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The Energy Transition in an Era of Low Fossil Fuel Prices

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THE ENERGY TRANSITION IN AN ERA OF LOW FOSSIL FUEL PRICES[1]

The human influence on the climate system is clear and is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system.

—Intergovernmental Panel on Climate Change, *Fifth Assessment Report*

The United Nations' 2015 Climate Change Conference (COP21) was by all accounts a success. Nearly all countries around the globe have now firmly committed to reducing their greenhouse gas emissions through the Intended Nationally Determined Contributions (INDCs). The post-COP21 agenda now focuses on the implementation of these INDCs. At the heart of that implementation is the so-called energy transition, which consists of moving away from using fossil fuels (petroleum products, natural gas, and coal) and toward clean energies to power the global economy. While the energy transition is arguably at an early stage, with important differences across countries, it is at a critical juncture. Indeed, to avoid the irreversible consequences of climate change induced by greenhouse gas emissions, the energy transition must firmly take root at a time when fossil fuel prices are likely to stay low for long. It involves significant opportunities and risks, which energy policies will need to tackle.

This section provides answers to four key questions about the energy transition:

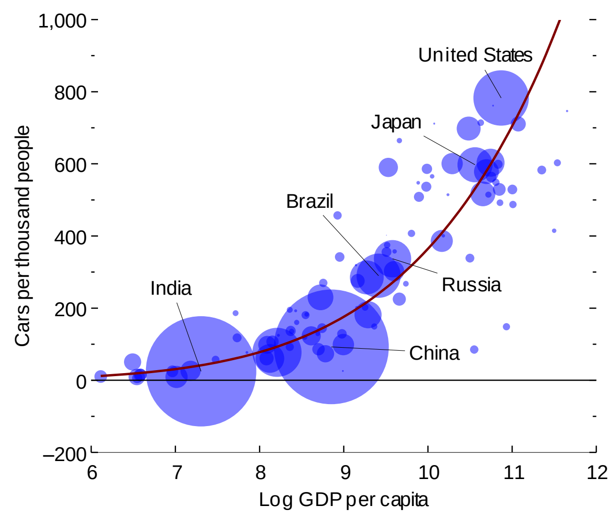
- Where do we stand on fossil fuels?
- What is the status of clean energy?
- What opportunities and risks are associated with the energy transition?
- What is the way forward?

[1] The authors of this feature are Rabah Arezki (team leader), Christian Bogmans, and Akito Matsumoto, with research assistance from Rachel Yuting Fan and Vanessa Diaz Montelongo.

Where Do We Stand on Fossil Fuels?

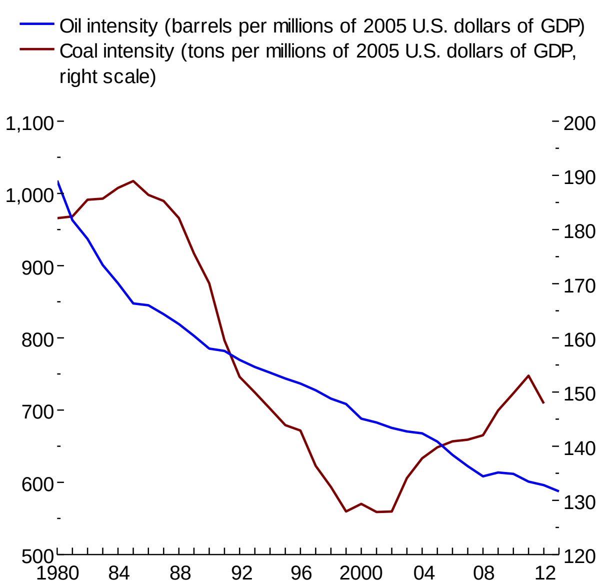
Oil prices have dropped by more than 70 percent since June 2014 and are expected to remain low for a long time owing to a variety of factors (see Arezki and Obstfeld 2015). On the supply side, the advent and relative resilience of shale oil production and increased oil production by OPEC members play an important role. On the demand side, lower GDP growth in emerging markets has tended to reduce oil demand growth, especially in light of the secular increase in global oil efficiency (Figure 1.SF.2), and is expected to continue to do so. That said, the expansion of the middle class in emerging giants is expected to increase dramatically the demand for transport services and the level of car ownership and, in turn, to support oil demand growth (Figure 1.SF.3). The balance among these forces will determine the strength of demand growth.

Figure 1.SF.3. Car Ownership and GDP per capita, 2013



Sources: International Road Federation, *World Road Statistics*; and IMF staff calculations.
Note: Size of bubble represents population in 2013. Cars per thousand people for India is from 2012.

Figure 1.SF.2. World Energy Intensity

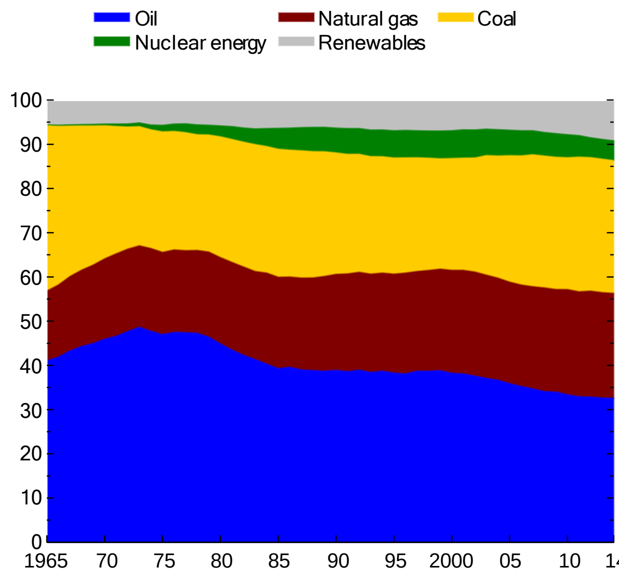


Sources: U.S. Energy Information Administration; World Bank, *World Development Indicators*; and IMF staff calculations.

Natural gas and coal have similarly seen price declines that look to be long lived. The North American shale gas boom has resulted in record-low prices there. Recent discoveries of vast gas fields in developing countries add to the pool of available reserves.[2] The resumption of nuclear-powered electricity generation in Japan is a permanent factor contributing to lower natural gas prices in Asia. Coal prices also are low, owing to oversupply and the scaling down of demand because of environmental concerns and slower economic activity, especially from China, which burns half of the world's coal.

The share of oil in global primary energy consumption has declined rapidly, from 50 percent in 1970 to about 30 percent today (Figure 1.SF.4). The share of coal, now reaching 30 percent of global energy consumption, has been increasing since the early 2000s, mostly on account of rising demand from China, and recently also from India. In contrast with the case of oil, more coal per unit of global GDP is now burned relative to the early 2000s (Figure 1.SF.2). Natural gas consumption has increased steadily since the 1970s, now accounting for nearly 25 percent of global primary energy consumption. Global demand for natural gas is projected to increase strongly over the medium term (IEA 2015), with emerging market and developing economies accounting for the bulk of the growth. The outlook for oil and coal demand growth falls short of that for total energy demand, partly because advanced economies are expected to drastically reduce their demand for coal and oil, in contrast with emerging markets.

Figure 1.SF.4. World Energy Consumption Share by Fuel Type
(Percent)



Source: BP, *Statistical Review of World Energy 2015.*
Note: Consumption of renewables is based on gross primary hydroelectric generation and gross generation from other renewable sources including wind, geothermal, solar, biomass, and waste.

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[2] The recent discovery of the giant Zohr gas field off the Egyptian coast and, more recently, the discovery of natural gas off the coast of Senegal will eventually have repercussions for pricing in Europe, the Mediterranean region, and western Africa. In addition, many other locales, especially in developing countries, that are opening up for resource exploration offer significant potential (see Arezki, Toscani, and van der Ploeg, forthcoming).

According to the IEA, the shares of oil and coal are expected to drop from 36 percent and 19 percent, respectively, in 2013 to 26 percent and 12 percent, respectively, in 2040.

Oil is used mostly to fuel transportation, whereas coal and natural gas are used mainly as inputs into the power sector, consisting of electricity and heat generation, which accounts for more than one-third of total primary energy consumption (Table 1.SF.1). For electricity generation alone, the biggest source of energy is coal, but renewables, including hydropower, are second, followed by natural gas.[3] Roughly equal, and substantial, amounts of energy are also consumed in the industry, transport, and building construction sectors. The transport sector accounts for roughly two-thirds of oil use in the world. The industry, transport, and building construction sectors also consume electricity and heat that are generated by primary energy.

Table 1.SF.1. World Energy Usage, 2013

(Million tons of oil equivalent)

Energy Source	Power Generation (electricity and heat)	Final Consumption			Total Primary Energy Demand
		Industry	Transportation	Buildings	
Coal	2,404	768	3	128	3,929
Oil	284	302	2,357	317	4,219
Gas	1,172	557	96	627	2,901
Nuclear	646	-	-	-	646
Hydro	326	-	-	-	326
Bioenergy/Biofuels	155	194	65	861	1,376
Other Renewables	127	1	-	32	161
Electricity and Heat	-	842	26	1040	. . .
Total	**5,115**	**2,664**	**2,547**	**3,004**	**13,559**

Sources: International Energy Agency, *World Energy Outlook* and *World Energy Balance*; and IMF staff calculations.

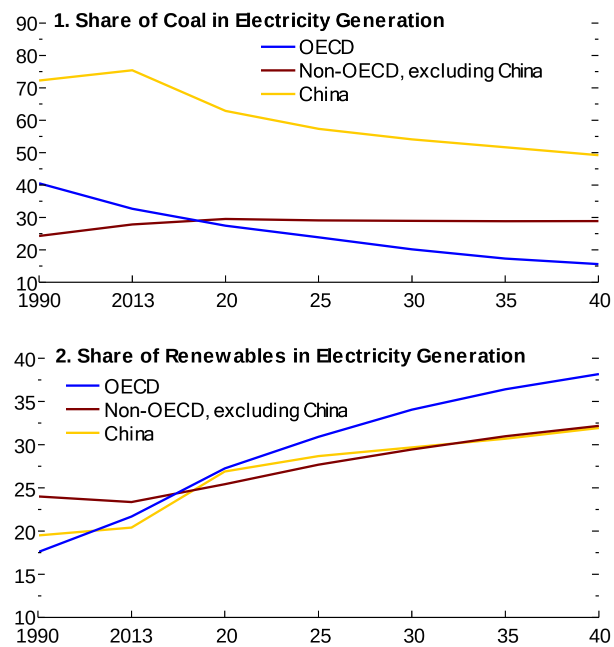
Note: Because of statistical discrepancies, individual data in each row do not sum exactly to total primary energy demand. - = negligible.

[3] The share of natural gas in total primary energy demand is expected to rise, but it faces competition from substitutes for gas in many sectors, especially from renewables and coal in power generation—in part because of subsidies and gas-pricing regimes. Natural gas is expected to make further inroads into the transportation sector in particular, in which its use is still very limited. This development, along with the eventual use of liquefied natural gas as shipping fuel, will contribute to the displacement of oil.

Natural gas is the cleanest energy source among fossil fuels in terms of carbon dioxide emissions. Oil is second to natural gas in this respect, and coal is the dirtiest source, especially when used by older, low-efficiency plants (Figure 1.SF.5, panel 1). Besides carbon dioxide, old plants tend to emit more air pollutants such as nitrogen oxides and sulfur oxides. While China, the world's largest coal consumer, is shifting toward renewable energy resources, demand from other developing countries, especially India, is expected to increase, especially if coal prices stay low (Figure 1.SF.6). In fact, global carbon intensity per unit of energy has increased since the beginning of the 1990s owing to the rising consumption of coal, especially in Asia (see Steckel, Edenhofer, and Jakob 2015). In spite of the increased use of renewables and the decreased use of oil as fuel, total greenhouse gas emissions have increased because of the increase in demand for coal (Figure 1.SF.5, panel 2). This increase has resulted from higher growth in emerging market economies, where coal intensity has risen.

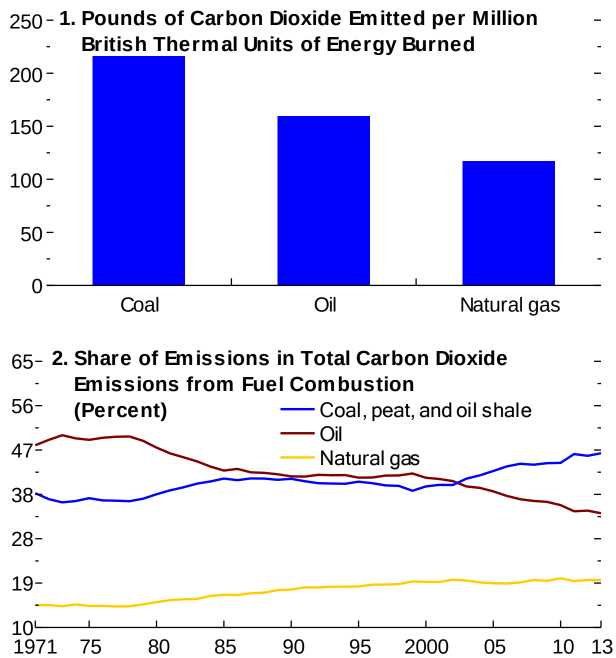
If the energy intensity of economic activity does not fall or if countries in the developing world do not adopt state-of-the-art technology for coal-powered plants to lower the carbon intensity of their electricity generation, economic development in most regions of the world will continue to drive global emissions upward. Emissions will reach dramatic levels and, in turn, accelerate global warming. Poorly designed regulations for the use of coal in developing countries could also discourage technological change in the electricity sector. As a result, the world might not benefit, in terms of lower global emissions, from the downward trend in coal use in developed countries.

Figure 1.SF.6. Electricity Generation
(Percent)



Sources: International Energy Agency; and IMF staff calculations.
Note: These shares relate to electricity generation only and exclude the heating sector. OECD = Organisation for Economic Co-operation and Development.

Figure 1.SF.5. Carbon Emissions for Various Fuels



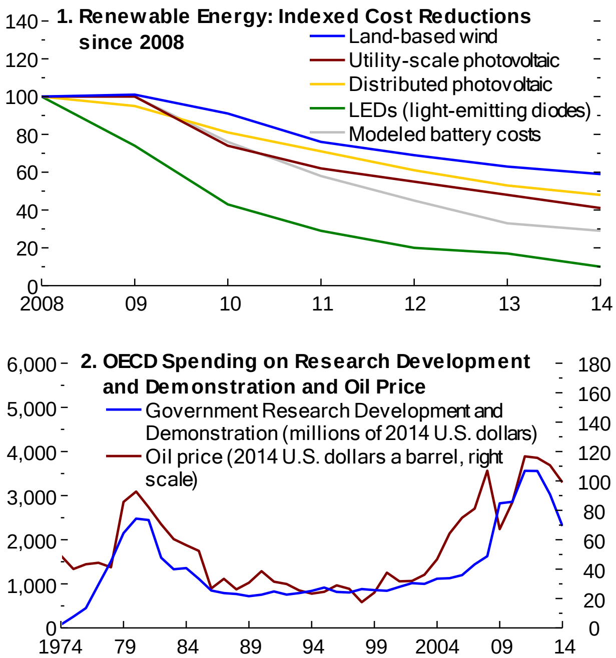
Sources: International Energy Agency; and IMF staff calculations.

Considering its relative cleanliness and abundance, natural gas can play a key role as a bridge in the transition from coal to renewables. Growth in shale gas production in the United States is expected to make natural gas the energy of choice there. There is also potential for growth in the use of shale gas and conventional natural gas in China and many other locales around the globe (see Chakravorty, Fischer, and Hubert 2015).

What Is the Status of Clean Energy?

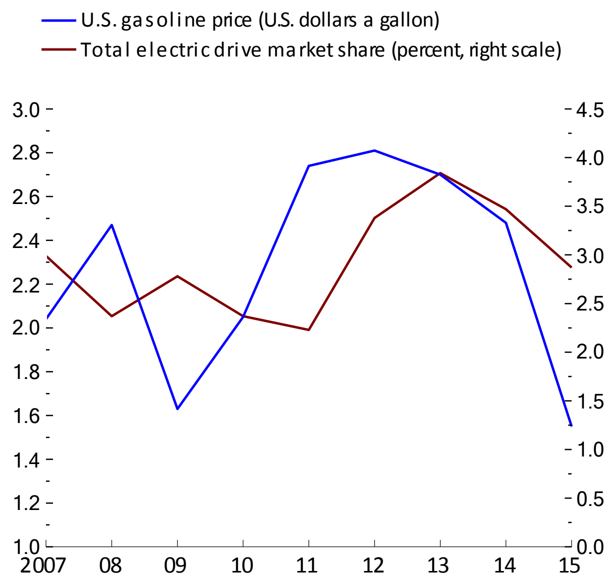
One of the most notable trends in energy consumption is the increase in the use of renewable energy resources (Figure 1.SF.4), which has been supported by a formidable reduction in the costs of various renewables, including solar and wind (Figure 1.SF.7, panel 1). These cost reductions are the result of research and development (R&D) efforts to promote clean energy and energy efficiency ("grey" technology) (Figure 1.SF.7, panel 2). Early R&D investment dates to the 1970s, an era of record-high fossil fuel prices, and was mostly government financed. This is no surprise, as the private sector typically does not internalize the positive externalities associated with an increase in R&D. Public R&D spending early on, however, paved the way for corporate R&D spending during the 2000s, another period of high fossil fuel prices. The result has been a flow of technological innovations across sectors, including the development of electric cars, although they (notably plug-in hybrid vehicles) still have a low penetration rate, accounting for less than 1 percent of car sales in the United States. Unsurprisingly, electric car sales have decreased with the recent drop in gasoline prices (Figure 1.SF.8).

Figure 1.SF.7. Cost of Renewables and Research and Development Efforts



Sources: International Energy Agency, Energy Technology Research Development and Demonstration 2015; and U.S. Department of Energy.
Note: OECD = Organisation for Economic Co-operation and Development.

Figure 1.SF.8. U.S. Sales of Electric Vehicles and Gasoline Price

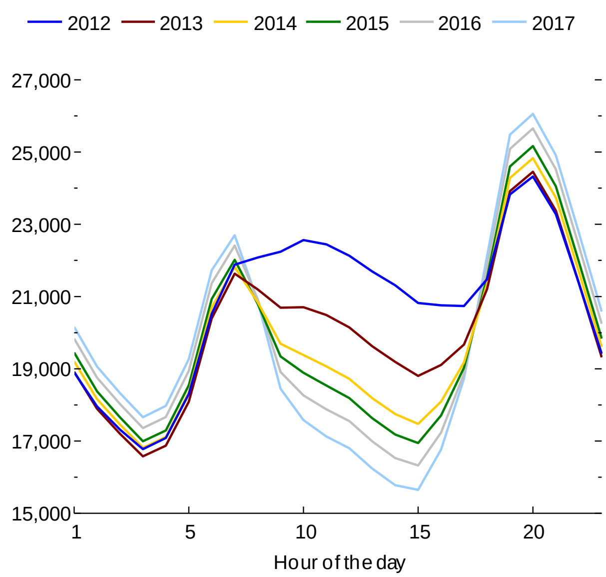


Sources: IMF, Primary Commodity Price System; and Electric Drive Transportation Association.
Note: Total electric drive market share includes hybrid vehicles.

Among primary energy sources, renewables (including hydropower) are the least carbon intensive. The IEA forecasts that the share of renewables in global total primary energy consumption will increase from 14 percent in 2013 to 19 percent in 2040 in light of expected energy policy changes. The electricity sector, in which the share of renewables is projected to increase from 22 percent to 34 percent over the same period, will be one of the sectors to change most dramatically.

One potential difficulty with depending on renewable energy in the power sector is intermittency, and hence reliability. Unstable supply patterns of wind, sun, and rainfall can trigger supply-demand mismatch. The increasing reliance on renewables, including solar and wind, as sources of power generation will require much steeper ramping up of supply during daily peaks to achieve load balancing.[4] In other words, the intermittencies associated with the increased usage of renewables trigger spikes in demand for "controllable" power, for example, from natural gas (Figure 1.SF.9). For renewables to overcome this problem, the power sector needs to develop economical battery backup technology and foster electricity exchange. Battery technology has shown steady progress, suggesting that eventually electricity storage technology will facilitate a more widespread reliance on renewables.

Figure 1.SF.9. Duck Curve: Illustrative Change in Projections of Net Load Curve
(Megawatts)



Source: California Energy Commission staff, Energy Assessments Division.
Note: Projections are based on load shapes and production profiles from actual data of California Independent System Operator on March 22, 2013.

Bioenergy has long been employed for generation in the electricity sector. Biosolids are relatively cheap sources of energy, as they are residuals from other processes or simply waste. Power plants fired by biomass also have the flexibility to compensate for generation lapses associated with other renewables, as they can operate at any time of the day.

[4] The net load curve represents the variable portion of the load that integrated system operators must meet in real time. The net load is calculated by taking the forecast load and subtracting the forecast of electricity generation from variable generation resources, wind, and solar (see California ISO 2013).

Both advanced economies and developing countries are expected to develop more bioenergy-based facilities. In the transportation sector, biofuels are usually blended with conventional gasoline or diesel, sometimes following government regulation. As a result, the share of biofuels in transportation fuels has doubled over the past decade. While biofuels can reduce carbon emissions, some types also put pressure on food markets and have been blamed for food price increases (see Chakravorty and others 2015).

Nuclear energy makes up only a small share of global energy consumption. Carbon emissions associated with nuclear energy generation are limited, but in the aftermath of the March 2011 Fukushima disaster, several countries have imposed moratoriums on nuclear energy use on account of environmental liabilities and safety concerns. In addition to human health risks, the overall impact on the environment is hard to judge, as waste management of used nuclear fuel is still at an early stage. There are also concerns about the diversion of materials involved in nuclear power generation to military use. There are, however, important benefits of nuclear energy. For example, and in contrast with renewable energy, nuclear power is not plagued by the problem of intermittency. Also, immediate fatalities associated with nuclear power plant accidents—as opposed to long-term health consequences related to radiation and pollution exposure—are historically much lower than for any other type of power plant, including coal-fired plants (Table 1.SF.2). The potential for using nuclear as a source of clean energy is relatively high. Some countries, such as China and the United States, are using more nuclear energy to curb their greenhouse gas emissions. While there are serious issues that need to be solved in terms of safety and waste management, many scientists argue that it will be hard to achieve INDC targets without greater use of nuclear energy.

Table 1.SF.2. Summary of Severe Accidents in the Energy Sector, 1970–2008

	OECD		Non-OECD	
Energy Chain	Accidents	Immediate Fatalities	Accidents	Immediate Fatalities
Coal	87	2,259	2,394	38,672
Oil	187	3,495	358	19,516
Natural Gas	109	1,258	78	1,556
Liquefied Petroleum Gas	58	1,856	70	2,789
Hydro	1	14	9	30,069
Nuclear	–	–	1	31
Biofuel	–	–	–	–
Biogas	–	–	2	18
Geothermal	–	–	1	21

Source: Burgherr and Hirschberg 2014.
Note: Accidents with more than five fatalities are considered severe. Accidents in Organisation for Economic Co-operation and Development (OECD) countries from hydro power refer to the U.S. Teton Dam failure in 1976. For nuclear accidents, only immediate fatalities of the Chernobyl accident are shown. – = negligible.

What Opportunities and Risks Are Associated with the Energy Transition?

The current low fossil fuel price environment will certainly delay the energy transition. Indeed, progress in the development of renewables could prove fragile if fossil fuel prices remain low for long (see Arezki and Obstfeld 2015).[5] While renewables account for only a small share of global primary energy consumption, renewable energy will need to displace fossil fuels to a much greater extent to forestall further significant climate risks. The current low prices for oil, gas, and coal may provide scant economic incentive for research to find even cheaper substitutes for those fuels. Lower prices have already raised demand in some countries, such as Germany, boosting the use of coal (the dirtiest fossil fuel) at the expense of natural gas (the cleanest).[6] Evidence indicates that higher fossil fuel prices strongly encourage both innovation and adoption of cleaner technology (see Aghion and

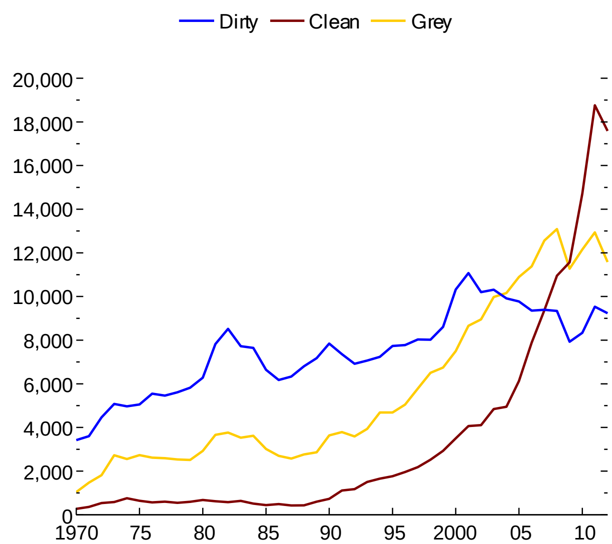
[5] Low oil prices may in part reflect, in addition to the factors discussed earlier in the chapter, an independent process of structural transformation that is taking place in China and is diminishing (or slowing down the growth of) the oil intensity of GDP (see Stefanski 2014).

[6] As the relative price of coal to natural gas in Europe declined in recent years, the share of coal in electricity generation increased in Germany, from 43.1 percent in 2010 to 46.3 percent in 2013. Over the same time period, the share of natural gas fell from 14.3 percent to 10.9 percent.

others 2012 and Busse, Knittel, and Zettelmeyer 2013). For example, lower gasoline prices reduce the incentive to purchase fuel-efficient or electric cars (Figure 1.SF.8). Similarly, the number of clean- or grey-energy patents correlates positively with the price of fossil fuels (Figure 1.SF.10). Finally, low prices for energy in general may hamper the decoupling of economic growth and overall energy consumption if consumers substitute energy for other commodities.

A few countries have committed to reducing coal-powered generation. Because coal is currently relatively cheap, however, it is tempting for a country to use coal for power generation, especially if it cannot afford cleaner alternatives, which are typically more expensive. As mentioned earlier, even advanced economies in Europe increased their use of coal when the shale revolution in the United States displaced coal there and international coal prices dropped.[7] In addition to these short-term effects of low coal prices, low prices may boost capacity investment in coal power plants but reduce efforts to develop more efficient technology.

Figure 1.SF.10. World Patents
(Number of Patents)



Source: Aghion and others, 2012.
Note: Calculations are based on the European Patent Office's World Patent Statistical database. Dirty = auto technology affecting internal combustion engines, Clean = auto technology in electric and hybrid vehicles and fuel cells for hydrogen vehicles, among others; Grey = innovations in fuel efficiency.

Efficiency and pollution intensity differ significantly across coal power plants. With the prospects of lower demand for coal plants over environmental concerns, power plant manufacturers that have up to this point improved plant efficiency and reduced emissions might now moderate their development efforts. This could leave emerging market economies

[7] The share of coal as an input in power plants among European OECD members increased from 23.7 percent in 2010 to 26.0 percent in 2012 (with the increase in coal use largely arising from displacement of natural gas use), although the share of renewable energy increased as well. Japan increased its share of natural gas and coal significantly after it stopped nuclear power plant operations after the Fukushima accident.

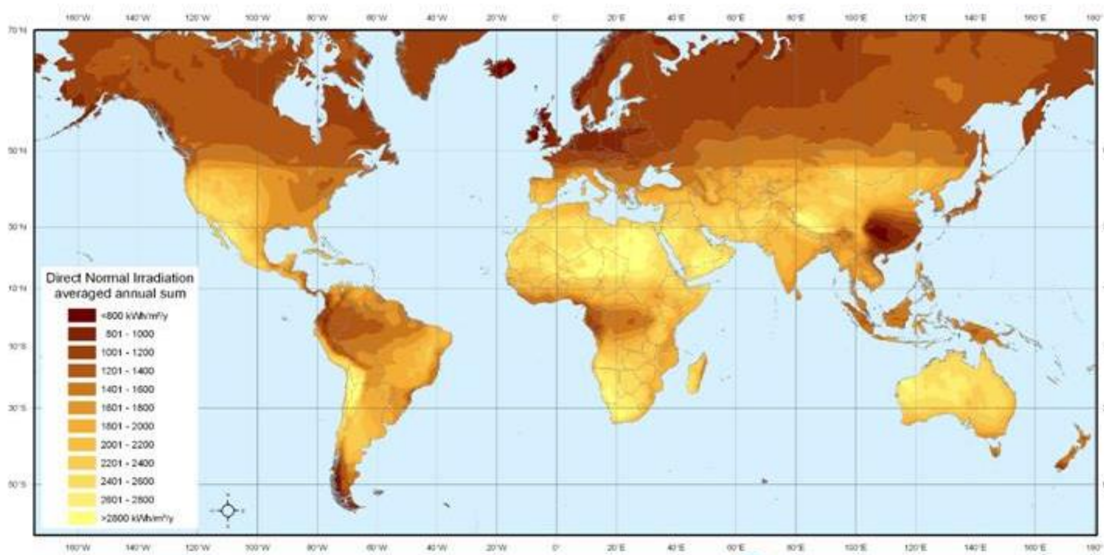
with less efficient and more pollution-intensive coal power plants. Another key technology that can potentially salvage the coal industry in regard to its poor emissions profile is carbon capture and storage, which will be useful not only for power plants but also in other carbon-emitting industries, such as steel production. At this point, carbon capture and storage and clean coal technologies are not considered to be main global-warming mitigation tools, but it may still be important for coal and oil producers to pursue these technologies to some degree.

In the long term, if and when the energy transition is successful, fossil fuels could become "stranded assets" (that is, assets that either lose value unexpectedly or prematurely or become liabilities) without proper carbon capture and storage. In the case of fossil fuel industries, stranded assets might involve "stranded reserves," that is, fossil fuel reserves that are no longer recoverable, and "stranded or underutilized capital," that is, sunk capital investments that would become obsolete (for example, an oil platform that will never be used). Because it remains to be seen how rapidly the energy transition might take place, however, there is significant uncertainty regarding the time horizon over which fossil fuel assets would become stranded. One important lesson from earlier energy transitions—which include the transition from wood and biomass to coal in the eighteenth and nineteenth centuries and the transition from coal to oil in the nineteenth and twentieth centuries—is that these transitions take time to complete. History may not repeat itself in that regard, however, in that the technological forces unleashed by the anticipated public and private response to climate change seem much more potent than the factors driving earlier energy transitions and may lead to a relatively swifter transition this time, notwithstanding the potential delay implied by the current low-for-long fossil fuel price environment. Considering the industry's carbon emissions intensity, coal-related assets are more exposed to the risk of becoming stranded than are oil and natural gas assets.

The consequences of stranded assets would be dramatic for coal and oil companies and exporting countries that rely heavily on fossil fuel exports, which would face heavy losses. Many major oil companies have long diversified across fossil fuels by investing more heavily in the production of natural gas and have also started to invest in so-called breakthrough renewable technologies in an effort to adapt to emerging realities. Oil-exporting countries have also attempted to diversify their economies away from oil, but this has proven challenging. Nevertheless, opportunities exist. For example, the United Arab Emirates has endorsed an ambitious target to draw 24 percent of its primary energy consumption from renewable sources by 2021.

Solar power concentration is highest in the Middle East and Africa and parts of Asia and the United States, according to the U.S. National Aeronautics and Space Administration (Figure 1.SF.11). Interestingly, Morocco, the host of the next United Nations Conference on Climate Change (COP22), has recently unveiled the first phase of a massive solar power plant in the Sahara Desert that is expected to have a combined capacity of two gigawatts by 2020, making it the single largest solar power production facility in the world.

Figure 1.SF.11. Direct Normal Irradiation



Source: U.S. National Aeronautics and Space Administration.

What Is the Way Forward?

Large economies tend to be the biggest emitters of greenhouse gases. Indeed, the 10 largest emitters are responsible for more than 60 percent of global greenhouse gas emissions (Table 1.SF.3). Any effort to address global warming should therefore encompass all of the largest economies (see Arezki and Matsumoto 2015). While high-income countries are big greenhouse gas emitters in per capita terms, energy efficiency has been gaining ground rapidly in these countries. Many high-income countries are reducing greenhouse gas emissions already and are committed to continue doing so. Consumption of fossil fuels by advanced economies can therefore be expected to continue to decrease. Though large economies account for the bulk of current emissions, emerging markets will continue to drive the growth of future emissions. In contrast to the falling emissions intensity of the advanced economies, emerging market and developing economies remain heavily reliant on coal, and their consumption of fossil fuels will continue to rise.

There are important variations across countries in efforts to shift their energy mixes at least partly toward renewables and away from fossil fuels, especially coal and oil. Today, the European Union and Sweden, respectively, get 13 percent and more than 38 percent of their energy from renewables. Sweden in 1991 was the first country to adopt a carbon tax. Pressured by very high pollution levels, China has adopted an ambitious plan to derive a significant fraction of its future energy needs from renewables.

Table 1.SF.3. Global Share of Greenhouse Gas Emissions by Country

(CO_2 emissions from Fuel Combustion, 2013)

Country	Share (of global)	CO_2/Population (tons of CO_2 per capita)	CO_2/GDP PPP (kilograms of CO_2 per current international dollar)	GDP per capita (current PPP)
China	28.0	6.65	0.55	12,196
United States	15.9	16.18	0.31	52,980
India	5.8	1.49	0.28	5,418
Russia	4.8	10.75	0.43	25,033
Japan	3.8	9.70	0.27	36,223
Germany	2.4	9.42	0.21	43,887
Korea	1.8	11.39	0.34	33,089
Canada	1.7	15.25	0.35	43,033
Iran	1.6	6.79	0.42	16,067
Saudi Arabia	1.5	16.39	0.31	52,993
Total share (top 10 countries)	67.3			

Sources: International Energy Agency; World Bank, *World Development Indicators*; and IMF staff calculations.

Note: CO_2 = carbon dioxide; PPP = purchasing power parity.

As noted earlier, the COP21 was by all accounts a success, with nearly all countries around the globe having firmly committed to reducing their greenhouse gas emissions through the INDCs (Table 1.SF.4). Well before Paris, in 1997, the Kyoto Protocol aimed to achieve internationally coordinated reductions in carbon dioxide emissions, but a few major countries, such as China, India, and the United States, did not agree to legally binding targets. The 2009 Copenhagen climate change conference did not yield any agreement, and real progress had to await the 2015 Paris conference. As mentioned previously, the challenge following the COP21 is, however, one of implementation. As such, setting the right incentives for achieving the INDCs is essential.

Table 1.SF.4. Greenhouse Gas Emissions Target Reductions, Paris Agreement, December 2015

United States [1]	Between 26 percent and 28 percent, below 2005 levels by 2025
European Union [1]	40 percent below 1990 levels by 2030
Japan [1]	26 percent below 2013 levels by 2030
Canada [1]	30 percent below 2005 levels by 2030
China [1]	60 percent to 65 percent below 2005 levels by 2030 (CO_2 Emissions Intensity)
India [2]	33 percent to 35 percent below 2005 levels by 2030 (CO_2 Emissions Intensity)
Russia [1]	25 percent to 30 percent below 1990 levels by 2030
Brazil [1]	37 percent below national baseline scenario by 2025
South Africa [2]	Between 398 and 614 million tons of CO_2 emissions by 2025 and 2030

Source: Admiraal and others 2015.
Note: By November 29, 2015, 184 parties (including the European Union) had submitted their Intended Nationally Determined Contributions in preparation for the adoption of the Paris Agreement in December 2015.
[1] Unconditional INDC.
[2] Conditional INDC.

The IEA (2015) and most scientists also note that the INDCs, in their current form, are not sufficient, and more is needed to avoid the worst effects of climate change. In addition to implementing mitigation efforts, countries will need to adapt to global warming, which calls for adjusting to the new reality of a warmer planet. This implies population displacements from exposed areas, or new infrastructure and housing better suited to withstand new climate risks. But adaption alone is neither fully acceptable nor sufficient, considering that global warming can cause irreversible damage. For instance, some ecosystems will be unable to adapt to rising temperatures and thus will experience substantially reduced biodiversity.

Short of pervasive and economically viable carbon capture and storage technologies, the planet will be exposed to potentially catastrophic climate risks (see Meehl and others 2007) unless renewables become cheap enough to guarantee that substantial fossil fuel deposits are left underground for a very long time, if not forever. The price of fossil fuels should reflect the negative externality that the consumption of the latter inflicts. The price of carbon should equal the social cost of carbon, which is the present discounted value of marginal global warming damages from burning one ton of carbon today.[8] In this regard, a global carbon tax would be the most efficient way to reduce emissions.

Politically, low fossil fuel prices may provide an opportune moment to eliminate energy subsidies and introduce carbon prices that could gradually rise over time toward efficient levels. However, it is probably unrealistic to aim for implementation of the full optimal price all at once. Global carbon pricing will have important redistributive implications, both across and within countries, and these call for gradual implementation, complemented by mitigating and adaptive measures that shield the most vulnerable.[9] The hope is that the success of the Paris conference opens the door to future international agreement on carbon prices. Agreement on an international carbon price floor would be a good starting point in that process. Failure to address comprehensively the problem of greenhouse gas emissions, however, exposes this generation and future generations to incalculable risks (see Stern 2015).[10]

For developing countries in particular, aid may be necessary to facilitate the clean technology imports necessary to ensure that these countries participate in the energy transition.[11] This aid would help offset the countries' transitional costs associated with removing carbon subsidies and levying positive carbon taxes. In this vein, the Green Climate Fund—a fund within the framework of the United Nations—was founded as a mechanism to assist developing countries in putting in place adaptation and mitigation practices. It is intended to be the centerpiece of efforts to raise climate finance to $100 billion a year by

[8] See D'Autume, Schubert, and Withagen 2011, Golosov and others 2014, and Rezai and van der Ploeg 2014 for useful references on the design of carbon taxes.

[9] Farid and others (2016) discuss macro and financial policies to address climate change.

[10] Li, Narajabad, and Temzelides (2014) show that, even when some degree of uncertainty is accounted for, taking into account the damage from climate change can cause a significant drop in optimal energy extraction.

[11] Collier and Venables (2012) discuss Africa's needs to achieve its potential in hydro and solar power.

2020. The IMF is also supporting its members in dealing with the macroeconomic challenges of climate change.[12]

As noted previously, shifting away from fossil fuels to clean, renewable energy resources or nuclear energy can help reduce greenhouse gas emissions. In addition, shifting from coal to gas in electricity generation can help significantly in this regard. Development of the renewable energy sector will require an overhaul of the existing energy infrastructure and involve the need to train and retool the labor force. These transformations will be a source of jobs and cleaner, more sustainable growth. Indeed, the investment needs associated with the energy transition come at an opportune time, when interest rates are at historic lows and the world economy needs infrastructure spending both to support demand and to spur future potential growth.

[12] See "The Managing Director's Statement on the Role of the Fund in Addressing Climate Change" (IMF 2015b).

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