for accelerating the transition post-pandemic. Will 2021 be a pivotal year for the energy transition?

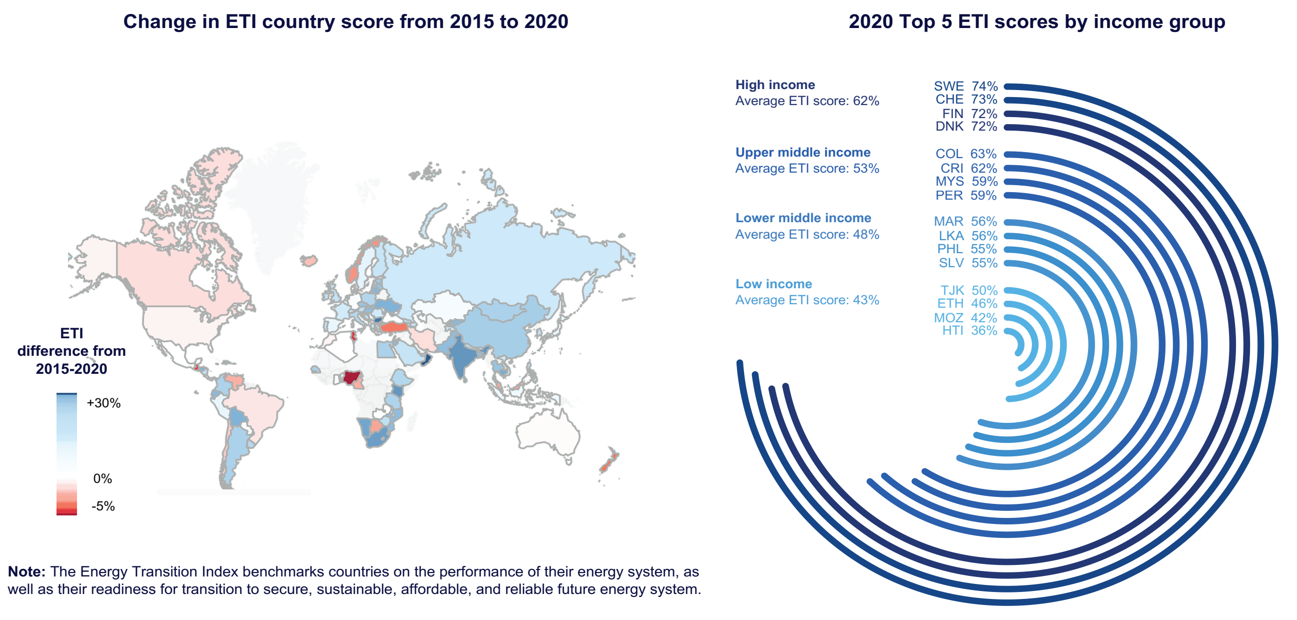
FROM A GLOBAL CRISIS TO A GLOBAL OPPORTUNITY

A year into the pandemic and a gradual recovery in sight. The social and economic shockwaves generated by the COVID-19 outbreak laid bare the vulnerability of our societies and created one of the deepest economic recession in generations. Governments and the health sector turned to scientific evidence to design and coordinate their responses. The World Bank and the IMF foresee an uneven and uncertain recovery for 2021 and beyond, and warn that the crisis hit the poorest nations hardest (Gopinath, 2021; Malpass, 2021), affecting their ability to respond to another looming challenge: the climate emergency.

A year for decisive climate action. Preliminary data for 2020 points to a temporary drop in global CO_2 emissions but also a net increase in overall greenhouse gas emissions despite the economic slowdown (WMO, 2020). A wide mobilization of scientific and financial resources is thus as urgent as necessary if the world is to avert the most severe impacts of climate change on our living environments. With firmed up political ambitions, the emergence of integrated low carbon solutions and harmonized corporate strategies, the year 2021 can culminate at the UN climate change conference in Glasgow with landmark outcomes.

Public and private leaders of the energy transition rally around high-stake opportunities to accelerate the recovery through clean energy adoption and pave the way to carbon neutrality. But countries' progress and access to these opportunities remain contrasted. The evidence compiled in this document points to a gradual and partial transformation of the global energy landscape, as confirmed by the World Economic Forum (WEF): The *Transition Readiness* index reveals incremental progress in 94 of the 115 countries monitored over the past six years (Fig. 1). High income countries appear best prepared to pursue the domestic rollout of clean energy as they are to weather the consequences of the pandemic. But fast progress is also observed in South Asia, Southern Africa and Latin America, albeit starting from a lower base. The pandemic did not alter the fundamentals underlying WEF country scores. The success of a green recovery, possibly giving new impetus to the energy transition, will depend greatly on governments' ability to set radical goals, implement policy reorientations and opt for sustainable supply chains across the entire energy sector.

Figure 1 – World Economic Forum Energy Transition Index[2]



Note: The Energy Transition Index benchmarks countries on the performance of their energy system, as well as their readiness for transition to secure, sustainable, affordable, and reliable future energy system.

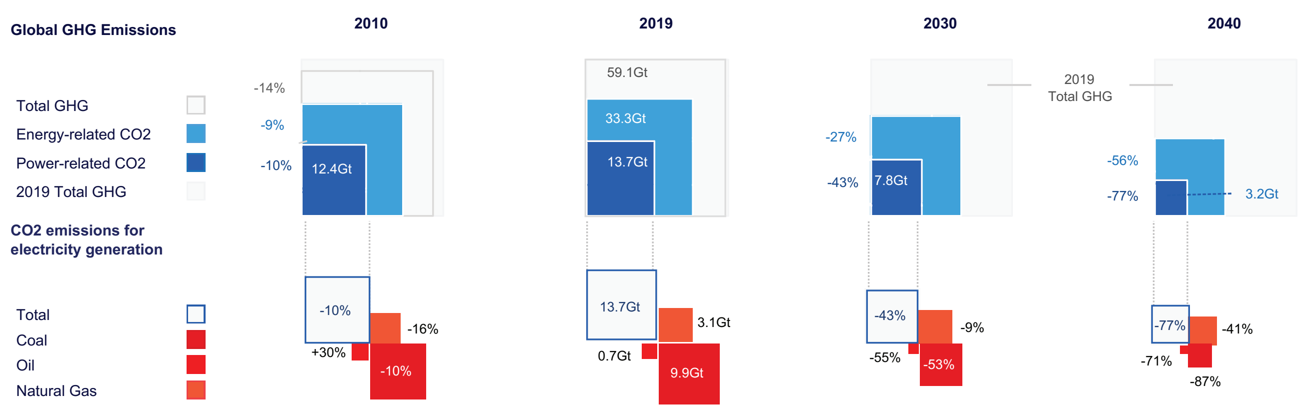
Recent findings from climate science underpin the considerable physical, social and economic benefits of limiting the global temperature increase well below 2°C. A strict management of our carbon budget is of the essence. Ongoing trends suggest a temperature rise in excess of 3°C before the end of the century. At current levels of global greenhouse emissions, our carbon budget would be exhausted in about a decade, triggering warming beyond 1.5°C irremediably (with one in two chances) (IPCC, 2018). Our energy systems rest on regular boundary conditions of water availability and temperature. Higher atmospheric temperatures would raise the odds of extreme rainfalls, flooding and droughts, eventually impeding the reliability of energy services; cooling demand in cities would soar, amongst other and numerous impacts. The Race to Zero, initiated by the UNFCCC, must therefore gain momentum. A quarter of greenhouse emissions expected by 2030 could be avoided with the sole implementation of unconditional Nationally Determined Contributions announced before the pandemic (UNEP, 2020a).

Policy makers gradually embrace holistic approaches to decarbonization, addressing all energy producing and consuming activities, but also governmental aspirations in favour of a just transition. The climate action instigated by individual countries is more and more embedded in inclusive strategies aimed at generating income and employment, in line with other industrialization objectives. Comprehensive policy frameworks, based on fiscal, financial and other social protection measures, as well as behavioural and sector coupling policies, are necessary to create the conditions for a just and cost-effective transition (IRENA, 2020a). Early adoption of low carbon measures and a progressive shift away from fossil fuels is expected in high income countries. Other jurisdictions with more limited financial and human resources means will see a more progressive implementation. Recent country pledges suggest that carbon neutrality may be reached by the wealthiest nations around mid-century and a decade later elsewhere through piecemeal approaches compatible with economic development.

The adoption of low carbon technologies will materialize as solutions gradually reach market maturity. The shift to clean and secure electricity will lay the foundations for end-use electrification. Coal replacement has become a political priority. Clean electricity is an indispensable precursor to carbon neutrality in other sectors (Fig. 2). Electricity-related emissions, trending upward for decades, must now drop by at least 6% every year through to 2030. In addition to nuclear and hydro, various clean electricity options have reached mass market in recent years ; their deployment can be immediately accelerated to replace uncompetitive coal assets, at the origin of two thirds of power-related emissions (SystemIQ, 2020). A coal-to-clean energy transition could generate over $100 billion in net financial savings as early as 2025. But a clear path to phaseout, including the refinancing of existing assets, is lacking (RMI, 2020).

The remainder of the document depicts ongoing trends and initiatives in support of the energy transition, including the overall impact of the COVID-19 outbreak on electricity systems. The emphasis is given on immediate opportunities for cleaner electricity in various economic contexts and in an evolving financial landscape. Some of the key enablers of the transition, including various options for flexible operations, are illustrated through selected examples. Broader policy drivers are also discussed, such as air pollution and the vulnerability of energy infrastructures exposed to harmful climate conditions.

Figure 2 – Illustrative transition to low carbon power systems in line with the Paris Agreement; 2019 serves as the reference year[3]



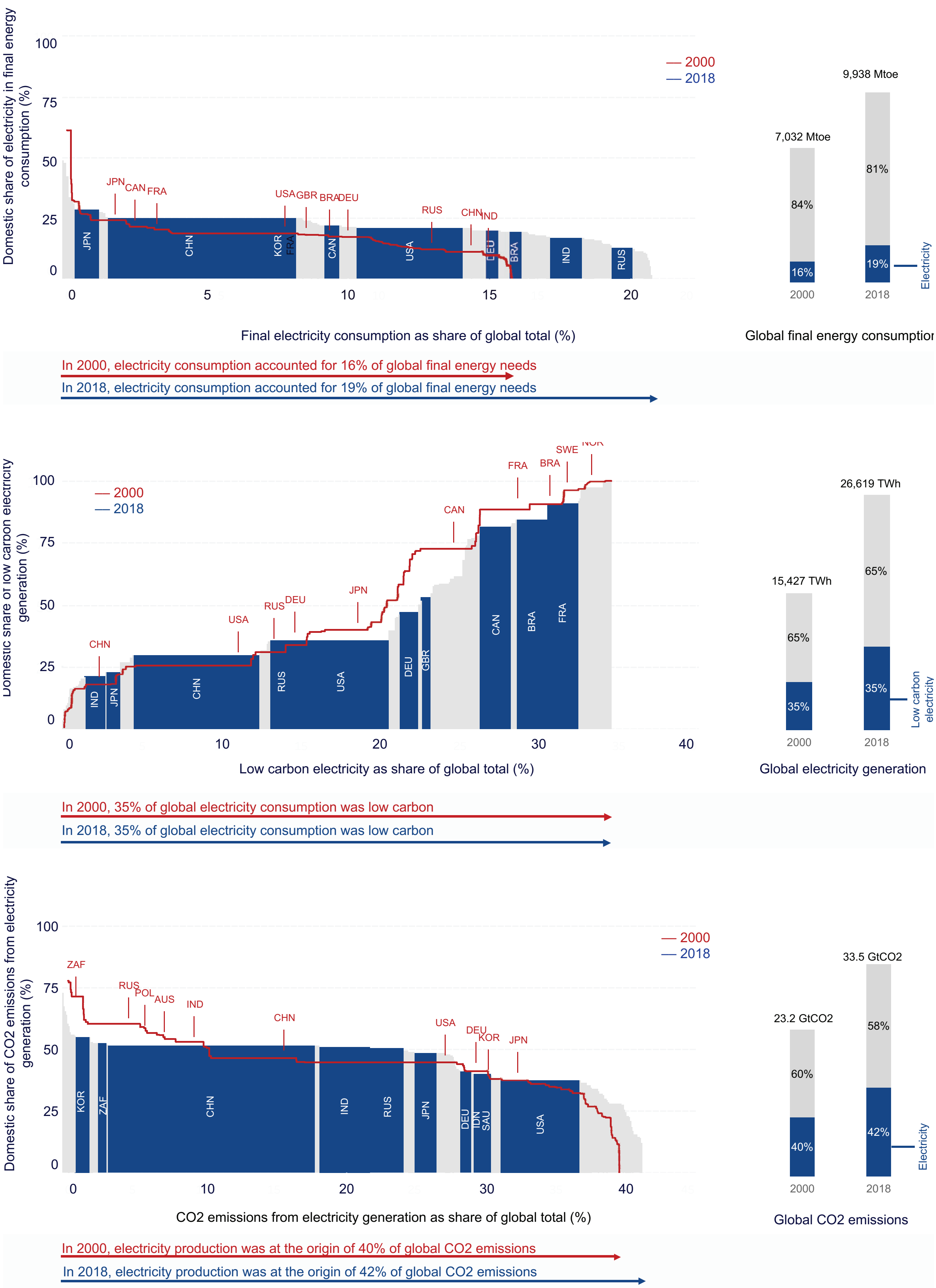
Clean electricity is on its way to replace fossil fuels and become the main driving force of economic, social and environmental progress. The switch to clean electricity is manifest in many markets but remains too slow for net-zero emission targets to be met on time. Among the main energy carriers, electricity is growing the fastest confirming a general trend towards electrification of energy use. A fifth of energy consumption is electric, leaving vast opportunities for fossil fuel displacement in final consumption sectors (Fig. 3, top panel). Electricity usage has levelled off in North America, Europe and other high-income regions thanks to effective energy-saving measures and moderate economic growth. By contrast, consumption grows swiftly in fast-growing economies, resulting in an acceleration of global electricity needs (on average +2.7% every year since 2010). Thirty five percent of global electricity was supplied with low carbon sources in 2018 (Fig. 3, mid panel). This share barely evolved in more than thirty years. Growing at an average 3.8% each year during the last decade, and 5% in the last five years alone, the expansion of low carbon electricity only makes up for the incremental electricity needs but remains insufficient to alter the sector's emissions perceptibly. Electricity generation is responsible for 42% of global CO2 emissions, another stable figure for more than two decades (Fig. 3, bottom panel).

Progress is unevenly distributed across income groups. Contrasted realities and prospects for rapid evolution stem from current market drivers and other legacy assets, chief among them are inefficient coal power plants. High income countries tend to have relatively lower carbon footprints of electricity largely as a result of early investments in hydro and nuclear power capacities. The carbon intensity in high income countries operating nuclear capacities is generally among the lowest, averaging 300 grams of CO_2 per kWh, and as low as 50 grams in Sweden (Fig. 4).Average intensities in other income groups are closer to 500 grams. In 2018, half of the low carbon electricity in countries with nuclear assets was produced from nuclear power plants. However, clean power progresses half as fast in high income countries as in lower income groups (resp. 3% and 7% on average since 2015). Rapid improvements in carbon intensities were realised in upper-middle to lower-middle countries, thanks to higher environmental standards and policy reforms such as fossil fuel subsidy removals, direct public support for low carbon programmes and waves of inefficient coal plant shutdowns. Strong policies, the development of local supply chains and enough production capacity to address both domestic needs and markets overseas have established China as the global leader of clean power manufacturing. The year-on-year change in low carbon power approaches 11% in China while electricity consumption progresses at more than 7%. At current rates of market penetration, about thirty years would be necessary to reach 100% low carbon electricity in China and almost fifty years globally, way too late to avoid severe hardships resulting from climate change (IPCC, 2018).

Non-dispatchable electricity sources are now on par with most conventional sources in many markets, stimulated by major technological advances and cost reductions as well as robust regulatory frameworks. Comprehensive policy and regulatory frameworks, indispensable to accelerate the clean energy transition, are now in place in a majority of countries (World Bank, 2020b). Direct mechanisms in support of renewable expansion are wisdespread, inlc. fiscal exemptions (e.g. production tax credits or investment tax credits), and various mechanisms to guarantee operators' revenues independently from market conditions. Auctions are often preferred options to identify the most competitive vendors. The enforcement of such measures has created favourable conditions for the uptake of modern renewable energy in a wide range of countries across all income segments. The surge in low carbon electricity from onshore wind and solar PV, but also small to mid-size hydropower projects, has resulted in a doubling of renewable capacities since 2010. On average, 200 GW of renewable capacity is installed yearly, incl. 100 GW of solar, 50 GW of wind and another 20 GW of hydro (IRENA, 2020b). Solar and wind sources now supply 7% of global electricity. In 2018, solar and wind supplied half of clean electricity in 27 countries. By comparison, hydro and nuclear account respectively for 16% and 10% (IEA, 2020b).

Clean energy leapfrogging is increasingly within reach for low income countries thanks to adapted solutions and innovative finance. But some bottlenecks remain for the transition to be fully inclusive. Distributed and renewable electricity access and mobile payments are accesible to the most vunerable populations. But stark regulatory discrepancies between the wealthiest and the poorest nations remain. Financially unhealthy power utilities, "the main off-takers of renewable energy and principal implementers of energy efficiency programs", should be at the centre of governments' attention (World Bank, 2020b).

Figure 3 – Domestic vs global distribution of final consumption of electricity by country (Top panel); Low carbon electricity by country (Mid panel); Electricity-related CO2 emissions by country (Bottom panel), 2000-2018. Top 10 contributors are highlighted in blue.[4]



The integration of large volumes of non-dispatchable electricity creates a challenging environment for investors and operators. Low operating costs characterizing wind and solar energy result in growing market price volatility and pose significant risks for investment in capital intensive technologies. Nuclear operators are directly exposed but large offshore wind and solar thermal developers are not exempt and can have risky profiles to private financiers as well.

The observed decline in fossil fuel generation in early stages of the COVID-19 pandemic, as well as frequency deviations observed early 2021 in the Continental Europe synchronous area, drew attention to additional grid stability challenges likely to emerge further into the energy transition. Replacing heavy rotating steam and gas turbines with variable renewables leads to a loss of inertia in the electricity system, and may result in greater instability, poorer power quality and increased incidence of blackouts. Large nuclear plants can alleviate the risk of supply disruptions in fully decarbonized electricity systems. Grid managers without nuclear or natural gas capacities at hand are gradually turning to synchronous condensers and storage solutions to integrate non-dispatchable renewable energy. New business models and revised pricing rules are foreseen to support this trend.

A wider adoption of carbon pricing regimes and fossil fuel subsidy reforms can be transformative for the power sector. But concerns persist regarding the choice of instruments, the sectoral scope, their practical implementation, and the economic and social impacts. 46 national and 35 subnational jurisdictions, representing 22.3% of global GHG emissions, have already integrated carbon pricing in their portfolios, through either direct taxation or tradable emission rights and other implicit charges stemming from regulatory standards (World Bank, 2020c). For instance, Swedish utilities and end-users have been facing a combination of market and fiscal instruments for years. With these instruments in place, and large hydro and nuclear capacities, the Swedish electricity is among the most carbon sober in the world. National emissions dropped by 25% and the economy grew by 60% since the carbon tax introduction in 1991, demonstrating the environmental and economic effectiveness of carbon penalties. Corporate decisions are also increasingly driven by internal climate objectives and carbon prices. Finally, reforms of fossil fuel subsidies were conducted successfully in many countries across all levels of income, e.g. Nordic countries but also Argentina, Costa Rica, Ethiopia, India, Indonesia and Zambia.

Figure 4 – Carbon intensity of electricity by income level, 1990-2018[5]

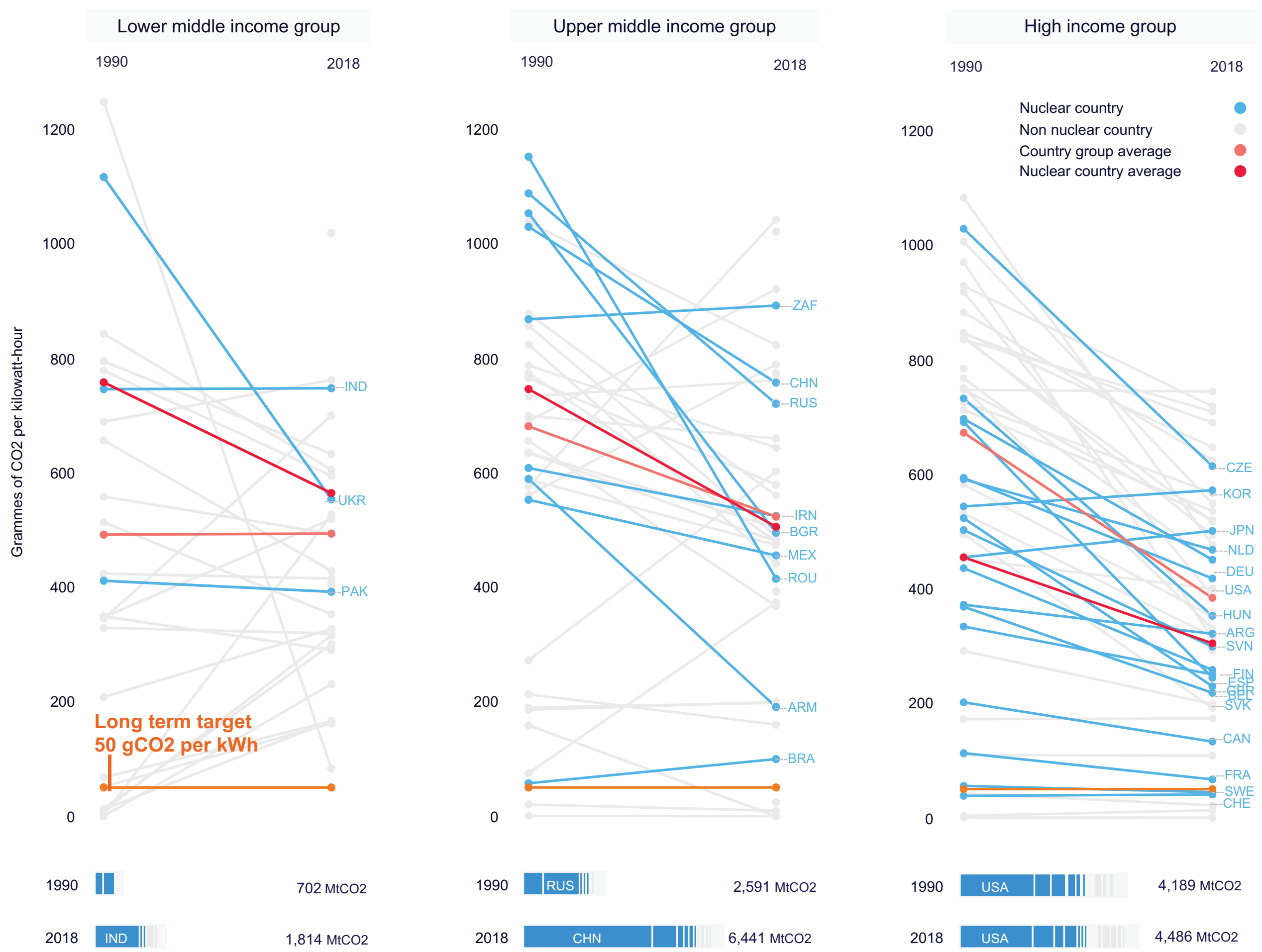
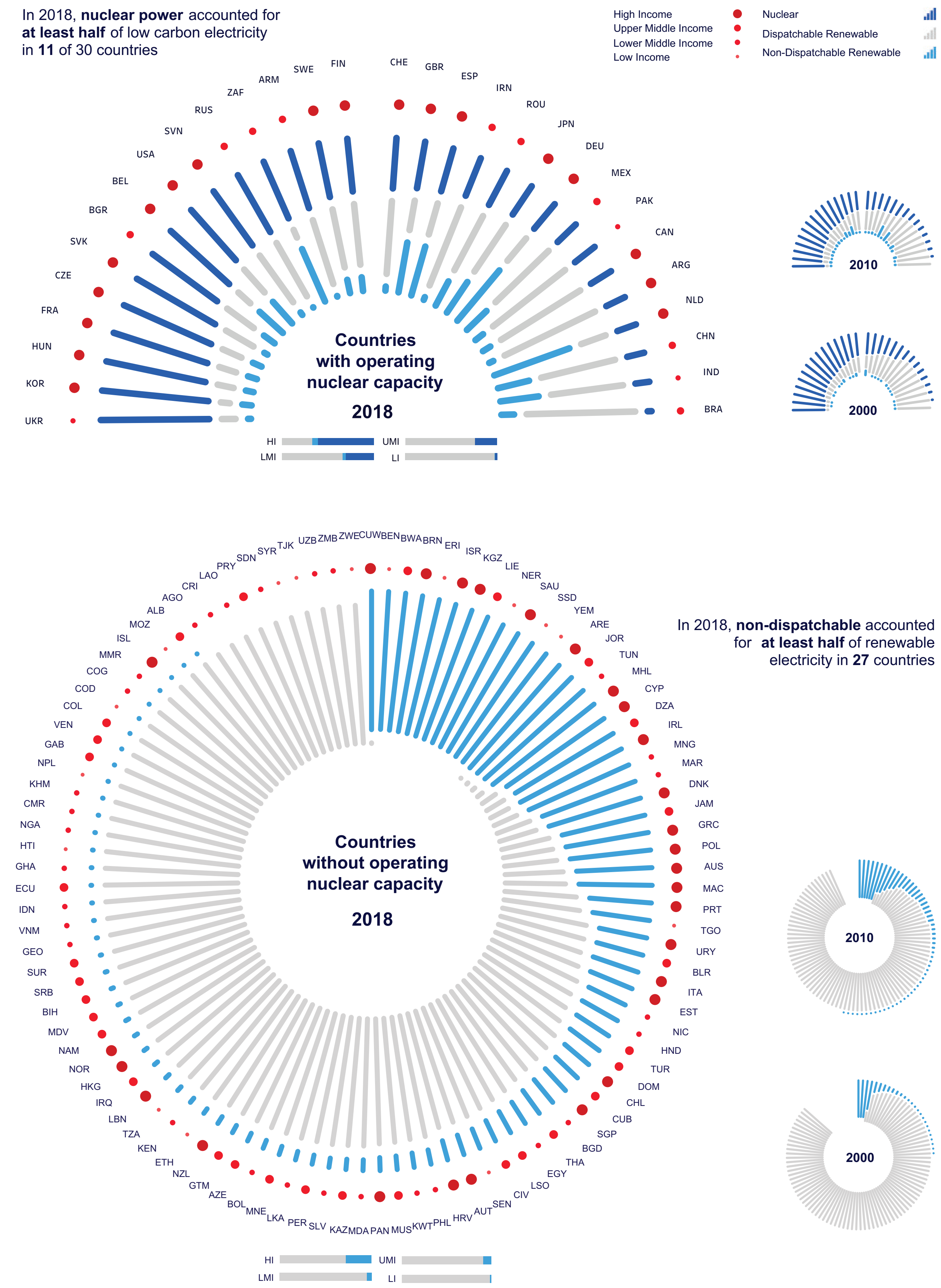


Figure 5 – Breakdown of low carbon electricity by country, 2018[6]



Note: High income= HI, Upper middle income = UMI, Lower middle income = LMI, Low income = LI

The merits of nuclear power and its place in the achievement of carbon neutrality are generally acknowledged. The extent to which nuclear power can favour the transition will depend on the industry's ability to bring costs down, accelerate innovation and garner enough public support. In 2019, the nuclear capacity installed globally saw a net decline of 4.5 gigawatts as the permanent shutdowns confirmed in Japan offset new grid connections elsewhere (IAEA, 2020a). But increased capacity factors, notably in the United States, helped maintain global power generation levels. Nuclear fleet extensions are at various stages of advancement in 16 countries while 5 new nuclear programmes are in the construction phase (Fig. 6). The centre of gravity of nuclear operations is swiftly moving towards Central and Eastern Europe and Asia at large.

The traditional economic model of nuclear power is challenged by liberalised electricity markets in which many plants operate, by the diversification of power mixes as well as the rapidly evolving policy, regulatory and technological landscape. Nuclear power provides predictable and reliable electricity, providing 32 operating countries with a secured supply of electricity. The need for flexibility in electricity generation and system management – a trend accelerated by the pandemic – will increasingly characterize future energy systems over the medium to longer term. Improved frameworks for remunerating reliability, flexibility and other services would favour nuclear operators.

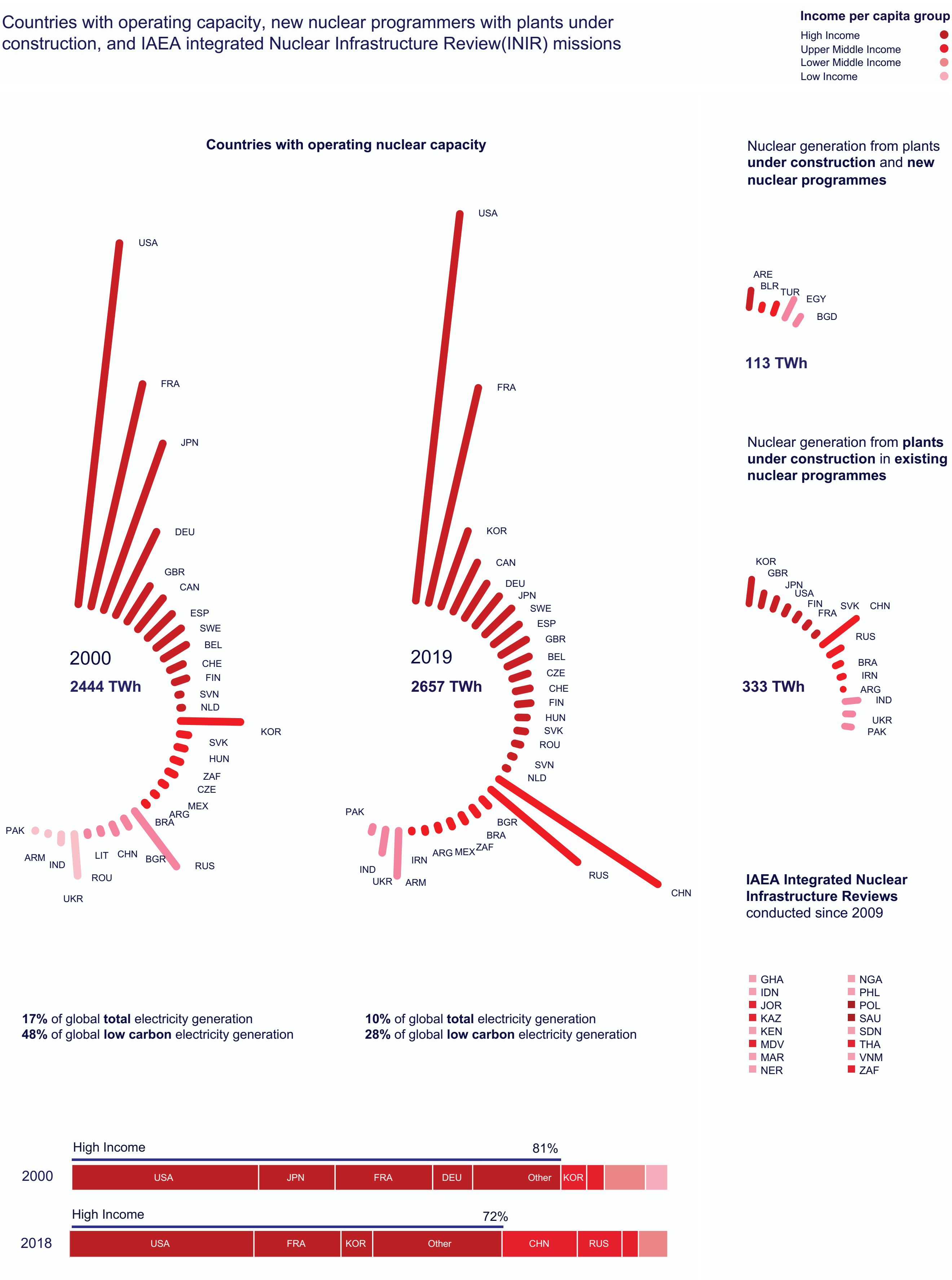
The climate imperative and a wider value proposition for better market adequacy may boost nuclear developments in the mid-term. The historical contribution of nuclear power to low carbon electricity is widely acknowledged, nuclear power remaining the second largest source of clean electricity globally. A single gigawatt-scale nuclear project can dramatically improve climate compliance in mid-sized countries, as shown by the recent start of United Arab Emirates's nuclear programme which will eventually supply a quarter of national needs with clean power. Nonetheless, a certain lack of governmental and policy support prevents nuclear energy from meeting its full mitigation potential. The inclusion of nuclear in taxonomies to channel sustainable investments could encourage potential investors (OECD, 2020). Small modular reactor designs draw attention in many countries seeking a quick transition to low carbon power but with limited financial and physical capacity to absorb larger projects. Fast tracking the manufacturing, shipping and installation of modules is expected to accelerate commercialization.

Construction risks and capital costs can undermine the financeability of nuclear projects in liberalised markets. Tailored fiscal support and risk transfer schemes to restore competitiveness are under examination. Financial innovation will be critical to overcome project risk and fiscal burden associated with delays in project delivery and cost overruns (NEA, 2020a). Risk premiums can be substantial. In the case of UK's Hinkley Point, where a contract for difference guarantees the operator's revenue irrespective of wholesale market conditions, risk premiums account for more than a third of the strike price approved by the government (£36 per MWh) (NSD, 2020). The proposed Regulated Asset Base model aims at transferring risks to consumers with enhanced government protection during the construction phase and could serve as a model for other projects worldwide (UK BEIS, 2020).

Maintaining and extending the safe operations of existing plants preserves clean power capacity, is economically sound and could, as such, be incorporated into COVID-19 recovery packages to boost local economies and foster the transition. Nuclear supply chains are generally considered valuable vectors of local economic development and job creation: Every million-dollar invested in nuclear creates four jobs (IEA, 2020d). With a supportive investment environment, a 10-20-year licence renewal can be realized at a levelized cost of around $30-35 per megawatt-hour, placing it among the most cost-effective low-carbon options, while maintaining dispatchable capacity (NEA, 2020b). Without such extensions, 40% of the nuclear fleet in developed economies may be retired within a decade, adding around $80 billion per year to electricity bills (IEA, 2019). Long term operation is common in the United States with most licences renewed for 60 years, four reactor licences subsequently renewed to 80 years and others set to follow. France's Grand Carenage programme aims at 10 to 20-year extensions for an estimated cost of EUR45-50 billion.

The nuclear industry has yet to find its niche in the supply of new services, including opportunities in a nascent hydrogen economy. Several business models are being designed. Arizona's public power utility is looking to produce hydrogen from its nuclear plant, blend it with natural gas to fuel another of its plants, and thereby optimize its production and reduce its overall carbon footpint. Alternatively, the UK Clean Energy Hubs in Sizewell and Moorside are fully-integrated propositions, conceived in partnership with local energy users, linking emerging technologies such as low carbon hydrogen and energy storage.

Figure 6 – Nuclear electricity generation by income group, 2000 and 2019. Estimated annual electricity generation from nuclear power plants currently under construction[7]



Note: Anticipated nuclear generation from reactors under construction

Electricity demand is set to become one the main indices of energy transformation. Contrary to most mature economies where consumption growth has come to a halt, electricity remains an essential driver of development in fast-growing economies. In high income countries, the yearly consumption of electricity per capita now lies above the 9,000 kWh mark, a slight decline since 2010, but also a 12% increase compared to levels observed in 2000 (Fig. 7, upper panel). Setting carbon neutrality goals may delay the saturation in consumption across all income segments. By contrast, consumption keeps growing in lower income countries, spurring industrialization and the emergence of middle class populations with increased ownership of electrical appliances and other electronic devices. Each year, the average individual consumption of electricity rises around 3% (resp. 4%) in upper-middle (resp. lower-middle) income countries. Per capita electricity consumption in China and India have reached respectively 5,000 kWh and 1,200 kWh per year but growing significantly faster than their peers in their respective income groups. The annual rate of progress has been closer to 2% in the lowest income countries where large electrification gaps – and deficient existing infrastructures – are closing only gradually.

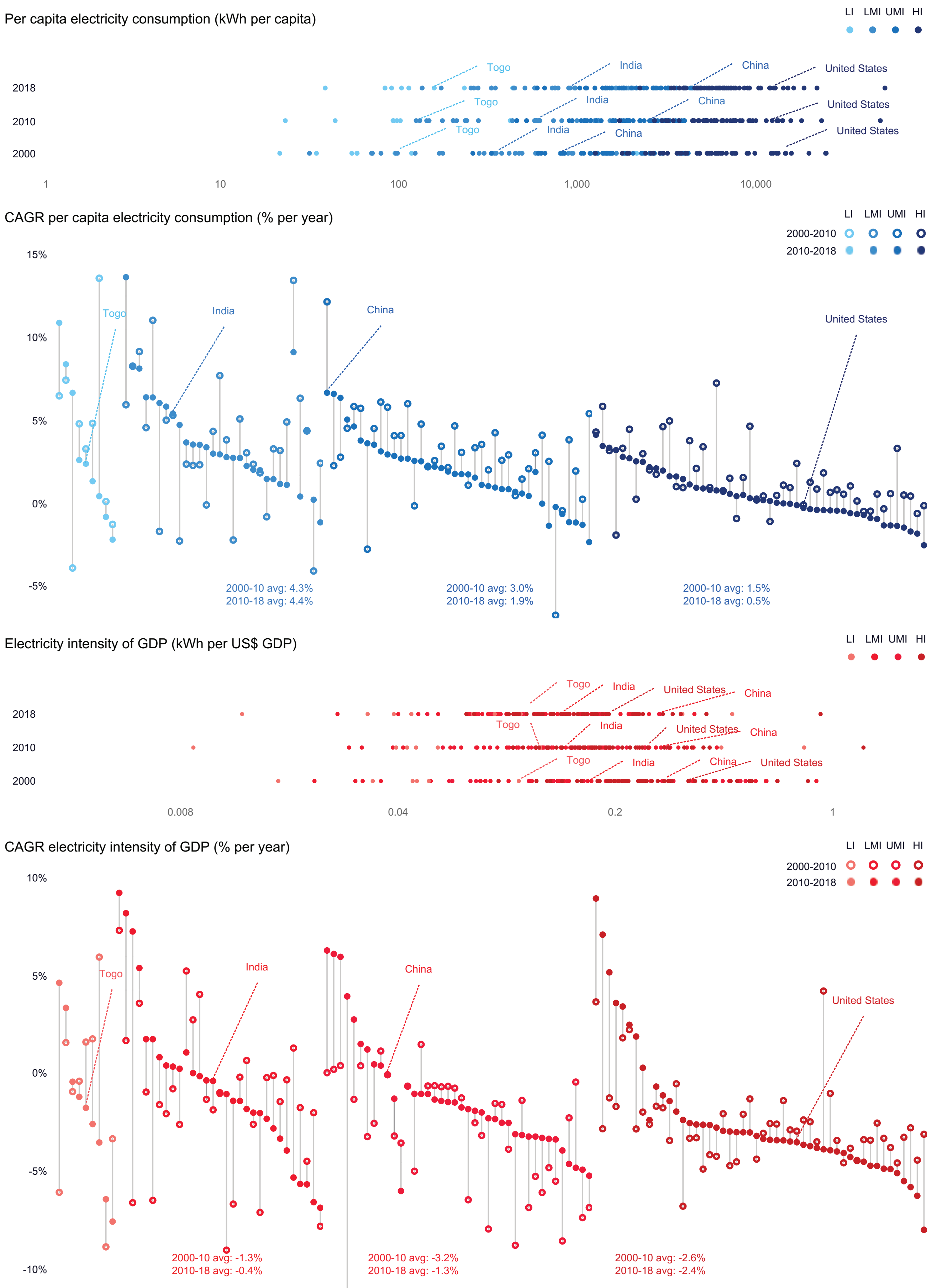
Access to reliable electricity allows economies to flourish and living standards to improve. The adoption of high-performance electrical equipment is also deemed good value for money. A quick access to electricity services, simplified administrative procedures, moderate and transparent tariffs, are vital for businesses to thrive (World Bank, 2020d). Frequent power outages and non-cost reflective tariffs, often the result of chronic under-investments, are common in lower income economies and can be particularly harmful to local entrepreneurial activity.

Electricity consumption is accelerating in many countries, often outpacing economic activity (Fig. 7, lower panel). Every dollar generated globally embeds roughly 23 kWh of electricity. The decoupling between electricity and GDP was sizeable two decades ago but has been slowing down more recently. Since 2010, the electricity intensity of the global economy has been growing at 1% per year (1.8% in upper-middle countries). Generalizing the electrification of end-use, either directly (potentially supplying 65% to 70% of final demand according to ETC, 2020) or indirectly through e.g. water electrolysis for hydrogen production (potentially 15-20% of energy needs), is likely to boost electricity consumption worldwide. Policies, fiscal incentives and wider value propositions from car manufacturers are boosting electrification of ground transportation, now considered a major source of value creation in the near term. Low-carbon electricity-based solutions also have the potential to eliminate emissions from cement, steel, plastics and aluminium production and increase industries' profitability. This trend may leave consumers better off given the small portion of electricity in the total cost of finished products. Plug-to-wheel consumption of battery-powered electric vehicles could be 73% lower than tank-to-wheel consumption of a typical gasoline car. Similarly, the tonne of green steel may increase by 20% but adding only $180 to the price of a car (ETC, 2020).

However, the sole availability of clean electricity does not guarantee a sustainable transformation of the energy sector. Unmonitored electricity consumption would result in overinvestments and higher energy bills, eventually altering the economic benefits of the energy transition. Anticipating realistic future needs is critical to schedule the cost-effective upgrade of energy infrastructures. The EU *Strategy for Energy System Integration* addresses the issue by placing the emphasis on more circular energy systems with an "energy-efficiency-first" principle (EC, 2020).

Tailored incentives and mandates, which are necessary to optimize electricity production and moderate consumption, remain the blind spots of existing policy frameworks. Incentives and mandates are decisive for power and grid utilities seeking efficiency gains and managing demand-side measures. But progress in regulatory frameworks is reportedly slow and penalties in case of non-compliance are often lacking, including in high-income countries (World Bank, 2020b). Public budget financing, consumer surcharges, combined with optimized time-of-use rate structures, can be used to compensate for revenue losses induced by mandated energy efficiency activities but are implemented too sporadically. Incentives and mandates can also be beneficial to large industrial and commercial consumers. But a lack of awareness and inadequate energy management programmes prevent the full optimization of electricity usage. Other incentives for further energy efficiency gains can be applied to public procurement rules with a binding obligation to track realized savings in public administrations and other types of institutional infrastructures.

Figure 7 – Per capita electricity consumption and electricity intensity of GDP by income group, 2000-2018[8]



Note: High Income=HI, Upper middle= UMI, Lower middle=LMI, Low income=LI; CAGR = Compound Annual Growth Rate.

The COVID-19 pandemic transformed the operation of power systems across the globe and offered a glimpse of a future electricity mix dominated by low carbon sources. The systemic economic and social impact of the COVID-19 outbreak, and the accompanying responses, have led to an unprecedented and sustained decline in demand for electricity in many countries, of the order of 10% or more relative to 2019 levels over a period of a few months, thereby creating challenging conditions for both electricity generators and system operators (Fig. 8, left panel). Early IEA projections anticipated a 2% reduction in global electricity usage for the entire year 2020, with a record 5.7% decline foreseen in the United States alone (IEA, 2020d).

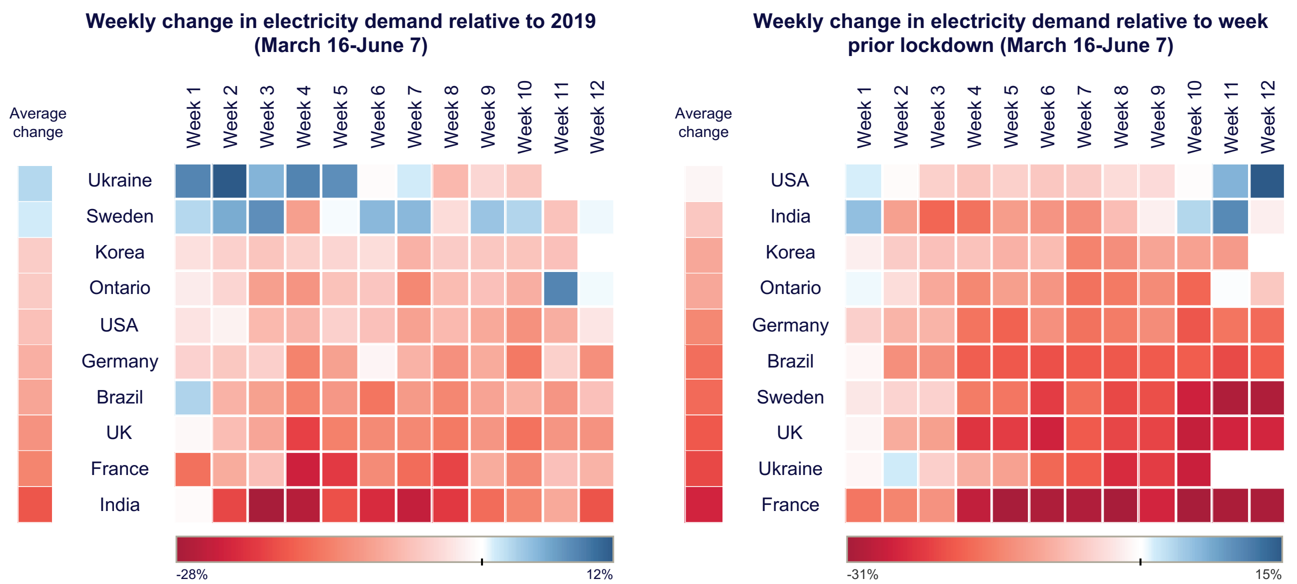
Electricity generation from fossil fuels has been particularly hard hit, due to relatively high operating costs compared to nuclear power and renewables and simple merit order effects. By contrast, low-carbon electricity prevailed during these extraordinary circumstances. In the first weeks of the lockdowns, the contribution of renewable electricity rose in many countries thanks to low operating costs, priority dispatch and favourable weather conditions (Fig. 8). Along with other measures, including curtailment of renewable generation in some cases, this has enabled grid operators to maintain a reliable system and largely avoid supply disruptions despite the challenging conditions, while also accommodating increased shares of low-cost, variable renewable generation.

The contraction in electricity demand during the first lockdown accelerated recent reductions in electricity prices, below already economically-unsustainable levels. The most noticeable impacts of the pandemic on the power sector occurred during the first period of global lockdowns. Then economic activity – and electricity markets – resumed to more regular conditions. The large price drops in Europe resulted from not only COVID-19 lockdown measures from March to June 2020, but also collapsing demand due to an unusually warm winter, increased supply from renewables, and a slump in commodity prices (S&P, 2020). Such low prices create a challenging environment for many electricity generators, including nuclear plants. France's EDF saw a 1% drop in its first quarter revenues. Similarly, Russia's Rosatom experienced a significant demand drop in April and May 2020, contributing to an 11% decline in revenues for the first five months of the year (President of Russia, 2020).

The competitiveness and resilience of low carbon technologies have resulted in higher market shares for nuclear, solar and wind power in many countries during the initial three months of lockdowns. Market conditions in the United States, India, Brazil or the Ukraine were noticeably favourable to solar and wind generation (Fig. 9, top panel). Severe restrictions on movement in China during early February led to an overall 6.8% contraction in activity during the first quarter, forcing power production to dip by more than 8% year on year: coal power decreased by nearly 9% and hydropower by 12% due to a dry season (Tan and Cheng, 2020).

Nuclear power generation also proved to be resilient, reliable and adaptable. The nuclear industry rapidly implemented special measures to cope with the pandemic, avoiding plant shutdowns due to COVID-19, despite impacts on workforce and other supply chain challenges. With an average 2% reduction only during the lockdown, nuclear has proved

Figure 8 – Weekly change in electricity demand relative to 2019 (left panel) and relative to week prior lockdown (right panel) in selected jurisdictions (Mar. 15–Jun. 6)[9]



reliable globally. Nonetheless, nuclear generators swiftly adapted to the changed market conditions. Faced with significant decreases in demand, nuclear generators curtailed output to maintain the grid stability. Along with other measures, this has enabled grid operators to maintain a reliable system and largely avoid supply disruptions despite the challenging conditions, while also accommodating increased shares of low-cost, variable renewable generation. In France, EDF increased the periodicity of its load following operations to accommodate variable renewable generation (EDF, 2020). In the UK, nuclear played a big part in almost eliminating coal generation for over two months (Fig. 9, mid panel) (Cockburn, 2020). EDF Energy was able to respond to the need of the grid operator by curtailing sporadically the generation of its Sizewell B reactor to ensure stability of the electricity grid. In the Republic of Korea, the share of nuclear generation rose by almost 9 percentage points during the pandemic. For the whole of 2020, the US EIA's *Short-Term Energy Outlook* saw the share of nuclear generation increasing by more than one percentage point compared to 2019, despite the general disruptions from the crisis. The performance of nuclear power demonstrates how it can support the transition to a resilient, clean energy system well beyond the COVID-19 recovery phase.

Despite the demonstrated performance of a cleaner energy system through the crisis to provide competitive, reliable, low carbon electricity when needed, challenges remain in both mid and long terms. Combined with the broader financial fallout of the crisis on national and corporate budgets, as well as latent risks associated with supply chain reorganizations, current conditions could impede the required investments in the clean energy transition, with longer term consequences on the achievement of climate goals.

Figure 9 – Weekly change in low carbon electricity generation (March 15–June 6) relative to 2019 in selected jurisdictions (Top panel); Change in nuclear, solar and wind generation market shares since start of lockdowns (mid panel); Average impact on 2020 electricity prices vs 2019 before and after lockdown starts[10]

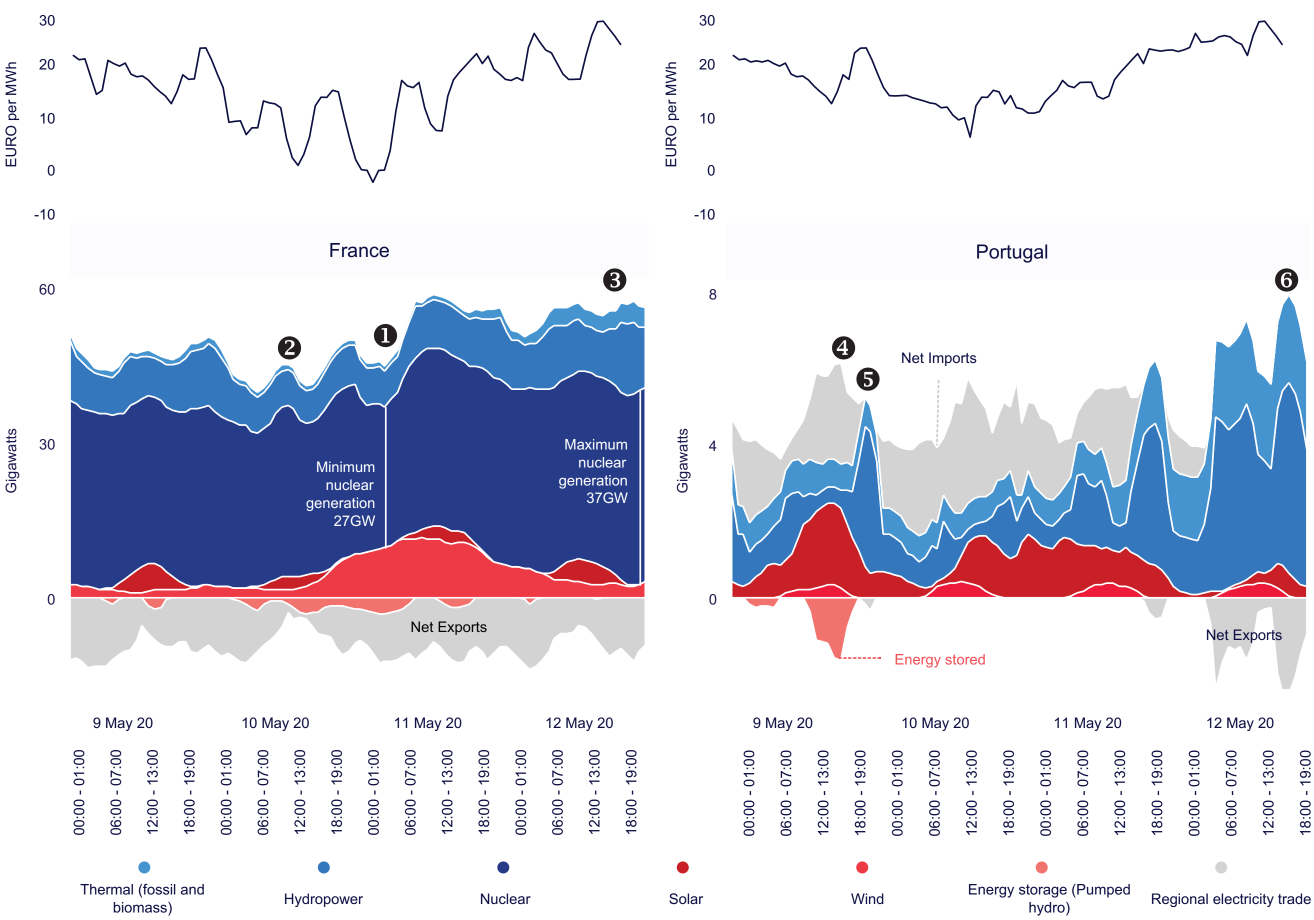
Tomorrow's electricity systems, the backbone of broader energy networks, will require flexible oversight to maintain reliable and clean power services. Electricty systems will be inherently more distributed, embedding both large and smaller production units tapping the full potential of local and clean energy sources – By 2070, 3 600 GW of rooftop solar PV coud be integrated into buildings envelopes (IEA, 2020e) – and using long distance transmission networks to monitor system imbalances (Oudalov, 2020). Digital technologies will be increasingly important to monitor the system complexity, incl. real-time consumer behavior and flexible storage.

A closer look at electricity mixes in France and Portugal shines a light on two polar approaches to system flexibility. Mix compositions differ, but both countries already feature large shares of dispatchable low carbon electricity sources. Both countries also aim for further integration of variable sources of electricity. France's carbon intensity of electricity is under 50 gCO_2 per kWh, i.e. ten times less than the G20 average while Portugal's lies at around 250 gCO_2 per kWh, close to the European Union's average (ICTP, 2018; EDP, 2018).

In France, flexible operations of the extensive nuclear fleet accommodate the variability of other electricity sources, a growing trend among nuclear nations (Patel, 2019). Between 9-12 May 2020, nuclear production varied by 10 GW, mobilizing 44% to 60% of its installed capacity, far from nominal power (Fig. 10, ❶). Similar patterns albeit with smaller amplitude emerge from nuclear plants in e.g. Germany, Slovakia, Czech Republic, Belgium, Finland, Switzerland, Hungary and the United States. Exports are minimized when electricity spot prices are the lowest (Fig. 10, ❷). Gas peaking units are sporadically mobilized when higher levels of demand kick in (Fig. 10, ❸).

Portugal's system flexibility and its security of supply hinge on large pumped storage capacities and its integration with the Spanish grid. On 9 May 2020, a surge of wind and solar generation and cheap imports supplied large electricity needs (Fig. 10, ❹). As wind died down, solar power plummeted, and trade cut off by high import prices, hydropower took over at full capacity (Fig. 10, ❺). On May 12, a new peak in demand was met with hydropower and fossil fuel units operating at full capacity (Fig. 10, ❻).

Figure 10 – Power generation mixes and spot prices of electricity France (left panel) and Portugal (right panel), 9-12 May 2020[11]

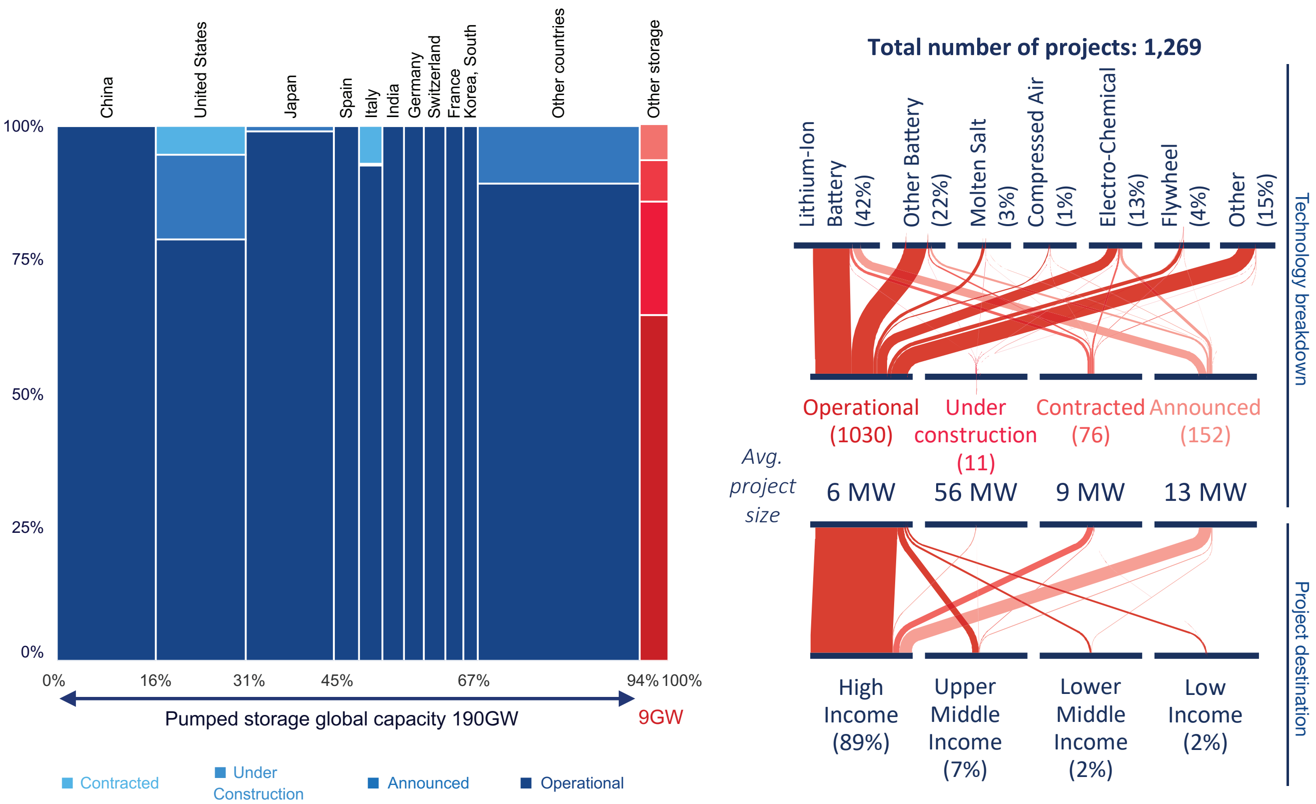


The Iberian Peninsula grid operates in relative isolation due to a lack of interconnectors with the rest of continental Europe. The proposed Biscay Gulf interconnector is expected to fill this gap, at an estimated cost of EUR1.9 billion and annual benefits in the order of EUR250-290 million (EC, 2016). The innovative Frades II pumped storage station also plays a key role in the system stability: Variable speed turbines allow for frequency regulation (Larson, 2018). A large pumped-hydro project under construction on the Tâmega river will alleviate the reliance on coal by 2023 and will help achieve the swift decarbonization of the Portuguese electricity sector.

As shown by the previous examples, historically, network operators have ensured market clearance thanks to regional interconnectors, dispatchable power generation units, including natural gas assets, but also pumped storage hydropower plants. Hydropower plants equipped with pumped storage have long been instrumental to match available sources of electricity supply with customers' needs. Almost 170GW of pumped storage capacity is operated worldwide, storing up to 9,000 gigawatt hours of electricity each year, equivalent to a third of global generation (Fig. 11, left panel). Almost half of these power plants are located in China, the United States and Japan. Smaller yet significant capacities are also operated in continental Europe. The International Hydropower Association sees potential for a 50% increase in pumped storage capacity within ten years. Such projects developments and their uneven geographical distribution remain insufficient to absorb future demand shocks, avoid curtailment, and accommodate the system integration of fast-growing non-dispatchable capacities.

The ongoing physical and digital transformations require the development of additional flexibility options. Solution developers are now turning to innovative energy storage solutions. The US Department of Energy recorded almost 1,300 projects worldwide covering a wide array of technological options, 80% of which are operational (Fig. 11, right panel). With more than 40% of the counts, lithium-ion battery designs have become the most common source of storage capacity. They now offer a full range of services across various timescales. Their flexibility and their ability for quick smoothing and firming of electricity production have raised interest among operators of variable renewables sources. Lithium-ion batteries are also becoming increasingly capable of performing scheduled time shifting of renewables over longer durations, depending on economic conditions and local regulations.

Figure 11 – Global mapping of energy storage capacities (left panel); Project developments of emerging storage technologies (right panel)[12]

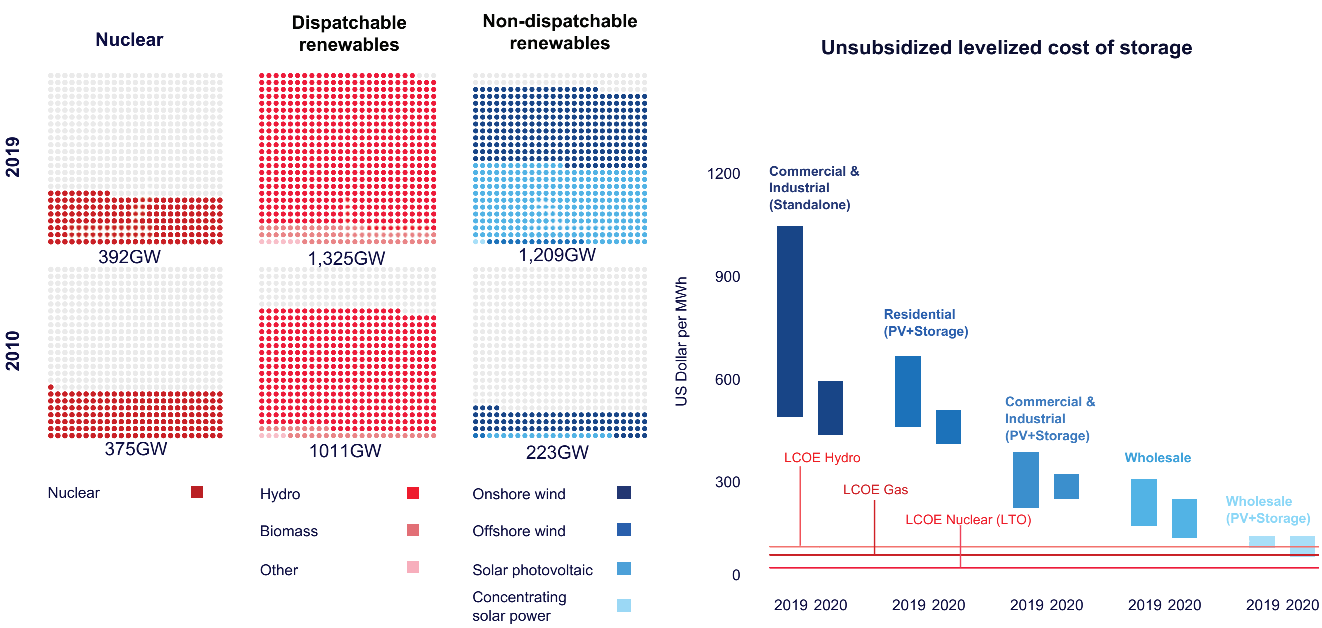


The fast-evolving energy storage landscape suggests significant potential for scalability. The average project size of lithium-ion battery projects (6MW) remains small compared with other types of storage technologies. But utility-scale lithium-ion systems with capacities greater than 10 MW and increasing storage durations have been commissioned worldwide in recent years. Some plants in California can run up to four hours (Research Interfaces, 2018). Compressed air solutions and molten salt thermal storage, a highly efficient process for 10-hour storage or more, and best combined with large solar farms, are fewer but much larger in scale, in the order of 60-70 MW (Dieterich, 2018). Overall, the average capacity of the storage projects announced is more than 50% larger the operational projects.

Energy storage is vital for the cost-effective transition towards decarbonized electricity systems. Battery storage installations are expected to become standard components of energy infrastructures. As illustrated in previous sections, clean and non-dispatchable electricity has gained a lot of ground globally in ten years, driven by strong innovation and various schemes to guarantee operators' revenues. One thousand gigawatts of new capacity have been connected to the grid since 2010, with strides also made off the grid in South Asia and Africa (Fig. 12, left panel). Variable renewables, now on par with conventional sources of power, have established themselves as low-risk options for governments and investors to realize their decarbonization objectives. They will live up to their promise only with competitively priced storage solutions that can maintain overall system reliability. The progression in dispatchable electricity (incl. three hundred gigawatts of hydropower capacity built since 2010 and fifty nuclear reactors under construction corresponding to fifty-three gigawatts of new capacity) will strengthen the security of supply.

The innovation path and the falling cost of battery systems give room for exponential growth in the coming years. In a decade, the cost of a lithium-ion 1 kWh battery pack — enough capacity to propel an electric vehicle for six kilometers — saw more than a 7-fold decrease, down to $156. The storage capacity installed globaly ramped up from 1 GW to over 10 GW in less than three years. Bloomberg New Energy Finance sees the $100 per kWh threshold reached within the next three years (BNEF, 2019). However, standalone applications remain costly to run outside peak hours. Once combined with solar PV systems, the levelized cost of electricity — a suitable metric to assess the competitiveness of baseload generation sources — falls under $100 per MWh (Fig. 12, right panel). Against this backdrop, the International Energy Agency projects around 220 GW of capacity installed globally by 2030 to accompany the aggressive deployment of solar and wind and meet the Paris Agreement objective. This is half of the 2030 requirements in pumped-hydro capacity alone (IRENA, 2020b). Some projects recently stalled due to the pandemic but market interest remains strong. Wood Mckenzie, among other observers, predicts that wind and solar, backed with storage solutions, are poised to dominate Europe's power grid by 2030 thanks to attractive risk/return profiles and despite increasing exposure to power market conditions (Wood Mckenzie, 2020). The electrification of mobility services will also boost the emergence of the storage industry, beyond stationary applications in the power sector.

Figure 12 – Market dynamics for batteries and other low carbon options, 2010-2019[13]



Most projects are currently concentrated in high income countries. The next frontier is deployment in lower income countries. The World Bank sees battery storage as a critical vector of rural electrification as well as more reliable grid-based electricity services. A $1 billion catalytic fund was provisioned and is looking to mobilize another $4 billion in concessional climate financing and other public and private investments (World Bank, 2018). Indian policy-makers also count on low-cost lithium-ion batteries to enhance the rollout of their solar ambitions and meet demand peaks (Ranjan, 2020).

Storage-centered policy and regulatory frameworks, as well as dedicated financial incentives, will turn technology readiness into a market reality. Regulatory frameworks must recognize storage as a source of energy on its own. Very few jurisdictions are yet ready to accommodate and compensate storage services, in particular in their ability to improve system stability, perform peak shaving and provide fast primary frequency response. The emergence of new system-based metrics to assess the competitiveness of electricity sources and transform the remuneration of operators, may prove useful to price storage services adequately. For now, storage is particularly valuable in small, inflexible systems. A suite of financial incentives commonly used for e.g. wind and solar technologies are under examination and could be transposed and adapted to batteries: Fiscal exemptions such as investment tax credits to foster investments; power purchase agreements for storage operators to guarantee firm energy delivery to a customer; other forms of production support incl. storage mandates and production tax credits.

Innovative solutions will also need to address growing concerns over the possible shortage of minerals required for battery manufacturing and the overall sustainability of supply chains. Current battery designs require raw commodities which entail polluting extractive activities and come at odds with sustainable development objectives (Scheyder, 2019). Several regional and global initiatives, as well as industrial coalitions, are burgeoning to circumvent these issues, simplify chemistry and invigorate the deployment of more local and sustainable value chains. For example, the Global Battery Alliance proposed a transparency-based “Battery Passport” to ascertain the chemical composition and quality standards of batteries, encourage material recycling and prevent child labour. The European Union announced a EUR350 million investment to build a battery factory in Sweden to take advantage of its clean power base and its experience in process manufacturing and recycling.

A lack of flexibility options to address resource inadequacies and respond to market swings can lead to undesirable and harmful outcomes, ranging from extreme price volatility to service disruptions. In January 2020, a combination of extreme temperatures and the collapse of grid interconnections in South Australia created a surge in wholesale electricity prices to a huge $14,700 per MWh during one hour, with prices remaining very high for the subsequent one and half hours. The regulator’s emergency response cost $8 million (AEMO, 2020). A market cap of $9,000 was also reached during the 2019 summer in Texas as demand for air conditioning ballooned (Rhodes, 2019). Soaring electricity prices are also observed occasionnaly on European wholesale power markets. The dire situation experienced in recent years in California, with rolling blackouts and renewables curtailement, also generated price hikes.

Solutions for demand-side response provide extra layers of flexibility to grid operators. They are progressively developed and implemented to improve the overall performance of electricity markets. Energy management and behind-the-meter solutions, incl. on-site generation and mini-grids, offer great potential to monitor residential consumption, reduce electricity bills and alleviate resource inadequacies by shifting power consumption to periods of lower rates. Optimized grid management, better operations of existing assets, more regular maintenance scheduling and enhancement of transmission and distribution networks also defer and/or minimize costly network upgrades, particualrly in low to middle income countries which suffer from chronic underinvestments in network infrastructures.

“Sector coupling” will reinforce the centrality of distribution networks, embedding them with end-use sectors, and forming a dense and interoperating energy supply infrastructure. Digital technologies can greatly improve grid resilience and the integration of distributed energy resources, commercial, industrial and residential storage units as well vehicle batteries. Batteries then operate as “virtual power plants”, acting as buffers between conventional sources of power and load centers.

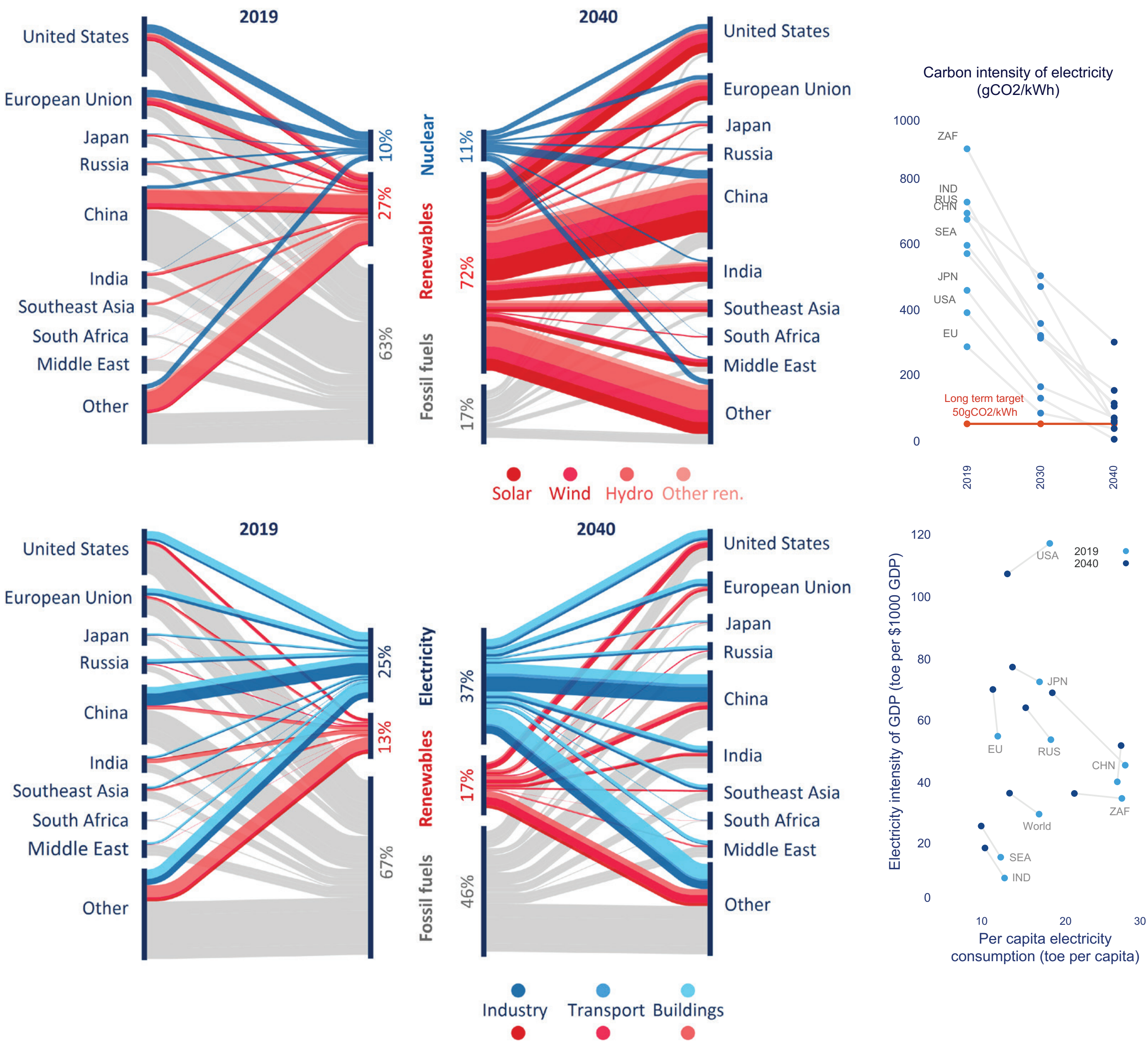
Clean hydrogen, produced from low carbon electricity, may also emerge as another valuable source of large-scale and long-term, seasonal storage capacity. Multiple projects are under development around large industrial clusters in the US, Europe and East Asia to demonstrate the economic viability and accelerate the uptake of hydrogen technologies. Technology-neutral policies will foster project delivery and will help tap the full clean hydrogen potential.

SETTING THE GLOBAL DECARBONIZATION IN MOTION: ALL ROADS LEAD TO CARBON NEUTRALITY

Assuming economic activity post-pandemic will eventually resume to normalcy, stringent climate objectives can only be met if all countries pursue every effort to deploy low carbon technologies. The pace of progress required at the national and more local levels will differ based on circumstances, incl. the periodicity of revisions of policy, regulatory and financial incentives, the creditworthiness of jurisdictions and businesses, the availability of skilled labour force, projects bankability, the nature of existing energy infrastructures and other built environments.

Every prospective effort to identify decarbonization strategies shows a swift displacement of unabated fossil fuels and a convergence towards clean energy technologies in both the power sector and final energy use. The IEA Sustainable Development Scenario provides the details of a possible pathway and integrates the vast array of measures percolating through the entire energy systems (Fig. 13). This scenario serves as a reference to most IPCC scenarios with century-long timescales (IPCC, 2018).

Figure 13 – A phased approach to decarbonization: Illustration with the IEA Sustainable Development Scenario, 2018-2040[14]



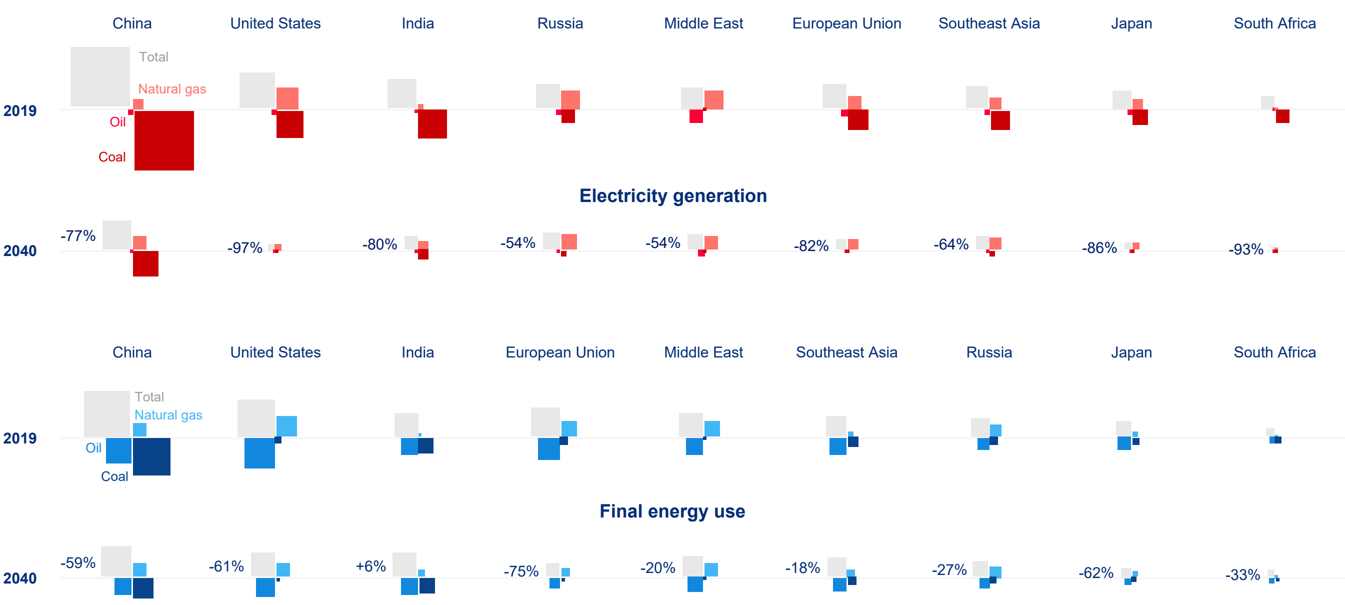
Decarbonizing in full force translates into a sea change in global electricity supply. By 2040, over 80% of electricity is low carbon, more than double current levels. The IEA scenario projects a vast and generalized deployment of renewable electricity, supplying 72% of electricity needs, two-thirds of which generated from variable sources alone. Hydropower and nuclear capacities broadly maintain their shares in the mix (resp. 17% and 11% in 2040). They provide dispatchable and low carbon power, thus ensuring the stability of systems jointly with battery storage capacity. As a result, the carbon intensity of electricity drops rapidly in all countries, particularly in high income economies which can reach levels lower than the 50 gCO_2 per kWh threshold in about two decades.

An exponential change is needed in energy end-use. The widespread availability of clean electricity fosters the electrification of energy end-use and the adoption of other clean fuels in hard-to-abate sectors. With the right policies and regulations in place and a clear reorientation of private businesses' strategy, almost half of final energy needs are covered by clean energy sources by 2040. According to the IEA scenario, the buildings sector, the largest sector in terms of energy use, is the quickest to embrace electrification. China, the United States and the European Union offers vast potential for early adoption of clean fuels. By contrast, the decarbonization of transportation remains only nascent in 2040 despite strides expected in the European Union where up to 35% of mobility needs could be electrified. Each country, jurisdiction, constituency should identify its own pace and means of the transition, but all pointing to a rapid acceleration in their implementation.

Taking the high road to decarbonization, through systematic deployment of energy-saving options, favouring synergies across transport, digital, heating, cooling and industry sectors, will bring about sizeable reductions in CO_2 emissions and will likely transform our economic structures. The global convergence towards clean energy sources greatly reduces the overall carbon footprint of energy. In the next two decades, power and end-use emissions could be two-thirds lower than their current level (Fig. 14). The right level of political ambition could lead to widespread access to modern, clean and reliable energy services, generate value and employment opportunities, redistribute the composition of goods and services across the entire value chain.

The pandemic laid bare the vulnerability of our societies to external shocks, triggering further commitments from public and private leaders to address climate change. A wave of even stricter objectives than what is depicted in the IEA Sustainable Development Scenario, i.e. numerous carbon neutrality objectives newly-set by numerous countries, is expected to achieve a faster-track decarbonization, with net-zero emission levels reached by mid-century. Under these revised ambitions, the construction of new, low carbon infrastructures would not suffice. Existing infrastructures may have to be retrofitted or dismantled, potentially with great economic and social costs. Reaching a 1.5°C target may also require technologies that are yet to be developed, incl. carbon dioxide removal and nuclear heat applications (IEA, 2021).

Figure 14 – Country emissions from electricity generation and final energy use in the IEA Sustainable Development Scenario, 2018-2040[15]

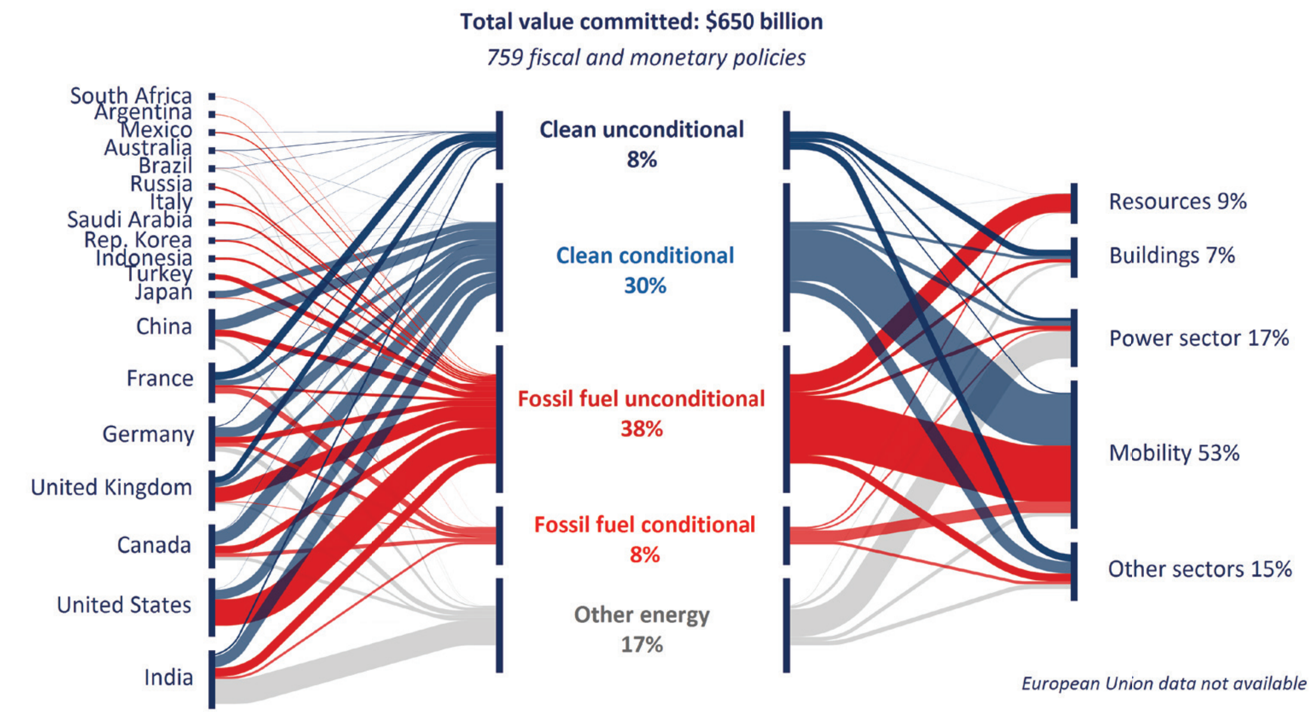


The response to the pandemic has shown that extraordinary circumstances can be met with extraordinary measures. The transition to a net zero economy requires financial commitments of equivalent magnitude. Without vast spending directed to economic stimulation, targeting notably the most vulnerable communities and businesses, the global COVID-19 outbreak would be a drag on our economies and social welfare for many years. According to early estimates into the crisis, the amount of money necessary to alleviate the worst impacts of the economic recession at play, bail out businesses and restore employment, lies around $12 trillion (Gopinath, 2020). In this context of massive public spending, decision-makers can take decisive actions that will set in motion an orderly decarbonization of energy. The investments realized in the coming five to ten years will determine our ability to reach net zero emissions targets by mid-century.

Private sector leaders, financiers and the civil society see a historic opportunity to design high-stakes recovery plans with a green focus, in line with climate change objectives. But the deep economic recession the world entered in 2020 leaves policymakers with little room to manoeuvre. The access to borrowing, the levels of public and private debt prior to the crisis, the domestic innovation landscape and the degree of healthy governance all drive COVID-19 responses by individual countries (Gaspar et al., 2020). Shrinking fiscal revenues following the economic downturn left a void in many national accounts. Support to the healthcare sector was prioritized for immediate public disbursements, incl. from international finance institutions, leaving energy projects with fewer credits.

Clear and timely policy incentives are of the essence. To date, public announcements to organize the recovery around clean energy opportunities remain largely at odds with climate change and sustainable development strategies (UNEP, 2020b). The commitments made by G20 countries, responsible for 85% of global emissions, fall well short of prioritizing low carbon solutions over fossil-related investments. At the time of writing, only 38% of their $650 billion commitments in support of the energy sector, through new or amended policies and direct project financing, are directed to clean energy (Fig. 15). Fossil fuel projects are prioritized. Fifty-three percent of these commitments may accrue to the mobility sector, often perceived as transformative and central to many sustainable development strategies. Mobility offers greater potential to leverage economic activity across the board. By contrast, only 17% of public support may serve clean energy projects in the electricity sector, which will have to rely more on private sector funding. Capital-intensive projects with long leading times such as nuclear or concentrating solar power may not offer enough return on investment in the mid-term to meet eligibility criteria from some governmental agencies.

Figure 15 – Public money commitments made by G20 countries to fossil fuels, clean and other energy in recovery packages, USD billion, as of 19 May 2021[16]



Climate considerations and risks, now perceived as key sources of financial instability by numerous central banks, financial actors and businesses, are also expected to guide energy investments in the longer term. Central banks now multiply initiatives to address physical risks inherent to climate change and other risks of asset depreciation during the energy transition that may threaten financial stability. A high-level Task Force on Climate-related Financial Risks was recently established for oversight by the Basel Committee on Banking Supervision (BIS, 2020). Another Task Force on Climate-Related Financial Disclosures was created in 2015 by the Financial Stability Board to develop consistent reporting frameworks for climate-related financial risk disclosures. The European Central Bank also encourages its constituencies to use green bonds, earmarked to finance investment projects with an environmental benefit, to stimulate the economic recovery and tackle climate challenges. These new opportunities serve as guiding principles in revised climate strategies of the World Bank, the European Investment Bank and a growing number of institutional investors.

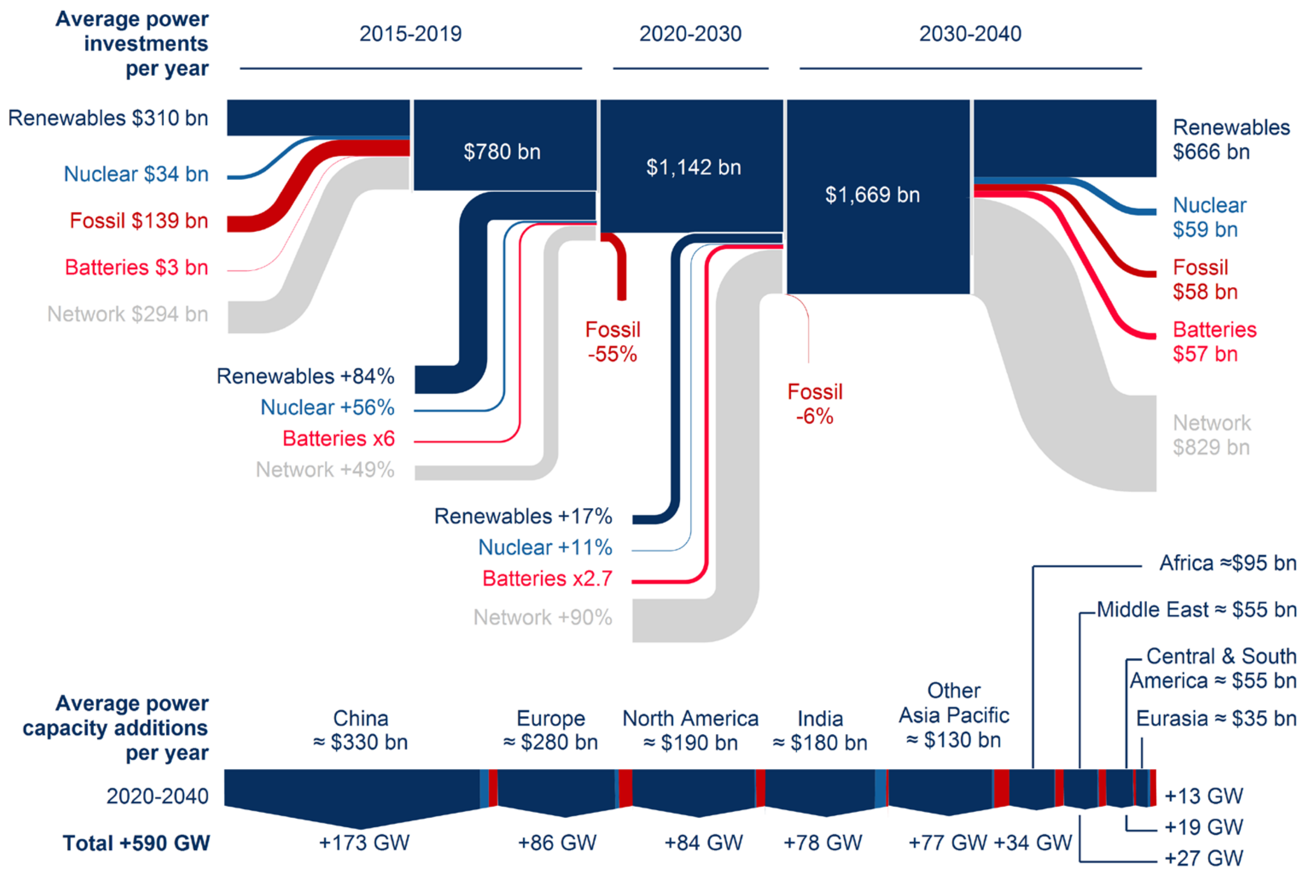
Climate risks can be mitigated with new underpinnings of capital investments, with sizeable payoffs in terms of value and job creation. There is a growing interest among investors to factor in climate science in their own decision strategies. 137 global financial institutions, with nearly US$20 trillion in assets, recently urged companies over 1,800 high-emitting companies to set science-based mitigation targets in line with net zero emissions by 2050. We Mean Business – a coalition of about 1,400 business players and a $24 trillion market capitalization, united to catalyse business action and drive policy ambition to accelerate the zero-carbon transition – estimates that a green recovery could deliver a 7% reduction in 2030 emissions compared with 2019 levels with millions of new jobs at stake (Cambridge Econometrics, 2020). McKinsey estimates that a EUR75-150 billion spending on a balanced low carbon stimulus in Europe, could deliver at least twice more value creation, generate 1-3 million jobs and eventually cut European emissions in 2030 by up to 30% (McKinsey, 2020). Empirical evidence confirms that green spending generates better returns to investors and higher economic growth than environmentally detrimental measures (IEA and ICBS, 2021; Batini *et al.*, 2021,). Strengthening power grid and low carbon electricity projects are considered key vectors of job creation.

As governments prepare for the submission of revised climate objectives and are still trying to kickstart their economies more sustainably, coal investments may finally come to a halt. Recent calls from global leaders, including UN Secretary General Gutteres, to phase out coal plants are finding more and more echo worldwide. New coal projects may be increasingly difficult to finance. Dozens of global banks, insurers, pension funds and asset managers, more than 140 globally significant financial institutions in total, have already put in place coal exit policies (Buckley, 2020). Declining utilization rates of existing coal power plants, the closure of non-competitive assets averaging 35GW per year, and other environmental regulations, triggered a fall in coal demand in 2020. The net-zero emission targets newly announced by China, Japan and South Korea, key funders of coal projects worldwide, are expected to accelerate this trend among coal-client countries. The Philippines and Thailand also intend to curb their heavy reliance on coal and are now taking advantage of more competitive low carbon alternatives to fuel their economic development. New South Wales, home of a third of the Australian population, also announced a comprehensive roadmap to phase out coal installed capacity within 15 years (NSW, 2020).

Solar PV and wind power technologies have now established themselves as default options to most financiers, policymakers and operators. Current investment volumes remain largely insufficient to operationalize the energy transition and reach carbon neutrality by 2050. More than $600 billion are invested yearly in clean electricity infrastructures (Fig. 16, left panel), with half of the spending delivering yearly about two hundred gigawatts of new renewable capacity. Energy efficiency measures require roughly $250 billion. The International Energy Agency projects almost a doubling of overall investment efforts by 2030 to maintain temperatures below 2°C (Fig. 16, right panel), with a seven-fold increase in battery storage investments. But the objective of carbon neutrality by 2050 can only met with a tripling of clean energy investments within ten years (IEA, 2020a). A third of spending should be dedicated to the expansion and the modernization of power grids to foster the integration of all clean energy sources.

The pandemic left investors' appetite for renewable electricity solutions largely unaffected. After a slowdown of capacity additions and delays in firm investment decisions during the first semester of 2020, renewable constructions resumed by year end. The investment pipeline points to an acceleration of renewable newbuilds in the next few years (IEA, 2020f). Nonetheless, only 62 renewable power projects worth $17 billion have been confirmed by G20 countries so far. The European Union's stimulus funds have attracted more than a thousand green project applications worth $200 billion (Chestney, 2020). But the bleak economic prospects anticipated for 2021 may discourage private investors to support the rollout of the most capital-intensive proposals.

Figure 16 – Global cumulative investments in low carbon technologies (annual average 2015-2019) and low-carbon power-sector requirements in line with the Paris Agreement (annual average 2020-2040)[17]



Nuclear investments have been relatively stable in recent years. But current levels of spending are misaligned with the climate mitigation potential of nuclear power. About $35 billion are invested each year in nuclear developments. Almost half of nuclear investments were recently made in China whereas nuclear power dominates clean electricity investments in the Russian Federation. About 30% of this spending goes to existing plants for long term operations, affecting about 40 GW of the capacity installed globally. Despite the need to double nuclear investments, financing new nuclear projects may be challenging in a context of drained public resources the near term. Conversely, nuclear projects are gaining interest among some institutional investors, incl. pension funds, as well as private investors seeking to decarbonize their portfolios and support technological innovation.

The majority of climate investments will need to be realized in emerging markets. The energy transition should act as an engine of inclusive green growth. A sustainable and successful transition will allow all countries, irrespective of their size and wealth, to take advantage of their local natural resource endowments, select low carbon options over fossil fuels. Between 2016 and 2018, the combined investments in nuclear and renewable capacities in China and India alone attracted a third of global low carbon energy investments. The International Finance Corporation sees a $23 trillion opportunity in green investments to 2030 in emerging markets, in which climate lending volumes for the next decade are poised to grow four times as fast as conventional lending (IFC, 2016). The bankability of emerging economies, their general lack of liquidity and their insufficient access to climate finance still impede the deployment of low carbon technologies.

Public financing institutions will have a critical role to play to align the pandemic response with climate policy objectives. Clean energy projects may not only be examined in the light of their financial returns but should also bring about significant economic returns. They may also address suboptimal market situations by integrating shadow carbon pricing beyond financial rates of return of low carbon projects. Projects integrating innovation and which give room for technology spill-over may also be rated more favourably.

The enforcement of lockdowns and other measures to restrain economic activity and contain the pandemic have resulted in better air quality worldwide. Greater air quality and clearer skies were on full display in major cities such as Delhi, Mumbai, Seoul, Sao Paulo or Los Angeles, where the year-on-year pollution concentrations dropped by 30% to 60% for several consecutive weeks (Dormido, 2020).

Poor air quality is a major cause of respiratory disease. The World Bank ranked air pollution as the fourth-highest risk factor for attributable deaths – just below tobacco smoke. The WHO estimates that only 1 out of 10 people worldwide evolve in environments with satisfactory air quality. The situation is particularly acute in South-East Asia and the Western pacific region where 4 million deaths are attributable to poor air conditions (CCAC, 2018).

Air pollution and climate change differ in their geographical scope and timescales. The former is by and large a local issue with immediate consequences on our daily lives, while the latter is a global and gradual phenomenon, with the most manifest impacts expected to occur within longer timeframes.

But air pollution and climate change have common origins. Incomplete fossil fuel burning resulting from e.g. trafic congestion, diesel engines ran by heavy industries and coal power stations, generates airborne particulate matters, the main cause of poor health and premature death in cities. These inefficient and unsustainable energy production and consumption modes drive episodic and often recurrent spikes in ambient air pollution, exposing primarily populations from large conurbations. Natural elements, incl. waste burning, wildfires, sand storms and volcanic acitivity, as well as weather conditions, including wind speed, humidity an rainfalls, in addition to non-combustion processes such as quarrying, also have a strong influence on air quality.

The level of economic development and the resulting carbon intensity of CO_2 emissions are good predictors of air quality. According to the latest urban air quality database, 98% of cities in low- and middle income countries with more than 100 000 inhabitants do not meet WHO air quality guidelines. However, in high-income countries, that percentage decreases to 56%. Ambient air pollution levels are lowest in high-income countries, particularly in Europe, the Americas and the Western Pacific. In European cities, air pollution has been shown to lower average life expectancy by anywhere between 2 and 24 months, depending on pollution levels (CCAC, 2018). Since 2010, CO_2 emissions have decreased in high income countries but often kept on rising elsewhere. Populations living in lower income countries are more and more exposed to outdoor pollution (Fig. 17). Only 4% of citizens living in low income countries enjoy good air-quality environments. This compares with 63% in high-income countries. Thanks to more stringent regulations, the global emission factor of particulate matter from coal power plants has dropped by about 40%, with North America, Europe, and Japan benefiting from a 70–80 % decline. China saw more than a 70% reduction, compared to only 20–30% in Russia and other countries in Central Asia (Klimont et al., 2017).

More and more leaders have come to terms with these challenges and are taking action both at the national and local levels. As governments are firming up their national climate plans, more than 450 cities and 22 regions, and thousands of private companies, already rallied the UNFFCC-backed Race To Zero global campaign to unlock inclusive and resilient growth. Local governments are more and more mindful of the 70% of global CO_2 emissions generated by urban lifestyles. These governments and their own policy-making organs in jurisdictions such as Tokyo, Mexico, or California, are expected to accelerate the rollout of their low-carbon plans post-COVID, in concertation with solution developers, asset owners and other institutional investors. Many examples of successful policies are developed in support of sustainable public transportation, incl. rapid transit modes, low emission vehicles and other shared mobility solutions; sustainable environments are at the core of urban planning thanks to the refurbishment of buildings with low emission footprints; clean technologies, incl. nuclear plants, reduce industrial smokestack emissions or the deployment of efficient co-generation plants supplying cleaner heat and power (WHO, 2020). Many municipalities are also deploying efforts to collect and analyse data, inform policy making, set targets and monitor progress.

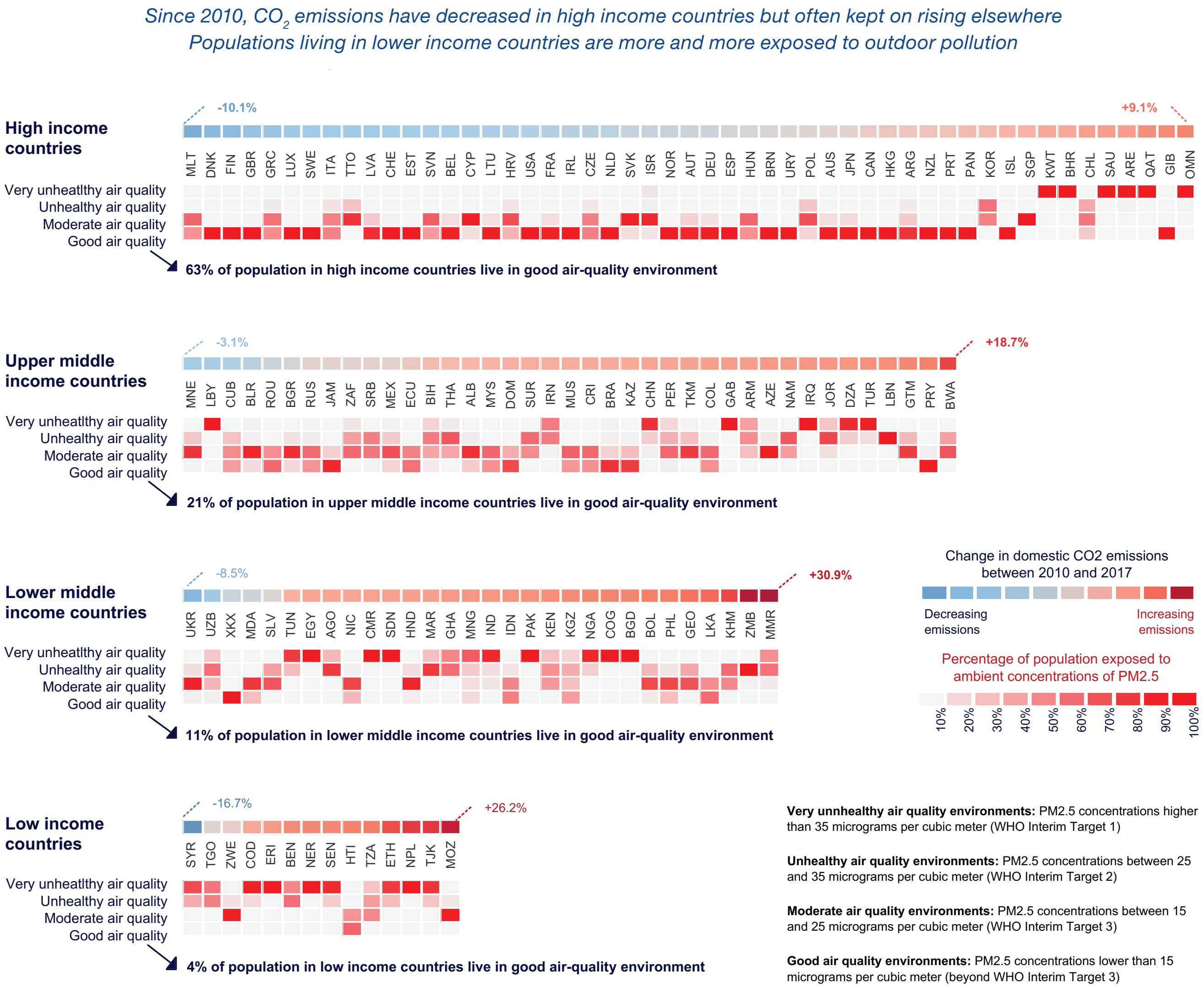
A swift transition to electrified energy use, particularly transport solutions powered by clean energy sources, has the potential to reduce greatly the acute exposure to high concentrations of particulate matters. The increasing appeal of battery-powered electric vehicles as well as fuel cells and hydrogen applications in transport and heavy industries are gaining political momentum in Europe, China, Japan or South Korea. The emergence of alliances of clean-hydrogen producers and industrial manufacturers, such as the European Clean Hydrogen Alliance, will contribute to the improvement of better air quality while serving the climate change agenda.

Air pollutants can also be transported over long distances, hindering regional development. While the adverse effects air pollution are mostly being observed at the local level, a large volume of air pollutants can be transported over long distances and thus impact far away regions too. International cooperation efforts are deployed to coordinate action in this direction. For instance, the UNECE contributes to climate change mitigation through the Convention on Long-Range Transboundary Air Pollution, which sets emission targets for a number of key air pollutants.

Addressing air pollution brings about direct public health and climate change benefits, improves well-being, but is also economically sound. Poor air quality is not only detrimental to public health. It also hinders the economy, food security and the environment and reduces global economic growth by 3.3% each year, as estimated by the World Health Organization. In 2015, air pollution-related healthcare costs amounted to $15 billion (OECD, 2016). According to the US Environmental Protection Agency, every dollar spent in the US on air pollution control generates 30 dollars of benefits, with much higher payoffs in lower income economies. Measures taken to reduce air pollution in Europe contributed to 15% of economic growth in recent years (Dechezleprêtre et al., 2020).

Better breathing conditions were short-lived after the lockdowns. Ambient air quality deteriotrated shortly after traffic congestion and industrial activity resumed, and coal power stations reignited (The Economist, 2020). The response to the pandemic, rising ambitions to meet net zero emissons and the availability of technological solutions can lead to far-reaching and visible benefits, in the form of clean air and blue skies.

Figure 17 – Change in domestic CO2 emissions between 2010 and 2017 and breakdown of population exposure to local air pollution, 2017[18]



FACTORING THE CHANGING NATURAL ENVIRONMENT INTO INVESTMENT DECISIONS

The occurrence of severe environmental conditions episodically affects infrastructures worldwide, at great economic and social expense for asset owners, insurers and local communities. In two decades, extreme weather occurrences have caused nearly half a million deaths and $3.5 trillion in economic losses. G20 countries alone lost $2.6 trillion, with the greatest damages reported in the United States ($51 billion on average annually) (ICTP, 2020).

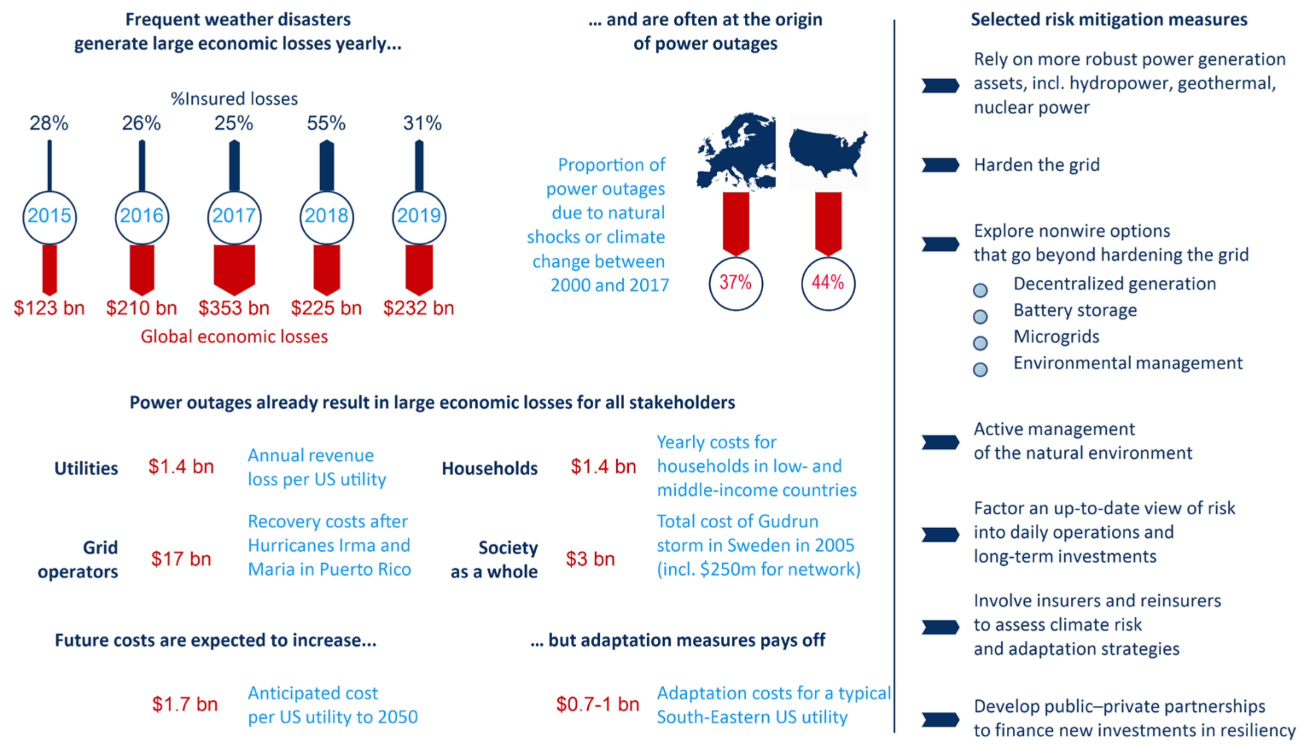
Energy infrastructures are as essential to our living standards as they are vulnerable to these extreme natural events. The power outages resulting from cold and heat waves, water stress, storms and floods – which are expected to increase in frequency and severity in the future due to the changing climate – already take a toll across our societies. Billions of dollars are also spent each year on repair, while many assets at risk remain at best only partly covered by insurance policies (Fig. 18).

The challenges created by COVID-19, as well as the catastrophic cold snap seen in Texas in February 2021, have also highlighted the need to ensure the built-in resilience of future energy systems and cope with a broader range of external shocks, including more variable and extreme weather patterns expected from climate change. Policies supporting the integration of all clean energy sources are critical to *build back better* from the crisis by creating more resilient systems and maintaining reliable electricity services.

The climate-smart investment decisions driving the transition must also factor in adaptation considerations. Tailored regulatory frameworks, resilience by design, innovative insurance and reinsurance products are necessary for asset owners to maintain operations under new environmental norms. The representation of extreme-weather events in energy planning must also be improved to address the specific vulnerabilities of energy systems' components, incl. power generating assets and grids. The value of services provided by more robust power infrastructures could also reward the intrinsic resilience of certain assets. In this regard, nuclear power plants are particularly well positioned to face extreme weather events, with limited forced outages on record due to facility design and limited reliance on the fuel supply chains (Schweikert et al., 2019). The foregone nuclear production due to extreme weather occurrences over 2004-2019 is equivalent to 0.11% of the electricity produced during the same period (IAEA, 2020c). However, like every other energy asset, nuclear plants are exposed to credit risks induced by climate change (Moody's, 2020). The ultimate credit impact depends on operators' ability to invest in mitigating measures.

Adaptation efforts pay off in the long term. Their upfront costs, designed to reduce the future costs of climate disasters, often incurred by state-owned enterprises, are recovered in the long term. The World Bank estimates that four dollars of future socio-economic losses can be saved for each dollar invested in prevention measures and orderly-implemented plans (Hallegate et al., 2020).

Figure 18 – Selected economic impacts of recent extreme weather events on infrastructures[19]



We could be at a turning point of the energy transition if decisive and consistent efforts are undertaken by public and private stakeholders. As low carbon technologies have become default investment options for many financiers, the transition shows encouraging signs of progress. Nonetheless, the emergence of low carbon electricity production, albeit steady, remains far too slow to meet the Paris Agreement objectives.

Governments have a unique opportunity to change the course of the energy transition through their response to the historic economic downturn at play in 2020. Governmental leadership is also essential to establish clear pathways towards the reduction of greenhouse gas emissions and other toxic pollutants through to 2050 and beyond. The pandemic forces governments to boost employment and economic activity with priority policy measures and sheer disbursements of public funds. Three decisive constituants will forge climate action for the years to come and need to be aligned unequivocally: the energy component of public recovery packages with a strong green focus; the ambition levels for the critical 2030 and 2050 milestones, i.e. countries' enhanced Nationnally Determined Contributions and firm and cost-effective Net Zero Emission plans.

The energy transtion cannot be effective without clear policy signals on the use of unabated fossil fuels. Carbon charges and the phase-out of fossil fuel support are economically-sound policy drivers to discriminate among energy sources, and should be integral part of any comprehensive and effective climate strategy. The environmental impact of the transition must also be regulated and more sustainable supply chains of the raw commodities required for the transition must be promoted.

Large coalitions of business leaders step in to accelerate the transition, encouraged by the civil society's raising awareness our vulnerability to future climate risks. More and more corporations and financial institutions opt of transparency by disclosing their climate vulnerabilities through comprehensive and science-based environmental, social, and governance propositions, and bank on sustainable strategies for their procurement and supply chains. However, inconsistent policy incentives and regulatory frameworks can hinder businesses action.

Policymakers and regulators need to adjust to a new political economy, characterised by the rapid emergence of capital-intensive, non-conventional sources of power, the transformation of supply chains and an evolving geopolitical landscape. Only new market and financing paradigms can deliver a green recovery with perennial social, economic and enviromental payoffs, and ensure the financial viability and timely delivery of clean energy projects. Low carbon investments are often realized outside the market, pushed by various fiscal and financial incentives. A regulatory level playing field would foster the deployment of all marketable and financeable low carbon solutions, while addressing existing market deficiencies.

Various institutional initiatives, including the issuance of green obligations and the establishment of sustainable finance taxonomies based on objective, transparent and science-based criteria, are designed to steer investments towards low carbon options more systematically. A priority is to be given to the modernization of existing infrastructure, including power networks and existing nuclear assets. The simplification of government bureaucracy, a strong will to reform the electricity sector and address utilities' chronic lack of creditworthiness, will enhance the rollout of clean infrastructure developments, particularly in emerging economies. Three is also a growing recognition that funding innovation will be key to a successful transition. In a period of historically low capital costs, many governments also see an opportunity to support nascent industries with far-reaching decarbonization potential such as green hydrogen.

Social and inequality concerns inherent to the transition must be tackled to ensure successful and just outcomes. A large public buy-in must be pursued by decision-makers and mechanisms be put in place to address conventional industries as well as vulnerable people and small businesses whose activities and revenues are at threat. The coal industry and its labor force are directly exposed by market competition and programmatic shifts to low carbon energy sources. Adequate support, in the form of e.g. compensations and requalification opportunities for workers, may be needed to support the decommissioning of the most inefficient and polluting assets, and ensure an acceptable transition for all.

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Notes

1. Low carbon and clean electricity may be used interchangeably in this document. Unless otherwise specified, low carbon and clean electricity referred to in the text include renewable and nuclear energy. Low carbon electricity may also refer to other potential sources of low carbon electricity, such as fossil fuels equipped with carbon capture, storage and utilization devices as well as clean hydrogen, i.e. hydrogen produced from aforementioned low carbon energy sources. The market shares of carbon capture, storage and utilization and clean hydrogen technologies are not yet significant enough to influence current patterns on the energy transition.
2. The World Economic Forum's Transition Readiness index benchmarks countries against their energy system structures, the capital and investment landscape, regulations in place and political commitment, human capital and consumer participation, infrastructure and the degree of innovation in business environment, institutions and governance. ETI benchmarks are dynamic in nature and vary year on year. As shown in the right panel, the 2020 top performer was Sweden with an ETI score of 74% (100% being the maximum score). With a score of 50%, Tajikistan is the top performer among low income nations. Source: WEF (2020).
3. IEA Sustainable Development Scenario in line with the 2°C objective of the Paris Agreement. Source: IEA (2020a).
4. Sources: IEA (2020b), IEA (2020c).
5. Sources: IEA (2020b), IEA (2020c), World Bank (2020a).
6. Sources: IEA (2020b), World Bank (2020a).
7. IAEA (2020a), IAEA (2020b), World Bank (2020a).
8. The compound annual growth rate (CAGR) of per capita electricity consumption (or equivalently the electricity intensity of GDP) corresponds to the mean annual growth rate of per capita electricity consumption between e.g. 2010 and 2018. Negative values represent decreases in individual electricity consumption, while positive numbers indicate increases. In the case of China, per capita electricity consumption grew on average by 6.6% between 2010 and 2018 (compared to more than 12% during the prior decade). The electricity intensity of GDP is defined as the ratio between a country's final electricity consumption and its GDP measured in purchasing power parity terms. Sources: IAEA (2020b), World Bank (2020a). One country per income group is highlighted for the sake of illustration. The World Bank's country classification by income for the year 2018 is provided in the Annex. Sources: : IEA (2020b); IEA (2020c); World Bank (2020a).
9. This chart and the rest of the section content draw largely on the IAEA web story "COVID-19 and Low Carbon Electricity: Lessons for the Future" published on 9 July 2020. Sources: European Network of Transmission System Operators for Electricity (ENTSO-E) (Europe), Ukrenergo National Power Company (Ukraine), Power System Operation Corporation (India), Korea Power Exchange (South Korea), Operador Nacional do Sistema Elétrico (Brazil), Independent Electricity System Operator (Ontario, Canada), EIA (USA).
10. Source: See previous note.
11. Sources: ENTSO-E Transparency Platform: www.transparency.entsoe.eu.org
12. The US Department of Energy (DOE)'s Global Energy Storage Database houses over 1600 energy storage projects worldwide. Source: www.sandia.gov/ess-ssl/global-energy-storage-database-home/
13. Sources : Renewable capacities: IRENA (2019); nuclear capacities: IAEA (2020b); Levelized costs of electricity: IEA (2020a); levelized costs of storage: Lazard (2019-2020).
14. Source: IEA (2020a).
15. Source: IEA (2020a).
16. Policies are classified as "fossil unconditional" if they support production and consumption of fossil fuels (oil, gas, coal, "grey" hydrogen or fossil fuel-based electricity) without any climate targets or additional pollution reduction requirements. Source: www.EnergyPolicyTracker.org/region/g20
17. Sources: IEA (2020a), IEA (2020g) and earlier editions (2016-2019).
18. Sources: World Bank (2020d): Population exposed to levels exceeding WHO guideline value - 1990-2017; WHO (2020), IEA (2020c).
19. Sources: Aon (2016-2020), Swiss Re (2017), USGCRP (2018), McKinsey (2019), Nicolas et al. (2019).

World Bank’s Country classification by income, 2018

Sources: IEA (2020b), World Bank (2020a). 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.

High Income Countries		Upper Middle Countries		Lower Middle Countries		Low Income Countries	
AUS	Australia	ALB	Albania	AGO	Angola	PRK	Dem. People's Rep. of Korea
AUT	Austria	DZA	Algeria	BGD	Bangladesh	COD	Dem. Rep. of Congo
BHR	Bahrain	ARG	Argentina	BOL	Bolivia	ERI	Eritrea
BEL	Belgium	ARM	Armenia	KHM	Cambodia	ETH	Ethiopia
BRN	Brunei Darussalam	AZE	Azerbaijan	CMR	Cameroon	HTI	Haiti
CAN	Canada	BLR	Belarus	COG	Congo	MOZ	Mozambique
CHL	Chile	BIH	Bosnia and Herzegovina	CIV	Côte d'Ivoire	NPL	Nepal
HRV	Croatia	BWA	Botswana	EGY	Egypt	NER	Niger
CUW	Curaçao	BRA	Brazil	SLV	El Salvador	SSD	South Sudan
CYP	Cyprus	BGR	Bulgaria	GHA	Ghana	SYR	Syrian Arab Rep.
CZE	Czech Republic	COL	Colombia	HND	Honduras	TJK	Tajikistan
DNK	Denmark	CRI	Costa Rica	IND	India	TZA	Tanzania
EST	Estonia	CUB	Cuba	IDN	Indonesia	TGO	Togo
FIN	Finland	DOM	Dominican Rep.	KEN	Kenya	YEM	Yemen
FRA	France	ECU	Ecuador	KGZ	Kyrgyzstan		
DEU	Germany	MKD	FYR of Macedonia	MDA	Moldova		
GIB	Gibraltar	GAB	Gabon	MNG	Mongolia		
GRC	Greece	GEO	Georgia	MAR	Morocco		
HKG	Hong Kong, China	GTM	Guatemala	MMR	Myanmar		
HUN	Hungary	IRQ	Iraq	NIC	Nicaragua		
ISL	Iceland	IRN	Islamic Rep. of Iran	NGA	Nigeria		
IRL	Ireland	JAM	Jamaica	PAK	Pakistan		
ISR	Israel	JOR	Jordan	PHL	Philippines		
ITA	Italy	KAZ	Kazakhstan	SEN	Senegal		
JPN	Japan	XKX	Kosovo	SDN	Sudan		
KOR	Korea	LBN	Lebanon	TUN	Tunisia		
KWT	Kuwait	LBY	Libya	UKR	Ukraine		
LVA	Latvia	MYS	Malaysia	UZB	Uzbekistan		
LTU	Lithuania	MUS	Mauritius	VNM	Viet Nam		
LUX	Luxembourg	MEX	Mexico	ZMB	Zambia		
MLT	Malta	MNE	Montenegro	ZWE	Zimbabwe		
NLD	Netherlands	NAM	Namibia				
NZL	New Zealand	PRY	Paraguay				
NOR	Norway	CHN	People's Rep. of China				
OMN	Oman	PER	Peru				
PAN	Panama	ROU	Romania				
POL	Poland	RUS	Russian Federation				
PRT	Portugal	SRB	Serbia				
QAT	Qatar	ZAF	South Africa				
SAU	Saudi Arabia	LKA	Sri Lanka				
SGP	Singapore	SUR	Suriname				
SVK	Slovak Republic	THA	Thailand				
SVN	Slovenia	TUR	Turkey				
ESP	Spain	TKM	Turkmenistan				
SWE	Sweden	VEN	Venezuela				
CHE	Switzerland						
TTO	Trinidad and Tobago						
ARE	United Arab Emirates						
GBR	United Kingdom						
USA	United States						
URY	Uruguay						

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